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Understanding Female Engineering Enrollment: Explaining Choice with Critical Engineering Agency

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Abstract

One path to increasing the diversity of the engineering workforce is to understand the affective self-beliefs of women who choose engineering and how those beliefs change over time. By understanding these self-beliefs, educators can help to empower women to identify with engineering and see its potential to make change in their world. Rigorous research in this area is needed and could have significant positive impact on the engineering workforce.

This research builds on critical agency theory by validating and refining the framework of Critical Engineering Agency (CEA), though which students' interest in engineering is enhanced when they see opportunities to make change in their world. This framework has been developed by drawing from prior qualitative research and through a quantitative national study. Structural equation modeling was used to understand the connections between the constructs of CEA. Additional work was conducted to understand other factors that influence students' choice of engineering. A pair of qualitative follow-up studies to this work were conducted to understand the reasons why students develop CEA and choose engineering as a career. The qualitative phase added explanatory context and interpretive power to previously identified relationships through open-ended surveys and a longitudinal case study.

The results highlight the salience of the CEA framework, indicating that recognition beliefs are the most important piece of identity development and holding agency beliefs about the positive impact that engineering and science can have on the world is more important for women than men in affecting their engineering choice. Qualitative results illustrated how identity and agency beliefs form and how the connection between

Communities of Practice and identity through agential bridging occurs. The results from an in-depth case study demonstrated how CEA is developed through constructed hybrid spaces and practically plays a role in engineering decisions and identity formation within an engineering Community of Practice.

Students' identities and agency beliefs provide insight into why students choose and persist in areas related to engineering, how professors might develop students' internalization of recognition in the classroom, and how this CEA framework might provide a lens for future research. Providing high school and college faculty, admissions and recruitment staff, and college administrators with research-based strategies to increase female students' personal engagement with engineering is an important step towards diversifying engineering.

Dedication

This dissertation is dedicated to my grandfathers. In memory of Dr. Bill Foreman who was a model for me as an engineering professor. I know you would be proud of me. To my Pepaw, Van Fleming, thank you for always believing in me and encouraging me. You are an inspiration to me. Achieving this accomplishment has given me an education which he would say, "is something that no one can take away from you."

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I would like to thank the participants of this research in their willingness to participate and allow me to study their lives and decisions. A special thank you to Sara and Michael from my case study for allowing me to probe into their lives through multiple communications. Their openness allowed me to tell a rich and detailed story about her engineering decisions.

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The Gender Landscape of Engineering

1.1 Background

As the need for quality engineering solutions increases in order to maintain America's competitiveness on a global scale, the need to understand why students choose engineering as a major in college and as a career deepens as well. Prior to college, students usually do not have direct engineering experiences and have yet to experience a community of practice within engineering [1]. Additionally, the requisite high school courses are often undifferentiated for students entering a variety of science, technology, engineering, or mathematics (STEM) fields. This lack of context makes the choice of engineering difficult to understand. Recent calls have been made for *one million* new STEM graduates in the next nine years [2]. In order to meet this demand, a new and diverse engineering workforce needs to be identified and prepared.

Few paths into an engineering career exist beyond the freshman year due to sequenced course requirements and a large number of credit hours needed to complete a degree in engineering on time [3]. Additionally, students who leave engineering do not do so because of inability. Students leaving engineering often did not attribute their behavior to limited ability, lack of adequate preparation or a lack of desire not to work hard. Instead, the four most common reasons students gave for switching were: a loss of interest in the subject matter of STEM fields; the belief that a non-STEM major would be more interesting or offer a better education; poor teaching by STEM faculty; and feeling overwhelmed by what students considered the unnecessarily demanding pace and load of STEM curricula [4]. Tinto's research supports this finding for all college students, both STEM and non-STEM. This interactionalist model cites family background, individual attributes, and secondary schooling as precollege factors that are related to the decision to remain in or leave college. However, the degree to which myriad individual differences combine to predict major retention is less clear [5]. The loss of students from engineering to other majors in college is not substantially larger than other STEM fields, unlike the differences in the representation of women in engineering. Across the numerous disciplines within engineering, there is a substantial variation in the representation of women (e.g. 44.3% in environmental engineering versus 9.4% in computer engineering) [6]. The point at which students need to choose engineering is the transition from high school to college. Students must be empowered to choose engineering before beginning their post-secondary education in order to attract the largest number of students. This transition point from high school to college is a crucial junction to begin to address the need for a larger engineering workforce and more diverse engineering solutions. Examining the attitudes of students choosing engineering can shed some light into this complicated decision and increase the likelihood for more students to choose engineering.

1.2 The Lack of Women in Engineering

The underrepresentation of women in engineering is a persistent issue which hinders the development of the most well-rounded engineering solutions, limits the engineering field's capacity, and limits access to the social, economic, and cultural capital available through the pursuit of an engineering career [7]. While other professions such as law, medicine, and business have achieved equal (or near equal) representation of women, engineering remains a field predominated by men, with bachelor's degree recipients comprised of less than twenty percent females overall [8].

Women face many barriers to the choice of engineering in college, beginning in childhood. It is common for female students to lose interest in science and mathematics courses in middle school [9]. This phenomenon, in turn, sets them on a path to take fewer Advanced Placement or International Baccalaureate mathematics and science classes, on average, in high school [10]. Such barriers may significantly reduce the number of females interested in pursuing an engineering degree after high school. Additionally, women do not receive as much encouragement as men to pursue degrees in engineering fields [11]. All of these factors likely contribute to the aforementioned reality that less than one fifth of engineering bachelor's degrees are earned by women [6].

Studies have demonstrated that females who choose to major in engineering in college remain in their chosen major at the same rate as men [12]. Additionally, there are few inroads into engineering programs after the freshman year for all students [3]. Thus, a key issue to increasing representation of women in engineering careers is to study recruitment (mostly before beginning college) rather than retention in engineering majors. For many students, men and women alike, the end of high school is the natural and conscious point in time at which students commit to their college direction; by this critical juncture females must be empowered to choose engineering. Otherwise, one of the best opportunities is lost; transitions into engineering in college are difficult and rarer, and without interventions prior to college the engineering community will continue to look much like it does today. While attitudes toward STEM careers often begin to form in middle school and female interest in math and science decreases over time, high school science and math experiences can empower females and change the prevailing disinterest to pursue engineering as a career: despite having lower interest in STEM careers on average, women do still take high school STEM courses in large numbers, including physics and mathematics. Understanding the gender issues for students before they have already chosen engineering may enhance educators' abilities to recruit and retain a broader diversity of students.

1.3 The History of Women in Engineering

As far back as formal education in the Middle Ages, professional schools have been a part of institutions of higher education. These types of schools were begun to provide training and education in areas of importance to society. Some of the earliest areas of education include the study of medicine in Salerno, Italy and Montpelier, France; the study of law in Bologna, Italy; and the study of theology in Paris, France. As society became more advanced and the need for technology grew, other subjects qualified for participation in a university environment, including engineering [13]. Traditional professional careers of medicine and law continue to be associated with universities as professional schools in many countries [14]. Throughout this era, science, mathematics, and philosophy have been domains of knowledge constructed mainly by men with both deliberate and unconscious exclusion of women. David F. Nobel comments that the underrepresentation of women in science and engineering or the "world without women" did not simply emerge, but was constructed [15].

Some of the first engineers were involved in military operations of building roads, bridges, and fortifications for the defense and invasion plans of their governments. The initial institutions that taught engineering were founded in France in the middle of the eighteenth century. The origins of the word engineer from the eleventh century are the Latin word *ingeniare*, which means to devise (in the sense of construct) or craftsmanship. Ingenuity along with several other words are related to *ingeniare* [13]. By the beginning of the nineteenth century, France had established military and polytechnic schools to teach engineering as a part of the curricula that produced such notables as Laplace, Lagrange, and Fourier [16].

The first American school that offered engineering as an area of study was the U.S. Military Academy at West Point, beginning in 1802. The first school teaching the discipline of civil engineering was Rensselaer Polytechnic Institute, which awarded the first engineering degree in 1835. By the end of the 1800s, multiple programs in engineering existed at a number of universities nationwide. However, women were unable to enroll in any college until Oberlin College permitted them entrance in 1837. The purpose of this education was ostensibly to provide ministers with intelligent, cultivated, and thoroughly schooled wives [14].

Between the late 1880s and the early 1900s a handful of women ventured into engineering studies, primarily at land-grant institutions [17, 18]. These women attracted a certain attention, since they were a rarity in this field. Reporting on the new female presence on campus, 1920s newspaper headline read, "Three Coeds Invade Engineering Courses and Compete With Men at Cornell University: Stand Well in Their Studies" [19]. The issue of women venturing into the traditionally-defined masculine spaces came to a head with World War II, when the United States suddenly faced a "manpower" crisis. As World War II ended, returning male veterans flooded into American engineering programs, and the wartime emergency rationale for encouraging women to develop their technical talents vanished. More than that, conservative gender roles of the postwar decades brought about a prevailing expectation that women's career ambitions must give way to the goal of marrying and raising children. Young girls who did express technical interests were often deliberately discouraged by negative remarks from family or teachers [20].

Despite this discouragement, additional opportunities for women to participate in the workforce as engineers grew in the 1950s and 1960s. Many engineering schools in the U.S. that had previously been committed to male-only education became coeducational institutions. Georgia Tech began to admit women engineering students in 1952, but only in programs not available in other state universities. Over a decade would pass before women were admitted to all courses offered by Georgia Tech in 1968. The lack of women in technical disciplines began to change during the Cold War and the period of the space race between the United States and the Soviet Union. Female faculty members at engineering institutions like MIT began to actively promote the cause of women's engineering education in the late 1960s and 1970s as a part of the second wave of feminism in the U.S. [20].

By the end of the twentieth century, however, women were still nowhere close to approaching proportional representation in the engineering profession. Women made up 12.1 percent of undergraduates enrolled in engineering across the United States in 1979, and by 1998, that percentage had risen only to 19.7 percent. In terms of graduation rates, in 1996, 11,316 women earned bachelor's degrees in engineering which was only 17.9 percent of the national total. By occupation, women constituted nine percent of all engineers in 1998 [21]. The number of American women who earned science and engineering degrees increased steadily from the 1960s to the early 1980s, then unexpectedly reached a plateau [22]. Today, the percentage of female students who receive their bachelor degree in engineering is still below twenty percent (18.9%) [6].

Frize offers three myths that still influence men and women's attitudes about which careers are appropriate for each sex [14]:

1. Gendered stereotypes have disappeared.

2. Boys are better than girls at math and science.

3. Sexual harassment has very little impact on women.

These ideas are persistent in the culture of engineering in the U.S. Academic performance is not one of the main barriers to women pursuing engineering. Instead, gender stereotyping in the media, family life, school, and society seem to be the main influence on career choice for students [14]. Women tend to underestimate their abilities in math, while men tend to overestimate theirs. However, a recent report [23] found:

> *from grades 2 to 11, the general population no longer shows a gender difference in math skills, consistent with the gender similarities hypothesis. There is evidence of slightly greater male variability in scores, although the causes remain unexplained. Gender differences in math performance, even among high scorers, is insufficient to explain lopsided gender patterns in participation in some*

STEM fields.

Dr. Ursula Franklin at the University of Toronto suggests that women in middle and high school probably need to invest 15 to 20 percent more energy than young men to get similar academic results [14]. This phenomena was documented in *Sexual Harassment: High School Girls Speak Out* [24]. Larkin observed that incidents of sexual harassment,

> *are logical products of a culture in which women are generally devalued, reviled and mistreated... Despite the gains made by some women since the early 20th century, the continual devaluing of women's work, the lack of women in positions of authority and decision making, the continual resistance to having control over their own bodies, the visual representation of women as sexual objects, and the disparaging jokes about blondes, mother-in-laws, and bimbos are just some of the ways the diminishment of women remains embedded in our cultural attitudes and practices. Sexual harassers don't just hatch in high school; they have evolved from years of training in a society that conditions them to treat women as less important than men* (p. 22-23).

These barriers can create conditions that are difficult for women to overcome. However, developing the self-beliefs that one can succeed in engineering is vitally important to begin to confront the underrepresentation of women in engineering. Beginning to address who women see themselves to be, what they can do with a career in engineering, and how they can use that career to make an impact in the world may begin to address many of these issues.

1.4 Overview

Student responses to a nationally representative survey on the backgrounds, attitudes, and career expectations of college students were used for subsequent quantitative analyses. Additionally, two qualitative studies were conducted with an open-ended survey of how these affective states were developed and an in-depth case study of the experience of a particular female student as she completed high school and enrolled in an engineering program. This study resulted in an understanding of the identities and agency beliefs that women who choose engineering exhibit and how these affective constructs are developed in context.

A thorough analysis of the literature has been conducted in order to identify potential factors that would influence students self-beliefs and increase female empowerment to choose engineering in college. This information is presented in the first three chapters of this dissertation. Chapter 1 gave an overview of the history of women in engineering and highlighted the underrepresentation of women in engineering today. Chapter 2 gives an in-depth overview of the theoretical framework used in this research and other related frameworks. Chapter 3 outlines the data sources, research methodologies, and research questions addressed in this work.

Chapters 4-6 are written to stand somewhat on their own and describe the results of this research investigation. Chapter 4 outlines the steps taken to validate the constructs used to measure Critical Engineering Agency (CEA). Chapter 5 outlines the bulk of the quantitative research testing structural equation models to explain the choice of engineering. Chapter 6 steps outside of the CEA framework to explore the effect of external factors other than students' self-beliefs on their choice of engineering.

Chapter 7 focuses on the qualitative research conducted to explain both how and why female students choose engineering. Generalizable connections were seen from the quantitative results in Chapters 4-6. Chapter 7 works to understand how these connections are formed and what they mean for women's choice of engineering.

Chapter 8 is a longitudinal case study of one female student beginning in the spring semester of her senior year in high school and following her through her first year in an engineering college. This case is a prime example of how developing CEA can impact females' choices and retention. By following this one case, a situated, transferable example of CEA can be examined.

Finally, Chapter 9 synthesizes the findings from Chapters 4-8 and offers an evidence-based explanation for the effect of women's self-beliefs on engineering choice that can be used by faculty, admissions decision-makers, and administrators to attract and retain women in engineering. This work can help reduce the gap of women in engineering.

1.5 Approach to Research

Mixed methods research makes use of both traditional qualitative and quantitative research techniques. This approach recognizes the importance of the long-held practices of both quantitative and qualitative research but also offers a powerful third paradigm choice that often provides informative, well-rounded, and practical research results.

Pragmatist epistemology objects to viewing knowledge as a "copy" of reality [25,26]. This paradigm focuses on knowledge as a construction rather than an achieved concept in order to act within the world. Dewey [25] writes: "The function of intelligence is therefore not that of copying the objects of the environment, but rather of taking account of the way in which more effective and more profitable relations with these objects may be established in the future." This approach does does not totally deny a correspondence view of truth, but claims that it is appropriate only for simple statements of small fragments of reality. Instead, knowledge or reality is filtered through an individual's own perceptions and is, therefore, constructed.

Pragmatism has high regard for the reality of and influence of the inner world of human experience in action [27]. In this approach, knowledge is viewed as being both constructed and based on the reality of the world we experience and live in. This perspective is particularly apropos for mixed methodology research because it connects theory to practice. Pragmatism offers an epistemological justification (via "pragmatic epistemic values or standards" [28]) and logic for mixing approaches and methods (use the combination of methods and ideas that helps one best frame, address, and provide tentative answers to one's research question[s]). Additionally, this approach is appropriate for understanding students' internal affective states that influence their constructed knowledge and reality. Knowledge construction is based on the inquirer's norms, values, and interests. Validity claims for this type of research are "warranted assertions" that result from inquiry into actual situations with concrete actions or narrative [28].

Pragmatism rejects the thesis that qualitative and quantitative paradigms are incompatible, conducting both quantitative and qualitative research. Research paradigms can remain separate, but they also can be mixed into another research paradigm of mixed methods [29]. Another attractive feature of pragmatism for mixed methods research is that pragmatism includes a wide range of theorists that mixed methods researchers can consider unhindered by philosophical debates. For these reasons, in this work a pragmatist approach was used.

Chapter 2

Framing

After highlighting some of the issues that women face in engineering, this work is motivated to address the gender gap by viewing the situation through affective framing. Understanding students' beliefs can impact how we understand the choices of women towards engineering and how to better retain these students by engaging their interests and goals. Additionally, as educators, it is possible to impact students' affective beliefs more readily than other external factors like socioeconomic status, race/ethnicity, or prior academic preparation.

2.1 Theoretical Framework

Critical Engineering Agency

One potential way to address the gender gap in engineering is through an improved understanding of the factors that influence and the processes through which students might choose to study engineering in college. Critical Engineering Agency (CEA) is a framework for conceptualizing and potentially understanding this choice. This framework utilizes multiple identities along with students' agency beliefs and is inspired by the Critical Science Agency framework developed by Basu and Calabrese Barton [30–32]. In CEA, identity is defined as the authoring of one's self within a particular context and in many senses is a continually evolving, self-reflexive process [33]. Students who enter science and engineering often need to see themselves as the “kind of people who would want to understand the world scientifically” [34]. Previous work in the CEA framework has identified that the development of multiple identities in physics, math, and science generally are important for students who choose engineering in college [35]. In addition, previous work has found that students who aspire to be engineers have different professional and vocational related identities than their peers [36, 37]. Additionally, students in an engineering track have higher attainment value which is related to an engineering identity or an engineering “sense of self.” This value has been found to be important for students’ persistence and more important than students’ interest or perceived utility of engineering for continuing with an engineering career [38]. In the past, there has been a focus on understanding engineering and professional identity development at the college level, after students choose an engineering major. For example, Chachra and colleagues [39] studied the development of an engineering identity at the undergraduate level and found distinct differences based on the culture of an institution and students’ perceptions of engineering practice. The effect of school culture on engineering identity development also has been noted in other work [40].

However, there are few studies that focus on the impact of student experiences prior to college and other self-beliefs that may be precursors to the development of an affinity for engineering [36], although the need for such research has been stressed in the past [41]. Much of the existing prior research has acknowledged the need for understanding multiple STEM identities prior to the choice of engineering [36, 38, 41]. Considering these identities is important because students’ self-beliefs can impact their educational choices and potentially the later development of an engineering identity. Understanding these, the beliefs that precede engineering identity development, will help educators to develop a better understanding of how and why students are drawn to engineering as well as the reasons why others may move away from it due to their perceptions that engineering conflicts with their view of themselves, career aspirations, and other self-beliefs.

In the CEA conceptual framework, domain-specific identities – that is, math, physics and general science identities – are each comprised of three dimensions of student beliefs: their performance/competence, recognition, and interest beliefs [42–46]. These constructs have been validated in previous studies in physics and mathematics using large-scale data [43, 46]. Students' performance/competence beliefs represents their beliefs about their ability to perform effectively (e.g. on an exam in a subject) and be competent in a particular domain. The recognition component of identity consists of a student's beliefs that they receive external recognition from parents, peers, teachers, etc. as a good student (or "kind of person") in a domain/subject (e.g. "mathematics person" or "physics person"). Interest in a particular domain also plays a key role in students' identity and their the choice of an engineering major. Students must have some understanding of how topics relate to engineering in order to be attracted to engineering and at least have the opportunity to develop an identity in engineering. Previous studies have shown that students who are interested in engineering show particular interest and skill in math and science [47], and that these identity constructs are connected to students' choice of engineering as a major in college.

Critical Engineering Agency is not simply a model of students' identities; it also involves students' agency beliefs. Agency, in this case, refers to the capacity of an agent, a person or other entity, to act in the world, and this work focuses on students' self-beliefs about their own agency in certain contexts. That is, this theoretical framework refers to students' perception of their ability to change their world through everyday actions and their broader goals. Students' agency beliefs involve how students see and think about STEM as a way to better themselves and the world [48] along with being a critic of themselves and science in general. The "critical" aspect of CEA incorporates the ways in which students become evaluators of STEM (in the sense of being critical thinkers) as well as become critics of themselves and the world around them through self-reflection. Being a critic, in this latter sense, is defined as evaluating, judging, and analyzing, not simply making negative judgments. The development of CEA can subsequently lend to students' professional identity development, advance their position or status in their community, society or the world, and/or alter their world in ways they envision through science and engineering.

2.2 Related Theoretical Frameworks

There are several constructs and theories in the STEM education literature that describe aspects of CEA. Understanding how these different research areas correspond and complement one another is important to understanding the state of research within the engineering education field. Once the current research is understood, areas where further improvements can occur can be highlighted and research can be conducted to fill gaps in current knowledge.

Agency

Agency beliefs are not synonymous with students' views on the nature of science and technology, but they are connected to specific epistemological aspects of their beliefs about the nature of science, which have been articulated in other literature. Beliefs about the "nature of science" most commonly refers to the values and assumptions one holds as inherent to the development of scientific knowledge [49]. Agency beliefs, in our description, are similar to students' conceptions of the nature of science specifically related to the influence of science and technology on society [50, 51]. Part of these conceptions describe how a student may view science/technology as related to society, while agency beliefs encompass a student's attitudes toward the ability of science/technology to influence positive change in the world with an emphasis on the subsequent actions. The perceived value of science and the development of one's self as a critic are encapsulated in the agency beliefs component of CEA. How students value science/technology is broadly measured in the nature of science literature by students' attitudes toward science [52]. Student attitudes toward science have been measured by a number of instruments including the well-known, large-scale study by Simpson and Troost including 4,500 students from schools in North Carolina [53]; the Attitudes toward Science Inventory developed to measure science attitudes including the value of science in society and students' science self-concept [54]; and the Views on Science-technology-society (VOST) instrument which is an empirically-developed, multiple-choice item pool (114 items) that offers a wide coverage of topics on science and technology in society and a particular methodology to assess them [50]. While these instruments measure constructs similar to agency beliefs, our framing of agency beliefs is somewhat distinct, because it involves the value of science/technology for action/change and in direct relation to students' lives as well as the role of science in becoming a critic of one's self and the world.

In classroom studies, pedagogical practices focused on students have been shown to facilitate critical agency development within the classroom [30, 31]. These strategies include items in the following domains and are related by the constructs shown in Figure 2.1. Additionally, the measures of each strategy are listed below:

Student Roles – the roles that students take on within science classrooms, their reasons for participating in particular ways, and the relationship they perceive these roles to have with scientific knowledge and practice within the classroom, a peer group, or a community. Measures include: participation in class, reasons for participation, role during group work, and relationships with others during group work.

Leveraging of Resources – resources include: personal, teacher, peer, and out-of-school resource network and opportunities for accessing both traditional and non-traditional scientific knowledge. Measures include: use of objects (computer), people (teacher), and social networks (peers, community).

Iterative and Generative Processes – exploring opportunities to refine students' understanding (e.g. revisiting/deepening understanding of a topic, critical thinking) and extend it to a new context (e.g. teaching topic to others, consider related career options, and applying understanding to real-world contexts like sustainability). Measures may include: revisiting ideas/topics, applying content to real-world contexts, and applying content to contexts in students' life.

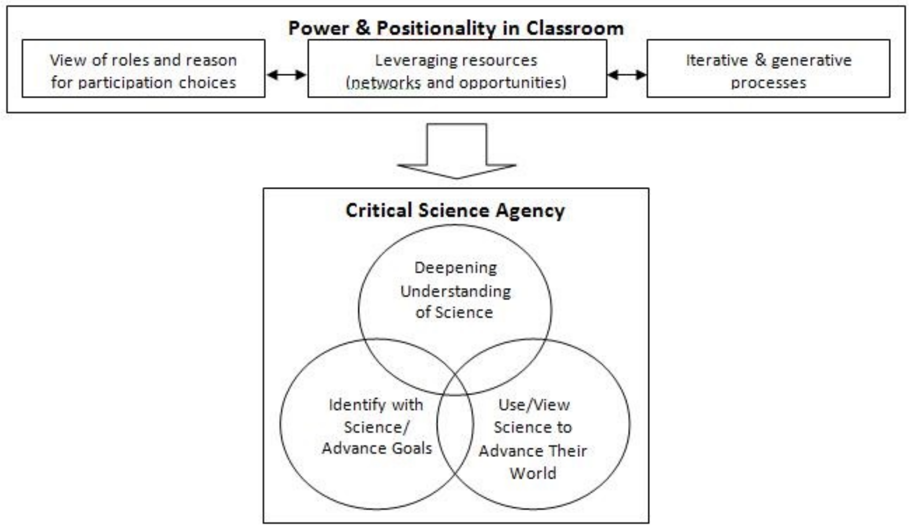

Figure 2.1: Conceptualization of how classroom experiences develop Critical Science Agency constructs [30].

Current research in engineering education supports that idea that developing agency within the classroom has an effect on identity development, performance, learning and persistence. All of these aspects are key components in critical engineering agency and the choice of engineering as a college major [42, 55–60].

In addition to papers directly related to the concept of agency, identity and role-confidence also play a part in understanding this framework.

Identity

Originally, the construct of identity is based on four measurable dimensions of students beliefs about their performance, competence, recognition by others, and interest as depicted in Figure 2.2 [42]. In subsequent literature, students early on in their college careers could not distinguish between performance (e.g. getting a good grade in a subject) and competence (e.g. understanding the concepts in a subject) [45], so these items became a single dimension of performance/competence. These three dimensions richly capture the formation of an identity and can be used to study the creation of an engineering identity specifically in relation to CEA. Additionally, the study of identity formation has proven useful in understanding persistence [61]. This framework for measuring identity has been proven through large scale studies in physics and mathematics [42]. The recognition component consists students' beliefs that they are seen as an engineer or good engineering student. Interest in the subject material also plays a key role in choice of engineering as a major. If students do not fully understand the realm of engineering, and females lose interest in math and science early on, how can more females be attracted to engineering without addressing this dimension of identity formation within CEA? No gender differences in engineering attrition rates have been shown for male and female students. Performance in math and science are not the primary reason that females either do not choose engineering as a major or leave [4]. While female students are able to perform as well as men in engineering, females' self-perception of their performance and their confidence in their engineering skills are lower when compared to men [62].

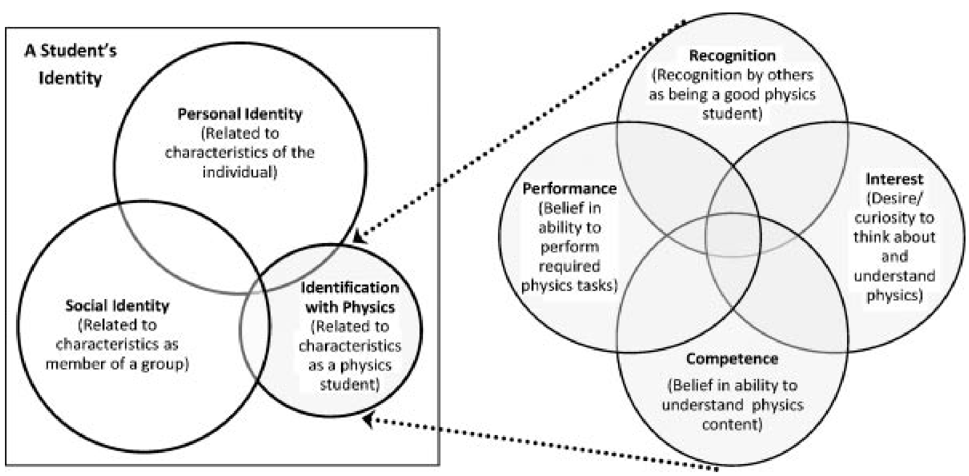

Figure 2.2: Framework for students' identification with a specific subject area – in this case, physics [42].

Traditional roles for male students and female students create gendered patterns for access to engineering professions and identity. While women bring many skills to engineering disciplines such as managing, planning, organizing, coordinating communications, and bringing different perspectives, these features are often not recognized as fundamental engineering skills. The emphasis falls to technical and analytical skills. While women perform just as well as men in these, the lack of recognition hinders the formation of an engineering identity and professional role-confidence. Women must not only author their identity as engineers, but they must contradict the traditional stereotypes surrounding engineering as a masculine field. The authoring of an engineering identity is not a one-time effort while pursuing a degree in engineering, but is a continual process [33]. Traditionally, the engineering field holds a professional ideology that puts emphasis on mathematical ability and technical expertise. This environment along with the masculine stereotype of engineering contributes to creating a condition that is particularly unwelcoming to women which is often termed a “chilly climate” [63].

In an ethnography of a public engineering school, a culture of gender discrimination was deeply ingrained [64]. The cultural identities within the engineering college did not include terms for women. Even though women comprised twenty percent of the student population, there was no sense of belonging to the established engineering culture. For men, belonging was defined in a variety of ways from being an over-achiever to being a slacker with a rich variety of identity terms. None of the terms highlighted by the studies participants related to women. Studies of two senior design groups illustrated the marginalization of females’ contributions and opinions within a group. One particular example stood out during a classroom discussion of sexual harassment. Two male students menacingly confronted a female student in the class and a male professor when they disagreed about a scenario around a hostile working environment for a female welder. One of the men responded by saying, “this is the way things were before the woman arrived.” This statement was referring to the inappropriate pictures of nude and partially-clothed women in the workplace of a previously all-male shipyard welding office. The student claimed that the female worker who filed a sexual harassment claim should “just deal with it.” Additionally, this type of behavior was not shown by freshmen male engineering students indicating that it might be a learned behavior. While this may be an isolated case, this study does illustrate the presence of stereotypes and discrimination in the current engineering education system [64].

Role-confidence

The concept of self-efficacy was introduced in by Bandura in 1977 and is rooted in social cognitive theory. Self-efficacy is one's confidence in one's ability to implement knowledge and actions to effectively perform a specific task. Efficacy perceptions are gained through four major informational sources:

1. Personal performance and accomplishments - one's patterns of past successes and failures.

2. Vicarious learning - comparing oneself to the performance of others.

3. Social persuasion - encouragement or discouragement one receives from others.

4. Physiological states and reactions - pleasant or unpleasant emotional or physical reactions [65].

The idea of self-efficacy is closely related to what has been called role-confidence or one's ability to perform a task related to one's identity or role. Self-efficacy is significantly related to a students' persistence in engineering [66]. This finding has also been shown in a larger meta-analysis that linked self-efficacy with academic performance and persistence [67]. Students' pre-collegiate experiences within a semester-long, engineering-related course or participating in hobbies like programming, electronics, producing video games, robotics, and model rockets have statistically higher engineering self-efficacy than other students. These hobbies are characterized by hands-on experiences, self-motivated learning, real-life application, immediate feedback, and problem-based projects [66]. Notably, most of these hobbies are traditionally associated with male students rather than female students. Thus, the number of men entering into engineering is reinforced by traditionally male hobbies.

Student self-assessment of their math abilities is significantly and positively related to whether students enter college as engineering majors. However, while female students self-assess their mathematics skills entering post-secondary education lower than males, students' math self-assessment did not significantly predict persistence once students enrolled in a STEM major. In addition, family plans do not have a significant influence on female students' persistence in engineering. Once students enter into a STEM major, other more complex self-assessment is the cause for student attrition. Cech and colleagues have termed this specific self-assessment professional role confidence [62]. This concept consists of a students' confidence in their ability to fulfill their expected roles, competencies, and identity of their profession. This concept not only includes the mastery of core skills, but a confidence and identity with the profession itself. Two factors influence professional role confidence: expertise confidence, or confidence in "one's ability to wield the competencies and skills required of practice in the profession," and career-fit confidence, or confidence that a "profession's career path is consonant with one's individual interests and values." Women do not develop these key pieces as strongly as men within engineering [62]. This finding may explain the gender differences in engineering careers. In order to develop a diverse engineering workforce, students must not only choose engineering as a major, but their choice of a career after receiving their degree must be nurtured as well. Professional role confidence may explain why more women leave engineering after post-secondary education.

Social Cognitive Career Theory

Social cognitive career theory (SCCT) has been widely used to investigate the choice of engineering as a career. This theory is based on the social cognitive approach originally introduced by Bandura [65, 68]. Social cognitive career theory is founded on the triadic reciprocal relationship between personal and physical attributes, external environmental factors, and overt behavior included. This model, first proposed by Lent, Brown, and Hackett [69], features three interlocking models including interest development, choice of a career, and performance (described by self-efficacy) developed from previous work by the authors as well as a meta-analysis of current vocational career models and research. The word "career" used in the title of SCCT is inclusive of academic interest, choice, and performance. Social cognitive career theory features three interlocking models including interest development, choice of a career, and performance. These three models are described using the constructs of self-efficacy, outcome expectations, and goals. This operationalization of self-efficacy defines this construct as "people's judgments of their capabilities to organize and execute courses of action required to attain designated types of performance" (p. 83). This theoretical framework defines outcome expectations as the desired effect of a course of action. The construct of goals is defined as the effort required to engage in an activity. This model attempts to incorporate several different factors in choice including a social or environmental impact on choice including factors like race, gender, physical status as well as background. The environmental aspects moderate the personal inputs for interests to choice goals and choice goal to actions (see Figure 2.3).

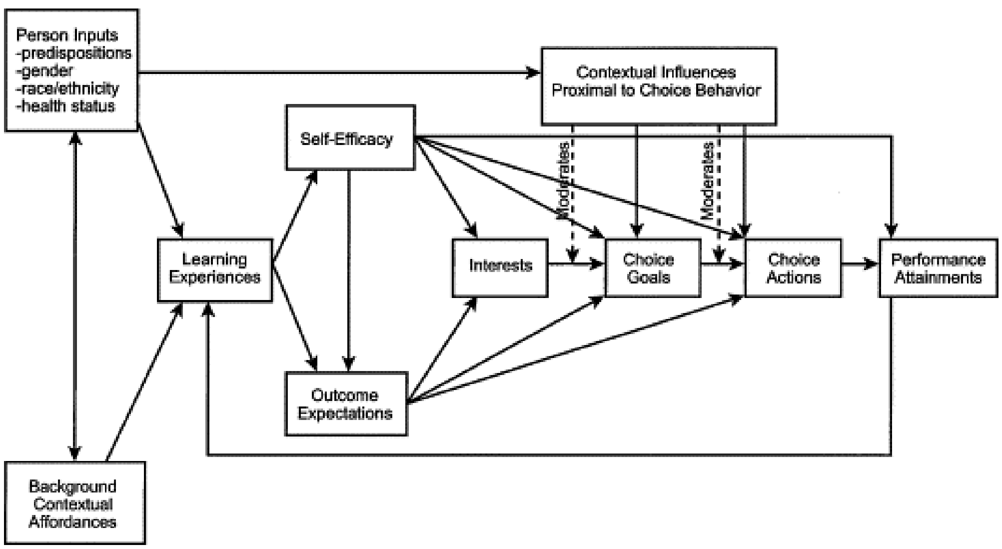

Figure 2.3: Model of SCCT proposed by Lent, Brown, and Hackett [69]

The authors proposed this model as a causal model, indicating that the links between constructs were directional. Additional work in SCCT has shown some issues with the proposed theory. A path model was constructed of the model pictured in Figure 2.3 for the choice of engineering [70]. This model was created in comparison to paths proposed by Bandura's work [71]. Social cognitive career theory proposed a direct paths model, which posits that support and barrier perceptions produce direct paths to choice goals and actions. In comparison, Bandura's model featured mediated paths, which suggests that environmental perception relate to choice actions indirectly through self-efficacy and goals. When the fit of these two path models was compared, the SCCT model did not fit the observed data matrix indicating that the fit of the proposed model should be rejected. Conversely, Bandura's mediated paths model did accurately reflect the measured data. The direct paths between supports and barriers and goals and actions were not significant. Despite this information, the authors of SCCT have continued to use the direct paths model and have rationalized this choice through sample collection (all engineering majors) and confounding effects in their model. This model does not consider reciprocal effects between self-efficacy and contextual variables as well as between self-efficacy and interests. These affective states at the core of the model have not been fully explored which leaves considerable room for improvement in this theoretical framework. However, SCCT continues to be a widely used and cited model for choice of engineering.

2.3 Significance of the Study

As have been described, there are many research studies that highlight individual issues that women face when choosing a career in engineering. However, in this work, the literature is fragmented and does not draw connections between these individual frameworks. Using critical agency theory as a way to understand the choice of engineering is a novel approach. This framework has been used in understanding physics and math affinity, but has not be utilized in engineering education research. While many factors are important for students' choice of engineering, students' self-beliefs may be more important than many external factors. Albert Bandura, one of the founding fathers of social modeling, stated that "people's level of motivation, affective states, and actions are based more on what they believe than on what is objectively the case" (p. 2) [72]. The types of people that students see themselves as is an important factor in how students feel about math and science and their career objectives. Additionally, these affective states can be influenced by targeted interventions [42]. Understanding how students, especially women, identify with engineering and are empowered to choose engineering as a career can begin to address the persistent underrepresentation of women in engineering.

Building on work in science education, this research extends previous findings to engineering through mixed methods to understand how high school science experiences can empower females to choose to major in engineering. A mixed methods approach allows for generalizable results from large-scale survey data and explanatory causal inferences from qualitative data. Both types of data allows for the triangulation of results using multiple reliable and valid methods which can help not only define but explicate new theory. These outcomes will result in practical ways to increase female enrollment in engineering programs through research-based pedagogies and recruitment strategies focused on female empowerment in engineering.

The results of this work will directly affect high school teachers and college faculty, staff, and administrators. By focusing on how females become empowered to choose engineering, females can be influenced to choose engineering upon entrance to college before routes into engineering are mostly closed. The practical methods identified in this study can be used to attract more women into engineering from the model developed. An increase of females in engineering will help initiate a much needed shift toward a more diverse engineering workforce and more balanced approach to engineering solutions. Advancements in the understanding of female empowerment in science and math careers can potentially transform an entire field of research and industry through new and more diverse participants. Additionally, this research can be applied to increase student empowerment in other areas suffering from underrepresentation. Unique approaches in the problem-solving strategies used by engineers are essential as growing global competition and the subsequent restructuring of industry, the increased use of technology, and the emphasis on new energy sources drive the need for more engineers with creative vision. Only by diversifying engineering as a whole can these goals be accomplished, and this change is essential to the National Science Foundation's (NSF) vision to "capitalize on the rich diversity of human resources by increasing the number of women, underrepresented minorities, and persons with disabilities who participate fully in engineering education, research, and practice” [73].

Chapter 3

Research Design and Methods

3.1 Purpose of Study

The goals of this study are to understand the framework of Critical Engineering Agency (CEA) and highlight ways that this framework can empower women to choose engineering. This mixed-methods explanatory study is two-fold: applying this framework on a large-scale to explain the choices of many, and utilizing this framework to explain student attitudes in specific cases. This second step of this study will advance understanding of the relationships discovered in the preliminary research on CEA in the first part of the application of CEA in a quantitative analysis.

To expand the knowledge base of how and why females become empowered to choose engineering as a major in college, the guiding question for this research is, "What factors can be used to help women develop critical agency in physical science and choose engineering as a major?"

The purpose of this research is to accurately measure how females develop CEA and apply that measure through a model to predict factors which empower females to change their world through an engineering profession. Additionally, another key purpose in this research is detailing the reasons why females choose engineering and how they develop CEA. I pursued specific objectives to help address this overarching purpose:

1. Identify, through a national survey, relationships between students' physical science experiences in high school related to engineering, beliefs regarding engineers' role and the ability to change their world, and choice of college major.

2. Develop a predictive model that validates the theoretical framework applied and the affective reasons for the choice of engineering for females.

3. Advance our understanding of the relationships shown in objective 2 through in-depth studies of college students identified in specific objective 1.

4. Understand how Critical Engineering Agency is actualized in one student's life.

3.2 Explanation of Research Design

To address the guiding research question, I will use a sequential explanatory mixed-methods design to: 1) construct a measure of Critical Engineering Agency and 2) apply that measure to predict factors which empower females to change their world through an engineering profession and 3) understand how women form and utilize these self-beliefs to choose engineering.

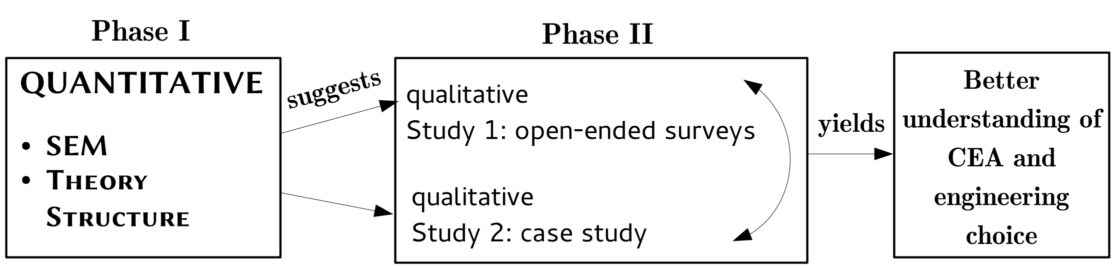

Figure 3.1: Depiction of research methodology for a sequential explanatory mixed methods study. The two phases of the qualitative research occur concurrently after the quantitative research to provide explanations of the trends discovered. The Study 1 and Study 2 will provide feedback to one another for analysis and additional questions to ask participants.

Phase 1 - Quantitative

This phase draws on data collected as part of a nationally representative quantitative study exploring previous high school classroom and extracurricular experiences of both engineering and non-engineering college students (NSF GSE 1036617).

This phase of my research addresses the following specific research questions:

Research Question 1: What are the relationships among students' identities in high school that predict the choice of engineering?

Research Question 2: How do students' beliefs about how science and technology can impact the world predict a choice of engineering?

Research Question 3: Are these beliefs (identity and agency) different for men and women?

Research Question 4: How well does Critical Engineering Agency as an explanatory framework describe students' choice of engineering?

Survey Development

The Sustainability and Gender in Engineering (SaGE) survey (Appendix A) was developed to understand specific factors (pedagogical, attitudinal, external, etc.) that can increase female enrollment in engineering. Questions specific to my research goals were included in this national survey.

The development of the SaGE survey was organized into three main components: 1) a literature review to identify factors that have been shown or hypothesized to influence increased enrollment in engineering, 2) extraction of items from previous validated national studies (Factors Influencing College Science Success – FICSS [74], Persistence Research in Science & Engineering – PRiSE [42], and Factors Influencing College Success in Mathematics – FICS-Math [46]) and, 3) hypothesis testing with students and high school science teachers.

During Spring 2011, undergraduate students at Clemson University, including both engineering and non-STEM majors, were queried on their previous high school experiences related to sustainability in order to generate hypotheses for further investigation. In total, responses from 82 engineering majors and 41 non-STEM majors were collected. In both groups, students reported an array of sustainability-related topics to which they had been exposed, primarily in the domains of environmental and social sustainability with few topics related to economic sustainability topics. Likely reflecting differences in prior course-taking, engineering students identified sustainability experiences distributed roughly evenly between their chemistry, physics, and biology classes, while non-STEM students primarily identified these experiences in biology classes. When asked to identify the pedagogical ways in which sustainability had been addressed in their classes, students identified several different types of experiences. The most common ways in which sustainability had been presented was through "Discussion" and "Projects." Less commonly identified were "Exams," "Homework," "Out-of-class Activities," and "Notes/Lectures." The responses were also analyzed with an exploratory factor analysis to determine if the constructs created were valid and held together [75]. Additionally, open-ended surveys were sent to members of the National Science Teachers Association (NSTA) listserv. Eighty-three high school science teachers responded to the survey regarding classroom pedagogies implemented in their math or physical science courses. These teachers were surveyed to understand typical classroom practices that may be hypothesized to affect student choice of engineering.

Additionally, the questions developed from these three steps were piloted and refined to a final survey instrument. Extensive feedback from grant assessors was used refine the survey. Also, an in-person full draft survey pilot and focus group with 11 first year engineering students at Clemson University was conducted to understand how students were interpreting and answering the survey questions. Another in-person full draft survey pilot and focus group was conducted with students at Virginia Tech.

All of these findings including feedback from hypothesis generation, pilot studies, and assessors were incorporated in the survey through wording of questions, selection options, and elimination of non-essential questions.

The final survey includes 47 anchored, multiple choice, and categorical items that include the following categories:

Demographic Information – measured by gender, race, ethnicity, parental education, SAT/ ACT scores, highest high school math taken, grades in high school math and science

High School Science Experiences – measured by querying classroom pedagogies and frequency for biology, chemistry, and physics, the number of students per class, type of high school attended

Beliefs About Engineers' Roles – measured by factors associated with engineering

Engineering Identity – measured by self-identification as a "math person" or "science person," student interest in math and science, systems thinking, student confidence about science ability

Choice of Major – measured by intended major in middle school, high school, and college from a choice of fields, importance of factors for career choice (e.g. time with family, job security, using his/her abilities, etc.)

Student's Perception of His/Her Ability to Change His/Her World - measured by individual actions, motivation for choice of major

Survey Distribution

In order to obtain a nationally representative sample of students, surveys were distributed to a stratified, random sample of colleges and universities. The list of all colleges and universities from the National Center for Education Statistics (NCES) was divided by institution type (two-year or four-year) and by institution size (small, medium, or large) into six lists. Note that for-profit universities were removed from the list. The stratification accounted for the size of the institution and prevented over-sampling of the smaller, but numerous, liberal arts colleges in comparison to the relatively few, very large public state universities. Each list was randomized, and then recruiters contacted schools starting from the top of the list. From August to November of 2011, recruiters contacted English department chairs, or individual English professors when necessary, by email. Follow-up phone calls were placed as needed. Fifty institutions agreed to participate which are indicated in Figure 3.2.

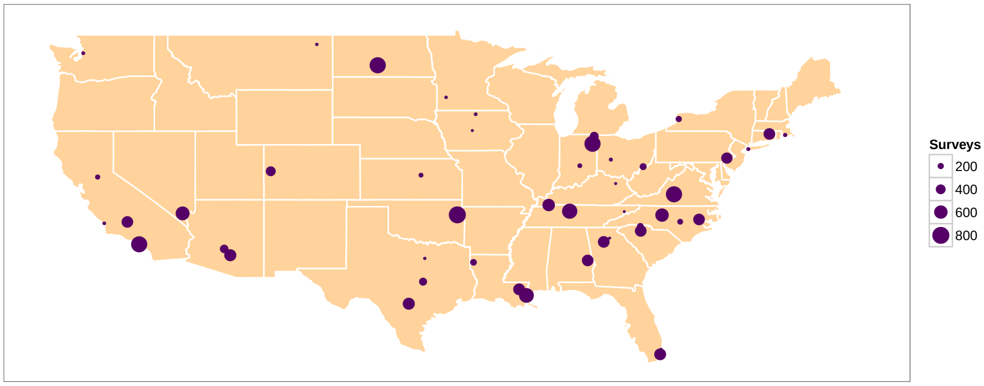

Figure 3.2: Schools recruited for participation in SaGE survey. Dot size represents the number of surveys sent to each school, not the size of the school [76, 77].

A total of 16,552 surveys were delivered to the 50 recruited colleges and universities. The surveys were distributed in introductory English courses and completed in class. Between October 2011 and January 2012, a series of four reminder emails were sent to participating institutions to ensure that they returned surveys. The institutional response rate was 100%. A total of 6,772 surveys were returned. Using this retrospective cross-sectional cohort methodology, substantial natural variability in students' background and prior experiences can be captured. In the data, students reported that they came from homes in at least 2,533 different ZIP codes across the U.S. A map of the engineering students' reported home ZIP codes is shown in Figure 3.3 (only the contiguous U.S. is shown). This map helps to illustrate the geographic distribution and representativeness of the sample, which is largely reflective of the population of the U.S. population. International students are also included in this study as a part of the cross-sectional sample gathered from the institutions surveyed. Of the total student population that completed the demographic portion of the survey, 54.7% were female. Each dot may represent more than one student and is located in the center of the reported zip code. This representation may visually inflate the populations in some areas like in North Dakota versus the East Coast due to larger areas for zip codes in the western part of the U.S. and more than one student per dot. The number of students in these more remote areas of the U.S. is much fewer than those in the more densely populated East Coast.

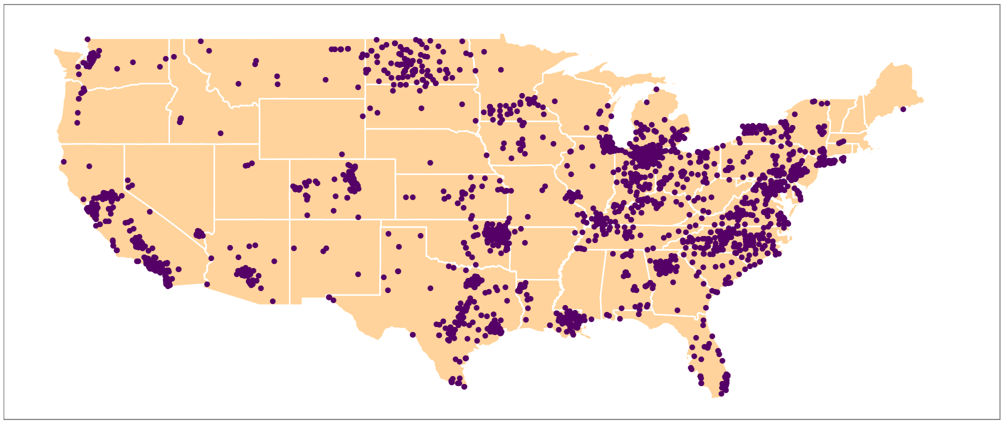

Figure 3.3: Home ZIP codes of students who participated in the SaGE survey. Note only the contiguous U.S. is depicted [76, 77].

Instrument Reliability and Validity

Once the instrument was developed, it was piloted with students and revised to ensure face validity and prevent survey fatigue in students. Lending to content validity, the hypotheses generated from the aforementioned survey of NSTA members as well as an open-ended survey of 82 first-year engineering and 41 non-engineering majors were included in the survey. Feedback from assessors familiar with survey development also added to the expert content validity of the survey.

To assure stability of the instrument, items utilized for this research were tested by test-retest method of 62 students with an average Pearson's correlation of 0.732.

Phase 2 - Qualitative

The quantitative part of this study cannot explain why identified factors might increase agency, empowerment, or the number of females majoring in engineering. To address these issues, additional study was required. Using contact information collected from students on the survey, Phase 2 of this research addresses the connection between student experiences and CEA.

Three research questions came out of Phase 1 to be addressed in the Phase 2 research. These questions address ideas that can not be answered from the SaGE data set through quantitative analyses. Qualitative data can provide the needed depth and richness to understand the connections and precursors to the CEA and engineering choices identified in Phase 1.

Research Question 5: How do women identify with physics and math?

Research Question 6: What do women believe they can do with engineering/science as a career?

Research Question 7: What factors influence women's identities and agency beliefs?

To address these research questions, two concurrent qualitative studies were conducted.

Study 1: Open-ended Surveys – Using contact information collected from female engineering students in the SaGE survey, this study addressed the connection between student experiences and CEA. This population will allow a number of contrasting cases to be examined for women interested in engineering with both high and low aspects of CEA. Student experiences, expectations, and attrition can be examined through the lens of CEA to better understand the connections between students' self-beliefs and career choices within engineering.

Study 2: Case Study – A student from the SaGE research project science classroom observations was highlighted as an exceptional case of a female entering engineering with high CEA. This student, with pseudonym Sara, started her academic career at a small, 4-year, private institution in Fall 2013. Following her development in understanding engineering careers, her identity as an engineer, and her beliefs about what engineering can do for the world and herself further refined the framework of CEA and the predictive model developed previously. Sara's story added insight to the larger quantitative survey and qualitative open-ended surveys collected from the SaGE population.

Open-ended surveys were chosen to investigate the same population that answered the SaGE survey. Analyzing responses from the female students who indicated higher agency beliefs than men and chose engineering on the SaGE survey gave a better understanding of why females reported these higher agency beliefs than men. Similarly for females reporting lower math and physics identities than men, the qualitative research gave insight into these responses and how these factors impacted their own choices. Examining the same population allowed for validation of the critical engineering agency model developed in Phase 1 through triangulation of student responses. This qualitative data gave explanations and interpretations for the quantitative data gathered from the same context.

A case study of one student allowed for a deeper understanding of the complexities of CEA and how a student's affective states interacted with their decisions, specifically her choice of a career in engineering. This case study gave a specific illustration of a more general concept, the application of CEA.

A qualitative approach to this phase of the research allowed for a more holistic approach to understanding why women become empowered to choose engineering. These data allowed for rich and vivid descriptions of students attitudes nested in a real context. This approach was the best method for investigating this new framework to understand students' engineering choices at a explanatory level. The design also allowed for an increased resolution in the lens used to examine CEA from a broad quantitative approach to a single focused case study.

3.3 Overview of Analysis Techniques

Quantitative Analysis

Four main statistical techniques were used to analyze the quantitative data: multiple regression, exploratory factor analysis, confirmatory factor analysis, and structural equation modeling. All analyses for this dissertation were conducted in R [75].

Regression is a statistical tool that allows the prediction of an outcome variable of interest from one or more other variables. This statistical technique allows variables that are statistically correlated with an outcome of interest (e.g. engineering choice) to be determined, and the amount of variance explained in the outcome to be ascertained.

Factor Analysis is a collection of methods used to examine how underlying constructs influence the responses on a number of measured items. A factor analysis is conducted by examining the pattern of correlations (or covariances) between the observed measures. Measures that are highly correlated (either positively or negatively) are likely influenced by the same underlying factors, while measures that are relatively uncorrelated are likely influenced by different factors. There are two primary types of factor analysis: (1) exploratory factor analysis (EFA) and (2) confirmatory factor analysis (CFA). Exploratory factor analysis tries to get at the nature of constructs (factors) influencing a set of responses or observed measures, whereas confirmatory factor analysis tests whether a specified set of constructs (factors) is influencing responses (or observed measures) in a predicted way. Typically a CFA is conducted after EFA to confirm the predicted relationships [78].

Structural equation modeling (SEM) is a method of analysis that tests and estimates causal relationships using a combination of factor analysis, regression, and path analysis. This technique was developed in response to the need for a method to look at the more complex nature of social science research and was the result of work conducted by Karl Joreskog, Ward Keesling, and David Wiley in the early 1970s. SEM addresses questions such as: "to what extent are observed variables actually measuring the hypothesized latent variables?" (p. 201) [79]. Typically, SEM is conducted with confirmatory factor analysis

(CFA) because a theorized model is needed to specify the pathways for the analysis.

Qualitative Analysis

A directed qualitative content analysis method will be used to draw meaning from the qualitative data. Originally, this method was developed within communication science to reduce large amounts of qualitative data to easily reportable quantitative data and an orderly way. In the 1980s the approach of *qualitative* content analysis was developed [80]. This approach has been defined as "an approach of empirical, methodological controlled analysis of texts within their context of communication, following content analytical rules and step by step models, without rash quantification" [81].

The analysis is guided by specific methodological steps [82]:

1. Prepare the data – The choice of the content must be justified by the research questions [83].

2. Defining the unit of analysis – The unit of analysis refers to the basic unit of text to be classified during content analysis. For Study 1, each open-ended survey was one unit. For Study 2, each of the three time points of the longitudinal interviews conducted was a unit of analysis.

3. Develop categories and a coding scheme – This analysis is directed. In this approach, researchers use existing theory or prior research to develop the initial coding scheme prior to beginning to analyze the data. As analysis proceeds, additional codes are developed, and the initial coding scheme is revised and refined. Researchers employing a directed approach can efficiently extend or refine existing theory [84].

4. Test coding scheme on a sample of text – This step involves validating the coding scheme through a detailed code book and conducting inter-rater reliability testing to ensure codes are consistent and reproducible.

5. Code text – The actual coding process uses a constant comparative method (described below). This method is used to prevent "drifting into an idiosyncratic sense of what the codes mean" [85].

6. Assess coding consistency – This step ensures reliability that the entire unit of analysis was coded consistently. Additionally, code meanings may have changed subtly over time and this step works to ameliorate inconsistent coding [86]

7. Draw conclusions from the data – This is the point at which the researcher makes sense of the themes or categories identified, and their properties. Researchers make inferences and present their reconstructions of meanings derived from the data.

8. Report methods and findings – For the study to be replicable, it is necessary to monitor and report the analytical procedures and processes as completely and truthfully as possible [83].

These steps were used to understand the experiences of women in engineering and expand the theoretical framework of CEA. In reporting these findings, a richer description of this method will be given as it applies to Studies 1 and 2 in Chapter 7.

In coding the data from qualitative data sources, a constant comparative method was used. This method describes the process of moving between the data collection and the data analysis to inform additional data collection. This method also involves finding similarities betweens statements and incidences in the same and different interviews and observations [86]. Open coding for the open-ended survey responses and interview data was used to divide the data into categories and coding segments that reflect specific themes that I was focused on (affective states, choice of college major/career, self-perceptions, etc.). After these data were categorized they will be scrutinized for properties that characterize the category. This process reduced the data to a small number of themes that reflect the underlying phenomena under investigation. Next, axial coding was conducted to find the connections between sub-categories. This part of the data analysis focused on conditions, context, strategies students' use, and consequences of those strategies with respect to the categories and sub-categories defined in open coding. Finally, selective coding was conducted to develop a story that describes the phenomena being studied (the relationship between student affect, self-perception, and choice of college major). From this final story the theory can be enriched, validated, or created. During this process, memo writing and diagramming was an important reflective step to elaborate categories and take a step back from the detailed coding scheme going on at the transcript level and organize the categories being developed and detailed during the coding process [86]. The software that was used to perform this coding process for both studies was RQDA [75, 87].

The data collected from students identified from the SaGE survey comprised open-ended survey responses. This qualitative data allowed for a triangulation of the data collected from the SaGE surveys in students' first year of college. The open-ended surveys, administered one to two years after the initial SaGE survey, focused on the experiences and connections that caused increased agency and empowerment by impacting students' view of themselves, their level of engagement, and their empowerment to pursue engineering. This method captured student experiences in rich detail and helped develop an understanding that can inform high school teachers, college faculty and staff, and the larger education community about how females can be empowered towards engineering. The data from this phase were not only used to help explain connections seen in the quantitative data but also to further refine the model created.

The case study student from the SaGE high school observations also was asked similar questions to the ones asked of the larger sample of students, but personal contact with this student allowed for probing to better understand questions and the ability to follow-up with additional research questions as needed. Also, student responses to the open-ended surveys in Study 1 informed possible questions to include in Study 2 interview protocol. Interviewing this study participant by phone with a semi-structured protocol allowed for probing responses to questions asked and researcher-generated questions as the discourse of the interview emerged. Critical events changing her CEA were documented and understood. Multiple interviews and discussions about her career intentions and attitudes about engineering through her first-year enlightened the proposed research questions. This student was interviewed about her engineering interest, identity, and agency beliefs while in her senior year of high school (Spring 2013). Earlier interview responses were compared to the proposed interviews to give a longer longitudinal understanding of her attitudes and interests. Telling the story of how one student navigates the first-year of the transition to engineering from intentions in high school to actual college practice is a powerful tool in understanding how students change over time and develop the engineering identities traditionally studied in college. This approach gives rich detail about how CEA affects students choices and actions over a period of time. A possible finding of this data was be actual agency that resulted in specific actions from her agency beliefs and choice of engineering as a career.

Chapter 4

Validating Critical Engineering Agency Constructs

This portion of research examines the identity and agency constructs and to build a regression model of choice of engineering as a major or career. The constructs hypothesized to measure Critical Engineering Agency (CEA) of performance/competence, recognition, interest, and agency were tested for construct validity before utilizing them in subsequent analyses. This chapter discussed the method ensuring that the items used to measure these constructs captured students' self-beliefs.

Methods

First, an exploratory factor analysis was conducted to examine how well the items on the SaGE survey related to mathematics identity, physics identity, and general science identity loaded on the theorized sub-constructs. If the resulting factors aligned with the framework, then the data also support the construct validity of the sub-constructs in the framework of identity (interest, recognition, performance/competence). For physics identity, nine items loaded onto the three constructs as theorized. Ten factors were included in the analysis of mathematics identity and loaded onto the three identity factors. For general science identity, a total of twelve factors were used, but only two factors were assessed: interest and performance/competence. A promax (non-orthogonal) rotation was employed in each case since the theory naturally permits inter-correlation between the sub-constructs (i.e. the factors were not expected to be orthogonal). Next, another exploratory factor analysis was conducted to examine how well the questions theorized to measure agency and being critical loaded together. From the survey, twelve items loaded onto two separate agency factors (described below). Finally, the constructs of physics, mathematics, and science identity along with the two agency factors were regressed on the choice of engineering as a career (i.e. engineering career choice was set as an interval/ratio variable in a linear regression model), while controlling for the level of parents' education (a socioeconomic indicator) and gender. The constructs for each of the different types of identity were created by averaging each of the sub-constructs measured by the factors in the exploratory factor analyses discussed previously. The choice of engineering was determined by utilizing a question that asked students to "Please rate the current likelihood of your choosing a career in the following:" for a variety of science, math, and engineering careers on a anchored scaled items. A student's strongest response to any of the several engineering disciplines was used as a proxy for a student's interest in pursuing a career in engineering. This method was used in order to capture students interested in engineering in general (but undecided on a discipline) as well as students with a very well-specified interest in one or two engineering disciplines.

Results

The 9 items for physics identity aligned on the theorized sub-constructs with competence and performance items loading together. Thus, performance and competence were combined under Factor 1. Factor loadings ranged from 0.546 to 0.943 indicating that, to a great extent, items accurately captured the same construct. The mean loading for the factors were as follows: 0.763 for performance/competence, 0.820 for recognition, and 0.686

for interest. For all exploratory factor analyses conducted, the cut off for factor loadings was set at 0.4 [88]. Any factors loading at values less than 0.4 are not a reliable measures for the sub-construct and were not included in this analysis.

Table 4.1: EFA of Physics Identity

Statement	**Factor 1 - Performance/ Competence**	**Factor 2 - Recognition**	**Factor 3 - Interest**	**Uniqueness**
Q27 Phys_b: my parents/relatives/friends see me as a physics person		0.743		0.237
Q27 Phys_c: my physics teacher sees me as a physics person		0.898		0.128
Q27Phys_d: I am interested in learning more about this subject			0.825	0.149
Q27Phys_f: I am confident that I can understand this subject outside of class	0.628			0.234
Q27Phys_g: I enjoy learning the subject			0.546	0.187
Q27Phys_h: I can do well on exams in this subject	0.943			0.147
Q27Phys_i: I understand concepts I have studied in this subject	0.901			0.126
Q27Phys_j: others ask me for help in this subject	0.602			0.334

The 10 items for mathematics identity also aligned on the theorized sub-constructs with competence and performance items loading together. Thus, performance and competence were combined under Factor 1. Factor loadings ranged from 0.486 to 0.979. The mean loading for the factors were as follows: 0.812 for performance/competence, 0.863 for recognition, and 0.732 for interest.

Table 4.2: EFA of Mathematics Identity

Statement	Factor 1 - Performance/ Competence	Factor 2 - Recognition	Factor 3 - Interest	Uniqueness
Q27Math_b: my parents/relatives/friends see me as a math person		0.904		0.157
Q27Math_c: my physics teacher sees me as a math person		0.823		0.169
Q27Math_d: I am interested in learning more about this subject			0.979	0.005
Q27Math_e: I am confident that I can understand this subject in class	0.829			0.176
Q27Math_f: I am confident that I can understand this subject outside of class	0.756			0.219
Q27Math_g: I enjoy learning the subject			0.486	0.254
Q27Math_h: I can do well on exams in this subject	0.932			0.166
Q27Math_i: I understand concepts I have studied in this subject	0.948			0.148
Q27Math_j: others ask me for help in this subject	0.637			0.312
Q27Math_n: I can overcome setbacks in this subject	0.768			0.486

The 12 items for general science identity aligned on the theorized sub-constructs with competence and performance items again loading under the same factor. Factor loadings ranged from 0.660 to 0.904. The items theorized to measure general science recognition did not hold together in the factor analysis and were subsequently removed from the analysis. The mean loading for the factors were as follows: 0.791 for performance/competence and 0.795 for interest.

The 9 items for agency and being critical did not align as expected on the theorized sub-constructs. Namely, the theorized construct of being critical did not load separately from the questions constructed to measure agency. Instead, the questions loaded as questions that related directly to students' lives and included first-person personal and possessive pronouns, such as "I," "me," and "my." The other factor included questions about how students viewed the ability of science to change the world. Factor loadings ranged from 0.543 to 0.957 indicating that, to a great extent, items accurately captured the same construct. The mean loading for personal agency was 0.831, and the mean loading for global agency was 0.738. It is important to note that the global agency construct identified here is a true agency measure because all of the students in this analysis have already indicated they intend on a STEM career. If this were not the case, the view of science's potential to affect the world may not be agential in character. Students' beliefs about science's impact on their lives coupled with a choice of STEM implies that these students see STEM as a way to accomplish change in their world, and, therefore, hold agential beliefs about science in a personal and/or global sense.

After the questions for each identity sub-construct were verified, the composite constructs of math identity, physics identity, and general science identity were created by averaging the sub-constructs for a single overall measure. Additionally, the questions for personal agency and global agency were averaged into two overall constructs for agency. These three identity constructs and two agency constructs were regressed on the choice of engineering and the choice of science in college. Gender, father's education, and mother's education were used as controls in the regression. Both parent's education was used as a

Table 4.3: EFA of General Science Identity

Statement	**Factor 1 - Performance/ Competence**	**Factor 2- Interest**	**Uniqueness**
Q25a: interest in understanding natural phenomena		0.660	0.547
Q25b: interest in understanding science in everyday life		0.835	0.283
Q25c: interest in explaining things with facts		0.691	0.513
Q25d: interest in telling others about science concepts		0.904	0.21
Q25e: interest in making scientific observations		0.864	0.223
Q26a: confidence to design an experiment to answer a scientific question	0.791		0.336
Q26b: confidence to conduct an experiment on your own	0.850		0.325
Q26c: confidence to interpret experimental results	0.896		0.232
Q26d: confidence to write a lab report/scientific paper	0.869		0.336
Q26e: confidence to apply science knowledge to an assignment or test	0.822		0.259
Q26f: confidence to explain a science topic to someone else	0.721		0.284
Q26g: confidence to get good grades in science	0.615		0.555

Table 4.4: EFA of Agency Beliefs Identity

Statement	**Factor 1 - Personal Agency**	**Factor 2- Global Agency**	**Uniqueness**
Q29a: learning science will improve my career prospects	0.795		0.335
Q29b: science is helpful in my everyday life	0.933		0.196
Q29c: science has helped me see opportunities for positive change	0.957		0.149
Q29d: science has taught me how to take care of my health	0.721		0.35
Q29e: leaning science has made me more critical in general	0.749		0.337
Q29f: science and technologies will provide greater opportunities for future generations		0.543	0.422
Q29j: a country needs science and technology to become developed		0.738	0.471
Q29m: science and technology make our lives healthier, easier and more comfortable		0.899	0.265
Q29n: the benefits of new technologies greatly outweigh the risks		0.772	0.483

proxy for socioeconomic status, which has been found previously to be a strong predictor of SES [47]. Results from the regression model predicting the choice of engineering as a career, appear in Table 4.5. The results for the regression model predicting a choice of science as a career (physicist, chemist, biologist, environmental scientist, etc.) are included in Table 4.6. These regression models show that the constructs used in this analysis are strongly predictive of the choice of engineering or science, with a few notable differences. For students who choose engineering, the estimate for male parental guardian's education level is a significant negative predictor for the choice of engineering ($p<0.01$).

Previous literature has shown that the socioeconomic status of students who choose engineering is lower than students who choose science [47]. Thus, the difference seen on this factor between science and engineering students is not surprising. Female parental guardian education level is non-significant for both engineers and scientists. Being female is a negative predictor for choice of engineering ($p<0.001$) and a positive predictor for choice of a science career ($p<0.001$). This difference is seen in the gender control variable because engineering is an underrepresented field while science has reached parity in gender representation as a whole [89]. One major difference seen between engineering and science students is a strong connection between mathematics identity ($p<0.001$) and engineering career choice, which is non-significant for a science career choice. Science students and engineering students both show strong personal agency in their views of science's ability to affect their immediate world ($p<0.001$). However, there is a marked difference in the way that science and engineering students view science's ability to affect the larger world, or what we have termed global agency. The global agency factor is a significant negative predictor for science students ($p<0.001$) but is non-significant for engineering students.

Discussion

The regression models show that there are differences in science and engineering students on a few factors. Math, physics, and science identities along with strong beliefs

Table 4.5: Regression on choice of engineering (N=2501, Adjusted R^2=0.295).

Factor	Estimate	Std. Error	Beta Coefficient	Significance§
Gender (0-male; 1-female)	-0.703	0.052	-0.237	***
Father's Education	-0.076	0.025	-0.0641	**
Mother's Education	-0.004	0.027	-0.0033	n/s
Math Identity	0.152	0.023	0.1285	***
Physics Identity	0.259	0.027	0.2085	***
Science Identity	0.33	0.056	0.1476	***
Personal Agency	0.139	0.036	0.1022	***
Global Agency	-0.056	0.035	-0.03495	n/s

§The level of statistical significance is coded in the final column: n/s represents a non-significant result, * represents a statistical significance less than 0.05 but greater than or equal to 0.01, ** represents a statistical significance less than 0.01 but greater than or equal to 0.001, and *** represents a statistical significance less than 0.001.

about science's role in their personal lives (personal agency) contribute significantly to a choice of engineering. These attitudes explain a large portion of the variance in the choice of engineering (0.295). While these constructs can account for some of the reasons students choose engineering, other factors like career expectations and other agential pieces about engineering may explain a larger portion. Future work should be conducted to understand more of these influencing factors on the choice of engineering in building a model of engineering career choice for high school students. Similarly, students who chose science majors in college had significantly positive physics and general science identities along with personal agency, but the construct of global agency was actually a negative predictor for the choice of science in college. One possible reason for this difference in global agency is that students perceive differences in the Communities of Practice of scientists and engineers. Scientists may solve problems similarly to engineers, but their goal is usually to explain, model or understand how the world works around them. Engineers, on the other hand, may solve problems with a pragmatic picture in mind. Their perceived value of discovery and information is encoded in the systems they build rather than in scientific laws or facts [90]. Engineering students frequently solve large systems with the "big picture" in mind. Many young students in science deal with small-scale, detailed experiments and may not be able to translate their findings into a solution with far-reaching implications. Or, these science

Table 4.6: Regression on choice of science (N=2530, Adjusted R^2=0.334).

Factors	**Estimate**	**Std. Error**	**Beta Coefficient**	**Significance**§
Gender (0-male; 1-female)	0.271	0.049	0.092	***
Father's Education	-0.029	0.024	-0.0248	n/s
Mother's Education	-0.004	0.026	-0.00303	n/s
Math Identity	0.02	0.022	0.01756	n/s
Physics Identity	0.151	0.026	0.12359	***
Science Identity	0.624	0.053	0.28317	***
Personal Agency	0.43	0.034717	0.32101	***
Global Agency	-0.143	0.03367	-0.0905	***

§The level of statistical significance is coded in the final column: n/s represents a non-significant result, * represents a statistical significance less than 0.05 but greater than or equal to 0.01, ** represents a statistical significance less than 0.01 but greater than or equal to 0.001, and *** represents a statistical significance less than 0.001.

students may be more skeptical of what science can do for the world than their engineering peers. These ideas may explain our measurement that engineering students have a high degree of personal agency and higher global agency than science students while science students only exhibit a strong personal agency.

Math and physics identity constructs have been used to predict the choice of a math or physics career [42, 43]. When these constructs were applied to engineering, the physics construct seemed too restrictive to predict an engineering career for a variety of engineering disciplines. Engineering students may not all have a strong physics identity; for example, students in engineering disciplines that involve chemistry and biological processes may not necessarily have a strong affinity towards physics. With this hypothesis in mind, general science identity factors were also measured with the same theoretical foundation as the published math and science identities. While the recognition sub-construct was not well measured by the questions in the SaGE survey, the interest and performance/competency pieces were captured, and this construct was included in the regression models to model interest in science besides physics.

These results are a step toward understanding why students may choose engineering over science. Students who choose a career in engineering may base their decision on their ability in math and science along with other factors. The framework of critical engineering agency may provide a way to understand why students choose engineering specifically. As a first step toward quantitatively measuring and validating this framework, the identity and agency constructs were built using exploratory factor analysis. This analysis showed that several items appropriately measure the three factors for mathematics and physics identity as theorized. Additionally, this process allowed for the identification and removal of items that did not accurately measure these sub-constructs. When general science identity construct was included, the questions theorized to measure recognition did not load into a single factor and were removed from the analysis. Future work to validate this newer measure will include developing items that measure students' perceptions of recognition in science generally.

Conclusion

In the analyses reported in this chapter, constructs have been developed for measuring CEA quantitatively. Some aspects of identity have been captured by math and science factors (physics as well as general science). The aspects of being a critic and having agency did not load on two separate factors as expected. Instead, the questions grouped differently into two factors based on the immediacy of the perceived influence of science in students' lives. These two new factors were termed personal and global agency based on the observed differentiation of the factors. Through this analysis it was found that engineering students have a strong personal agency and that global agency has no significant relationship on the choice of engineering. Conversely, having a strong global agency was a negative predictor for a science career. Since many students who choose science have strong science identities and strong math skills (as engineering students do as well), this factor may be used to differentiate between students who choose science and engineering careers. This finding has implications for recruitment, retention, and pedagogy for engineering students. If the previously uninformed and possibly irrational decision of an engineering career can be understood through these constructs, more students can be identified, encouraged, and developed to become engineers. This work reaffirms the importance of experiences and attitudes towards mathematics and science to future engineering students but it also illustrates the differences in students beliefs about the impact of these subjects on their future career choices. Furthermore, this examination revealed that the differences between students who choose engineering over science are significant for some of the factors considered in this chapter, particularly math identity and global agency.

Providing some validation of these constructs is a first step in building a predictive model for the choice of engineering. Understanding why students choose engineering in particular, out of the spectrum of STEM disciplines, can assist in identifying students who would not normally choose engineering for recruitment and developing pedagogy to retain these students in engineering. Both of these scenarios are an opportunity to increase the number of engineers and engineering solutions for the future.

Chapter 5

Using Validated Constructs to Build Structural Equation Model

With the validated constructs described in Chapter 4, structural equation modeling (SEM) was used to understand the relationships between the latent variables. This method allows for confirmatory testing of a theory. The expansion of Critical Science Agency to engineering can be understood and described through estimating the direction and size of paths between latent constructs and the outcome variable of engineering choice.

Introduction

Engineering choice has been explored in other frameworks including, notably, social cognitive career theory (SCCT). However, SCCT does not include other affective states that may be important to understanding students' choices. This theoretical framework has been evaluated using SEM for the choice of engineering on a medium scale (n=338) [70]. In this analysis, contextual supports and barriers are linked to persistence in engineering (not the choice of engineering) indirectly through self-efficacy. This finding is counter to SCCT and more consistent with Bandura's broader, original work on social cognitive theory. While this study does illustrate some of the same connections posited in the analysis of the current work (performance/competence linked to interest, for example), it does not have the same scope and goals. The path from students' goals to the outcome measurement, persistence, accounted for 28% of the variance in persistence which is a large portion for which one construct to account. However, this study was conducted with a small sample of students from one institution with strong math abilities. These students also reported favorable environmental conditions with strong contextual supports and few reported barriers. Finally, the sample was 80% male and 63% European American descent. For these reasons, the study could not make causal links between the variables studied and engineering persistence.

A recent paper has investigated students' choice of a STEM career also utilizing the methodology of SEM [91]. Drawing upon social cognitive career theory [6], this paper examined the effects of intentions to major in STEM, high school math achievement, and initial post-secondary experiences over a period of four years starting in the 10th grade running until two years into college (2002-2006). The largest impacts on STEM major intentions were found to be from: 12^{th}-grade math achievement, exposure to math and science courses, and math and science self-efficacy beliefs. The study found no differences for men and women, but did identify differential effects for majority students and underrepresented minority students. These previous findings on students choice give a strong incentive to continue to understand how and why students choose engineering. Developing this understanding will allow for the development of students desire to choose engineering which in turn, can create a more diverse engineering field and more creative engineering solutions. There is a documented need to recruit and retain more engineering students in the future.

Guided by the Critical Engineering Agency (CEA) theoretical framework and motivated by the continued lack of gender diversity in the college engineering population, this study examines the direct and indirect influences of students' self-beliefs in multiple identity domains and their agency beliefs on their college engineering intentions utilizing structural equation modeling (SEM). This study addresses the first four research questions of this dissertation through quantitative methods.

Research Question 1: What are the relationships among students' identities in high school that predict the choice of engineering?

Research Question 2: How do students' beliefs about how science and technology can impact the world predict a choice of engineering?

Research Question 3: Are these beliefs (identity and agency) different for men and women?

Research Question 4: How well does Critical Engineering Agency as an explanatory framework describe students' choice of engineering?

Methods

Data Source and Measurements

The data for this study are drawn from the nationally representative SaGE survey. One question central to the current analysis asked students to "Please rate the current likelihood of your choosing a career in the following." The various career options were "Mathematics," "Science/math teacher," "Environmental science," "Biology," "Chemistry," "Physics," "Bioengineering," "Chemical engineering," "Materials engineering," "Civil engineering," "Industrial/systems engineering," "Mechanical engineering," "Environmental engineering," and "Electrical/computer engineering." Students were asked to rate the likelihood of choosing a career in each discipline on an anchored scale from 0 ("not at all likely") to 4 ("extremely likely"). In the current analysis, students' choice of engineering was the strongest response to any of the eight engineering responses . This method was chosen to include students interested in engineering generally (but as-yet undecided on a particular discipline) as well as students with a very well-specified interest in one or two engineering disciplines.

Confirmatory Factor Analysis

To conduct this analysis a two-part approach was undertaken. First, a "measurement model" was examined utilizing confirmatory factor analyses to assess how well the indicators items measured the hypothesized latent variables. If the measurement model was deemed acceptable, then the structural and measurement parts of the model were estimated simultaneously. Seven latent constructs related to the various components of CEA were measured: the three sub-constructs of identity (performance/competence beliefs, interest, and recognition beliefs) for each of physics and mathematics, and agency beliefs. During this step, the fit indices of the measurement model were assessed and convergent validity was checked by examining the factor loadings.

Structural Equation Modeling

Next, the proposed model was tested using structural equation modeling (SEM). Figure 5.1 shows the proposed model constructed from the CEA framework. From previous work on modeling CEA [35], the constructs of physics and math identity were built to include mediating paths from performance/competence to identity via interest and recognition. Items that asked students the degree to which they identify as a "physics person" or a "math person" were used as an overall measure of identity [42]. These identities, along with agency beliefs, taken from the "personal agency" beliefs from Chapter 4, were hypothesized to predict the choice of engineering as a major/career. Previous work modeling engineering choice using an identity framework showed no significant relationship between general science identity and engineering choice [35]; therefore, this construct was eliminated from this analysis. The student beliefs model represented in Figure 5.1 was tested using the lavaan package in R [75, 92] with a subset of the SaGE data input as a correlation matrix. As is common with survey research of this nature, some of the variables included in the study had missing data. To moderate the potential biasing effects of this, the data were imputed for missingness using a full information maximum likelihood method for the model-dependent variables which is considered best practice for this methodology [79, 88, 93, 94].

This technique utilizes all of the data in the analysis. It has been shown to produce unbiased parameter estimates and standard errors under MAR and MCAR data. The process works by estimating a likelihood function for each individual based on the variables that are present so that all the available data are used.

Additionally, the variance of each latent variable was fixed to one. A Satorra-Bentler estimation method [95] was used to account for any non-normality in the data. This method rescales the value of the full information maximum likelihood chi-square test statistic by an amount that reflects the degree of kurtosis. Several simulation studies have shown that this correction is effective with non-normal data [96,97], even in small to moderate samples. Thus, it is appropriate to use traditional cutoff values when using this estimation method. The model was trimmed of non-significant paths and for parsimony following Byrne [93]. This structure simultaneously estimates thirteen regression equations and one covariance between physics identity and math identity. Several fit indices and path significance tests were used the evaluate the model based on Byrne's suggestions [93], including chi-square, Comparative Fit Index (CFI), Non-Normed Fit Index (NNFI), and root mean square error of approximation (RMSEA).

The proposed model (Figure 5.1) includes mediated paths for the construction of physics and math identities. Maxwell and Cole argued that mediation in models can result in biased estimates due to the lack of time-responsive data [98]. However, the use of mediated models in cross-sectional studies is acceptable if the bias can be determined to be non-significant and the directional influences of the latent variables are essentially instantaneous. In a study of the effects of mathematics self-efficacy on performance on mathematics tests, Pajares and Miller argued that the effects of interest and self-efficacy were essentially instantaneous on the outcome and the variables should be measured as closely together as possible [99]. In this study, the same variables of interest and performance/competence are used along with students' perceptions of recognition. These quasi-traits measured do not change over the time period of interest [100], and can therefore be interpreted in a mediated model. This argument is upheld by the discussion that as students move further along in their education, their identities become more and more established with each additional interaction with STEM-related subjects. At the macro time level when students are asked to think reflexively, these identities are relatively stable rather than moment to moment instances [101]. Only significant changes or experiences can dramatically shift students' identities. In this study, college freshmen are asked about their self-beliefs in traditional subjects like math and science, which have been practiced over numerous years of formal education. Their identities are stable, or in equilibrium, unless a perturbation occurs and offsets the balance between interest, performance/competence, and interest. These perturbations cause identity renegotiation and new identity development. We controlled for these perturbations in the sampling of students at the beginning of their freshman year in college before they had new STEM experiences. Additionally, the magnitude of bias for mediated models can be estimated based on the stability coefficients of the latent variables [98]. The bias for stable variables within a time of interest is negligible if the stability coefficients are similar. In this case, the equilibrium between the identity variables results in stable measurements and non-significant bias.

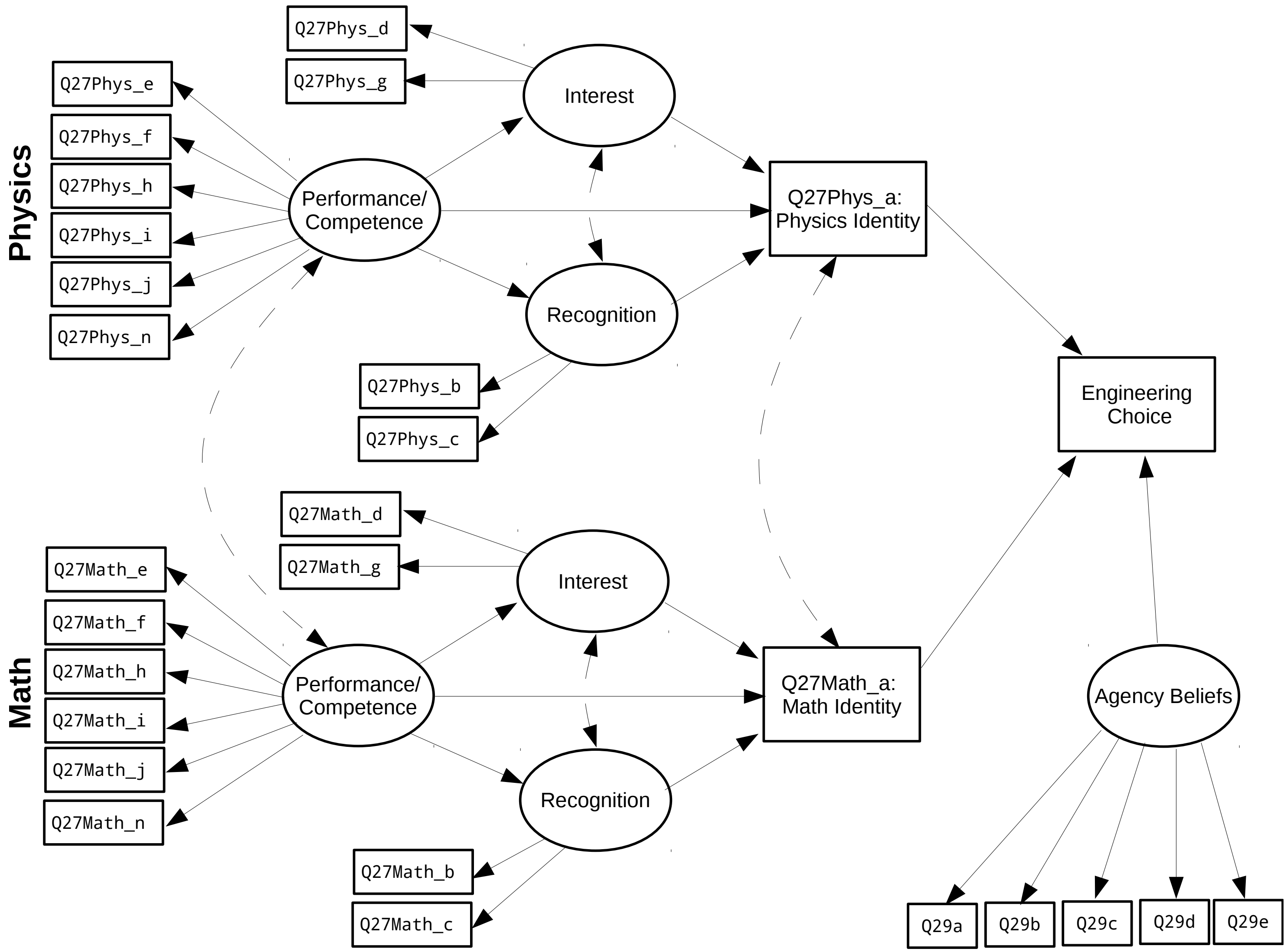

Figure 5.1: Diagram of proposed structural model for the structural equation modeling analysis based on CEA theoretical framework.

Multiple Group Analysis: Testing for Model Invariance

After the full SEM model was evaluated for fit, the model was compared for females and males to see if the proposed structure was equivalent across these groups. Model invariance tests were conducted to determine significant differences in the measurement and structural path parameters. Firstly, a baseline model was created for males and females with all parameters freely estimated (see Figure 5.2). Next, a model was created with only factorial equality constraints - the factor loadings between the male and female model were constrained to be equal while the regression coefficients were freely estimated across the groups. A measurement invariance test was conducted based on the chi-square difference statistic when compared to the baseline model. This chi-squared difference, called a mod or modification indice should be greater than 3.841 as indicated on a chi-square distribution table with one degree of freedom. A non-significant test (mod indice <3.841) would indicate that there was not a significant difference between the two groups and, therefore, invariance across the two models. If non-invariance was indicated by a significant chi-square difference test then the groups did differ significantly. Examination of the modification indice for each variable revealed factor loadings that were different between groups and these loadings were allowed to be freely estimated until the chi-square difference test indicated model invariance. This process was repeated to test for structural invariance by then constraining the regression coefficients to be equal across the models and testing for invariance with the modified factoral equality constraint model.

Results

The CFA analyses included in Tables 5.1, 5.2, and 5.3 indicate that the measurement model fits the data. Individual item reliability was evaluated with the square multiple correlation (R^2). Each correlation was above 0.5 indicating that construct reliability accounted for over 50% of the variance in each measured item in reference to the other observed items [94]. Construct reliability[1], also known as composite reliability, for the various latent constructs ranged from 0.881 to 0.941. This reliability gives a better estimate of the overall reliability of an item taking into account the individual reliabilities as well as standard errors. Values greater than 0.70 are acceptable [102]. Though the squared multiple correlation (R^2) indicates the reliability of a single measure and the construct reliability the reliability of the construct as a whole, neither one measures the amount of variance that is captured by the construct in relation to the amount of variance due to measurement error [103]. The average variance extracted[2] (AVE) provides this information and was calculated for each latent variable ranging from 0.717 to 0.825. The average variance extracted is the amount of variance that is captured by the latent variable in relation to the amount of variance due to its measurement error. In different terms, is a measure of the error-free variance of a set of items measuring a single construct. Average variance extracted is used as measure of convergent validity, which should be 0.50 or above [104]. These results demonstrate that the items hypothesized to measure a single construct do, in fact, measure the intended construct and capture a strong majority of the variance within each block of items. Convergent validity establishes that measures that should be related are in reality related. This type of validity was determined by examining the factor loadings in the model, since all of these values were greater than 0.70 the criteria for convergent validity were met. Discriminant validity establishes that measures for one latent variable are not overly rated to another latent variable and was established through multiple methods. First, the AVE should be greater than squared multiple correlation between latent variables which was established in Tables 5.1, 5.2, and 5.3 [94]. Additionally, the correlation between items of unrelated latent variables is less than 0.85 (Appendix C) [93].

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[1] Construct Reliability = (sum of standardized loading)^2/[(sum of standardized loading)^2 + sum of indicator measurement error], where the measurement error of each indicator is 1 minus the square of the indicator's standardized loading.

[2] Average Variance Extracted = (sum of standardized loading)^2/(sum of squared standardized loading + sum of indicator measurement error), where the measurement error of each indicator is 1 minus the square of the indicator's standardized loading.

Table 5.1: Confirmatory Factor Analysis Estimates for Physics Identity. *To summarize acceptable values: Item reliability* (R^2) *>0.50, Construct Reliability >0.70,and Average Variance Extracted >0.50.*

Latent Variable	**Indicator Variable**	**Standardized Factor Loadings**	**Standard Error**	**Item Reliability ($\mathbf{R^2}$)**	**Construct Reliability**	**Average Variance Extracted**
Interest	Q27Phys_d: Interest in physics	0.866	0.025	0.750	0.883	0.791
	Q27Phys_g: Enjoyment of physics	0.912	0.025	0.832		
Recognition	Q27Phys_b: Physics recognition from family/friends	0.898	0.013	0.806	0.886	0.796
	Q27Phys_c: Physics recognition from teacher	0.886	0.013	0.785		
Performance/ Competence	Q27Phys_e: Confidence in learning physics	0.886	0.014	0.785	0.940	0.724
	Q27Phys_f: Confidence in understanding physics	0.877	0.014	0.769		
	Q27Phys_h: Can do well on physics exams	0.903	0.014	0.815		
	Q27Phys_i: Understand physics concepts	0.921	0.014	0.848		
	Q27Phys_j: Others ask me for help in this subject	0.787	0.012	0.619		
	Q27Phys_n: Can overcome setbacks in physics	0.711	0.012	0.506		

Table 5.2: Confirmatory Factor Analysis Estimates for Math Identity. *To summarize acceptable values: Item reliability (R^2) >0.50, Construct Reliability >0.70,and Average Variance Extracted >0.50.*

Latent Variable	**Indicator Variable**	**Standardized Factor Loadings**	**Standard Error**	**Item Reliability (R^2)**	**Construct Reliability**	**Average Variance Extracted**
Interest	Q27Math_d: Interest in math	0.866	0.013	0.750	0.881	0.788
	Q27Math_g: Enjoyment of math	0.909	0.013	0.826		
Recognition	Q27Math_b: Math recognition from family/friends	0.922	0.023	0.850	0.904	0.825
	Q27Math_c: Math recognition from teacher	0.894	0.021	0.799		
Performance/ Competence	Q27Math_e: Confidence in learning math	0.897	0.011	0.805	0.941	0.727
	Q27Math_f: Confidence in understanding math	0.875	0.011	0.766		
	Q27Math_h: Can do well on math exams	0.900	0.011	0.810		
	Q27Math_i: Understand math concepts	0.909	0.011	0.826		
	Q27Math_j: Others ask me for help in this subject	0.814	0.011	0.663		
	Q27Math_n: Can overcome setbacks in math	0.703	0.010	0.494		

Table 5.3: Confirmatory Factor Analysis Estimates for Agency Beliefs. *To summarize acceptable values: Item reliability (R^2) >0.50, Construct Reliability >0.70,and Average Variance Extracted >0.50.*

Latent Variable	**Indicator Variable**	**Standardized Factor Loadings**	**Standard Error**	**Item Reliability (R^2)**	**Construct Reliability**	**Average Variance Extracted**
Agency Beliefs	Q29a: Learning science will improve career prospects	0.814	0.012	0.663	0.927	0.717
	Q29b: Science is helpful in my everyday life	0.895	0.011	0.801		
	Q29c: Science has helped me see opportunities for positive change	0.920	0.010	0.846		
	Q29d: Science has taught me to take care of my health	0.794	0.012	0.630		
	Q29e: Learning science has made me more critical	0.804	0.012	0.646		

The proposed SEM model was then fit for the entire imputed sample in Figure 5.2. There were 1,288 patterns of missingness found and imputed, and cases in which were MNAR were deleted, for a final sample size of 6,511 from the original 6772. The chi-square statistic for this model is 10,062 and is significant. Due to the large sample size, the chi-square statistic is artificially inflated and the chi-square statistic is expected to be significant without indicating a poorly fitting model [79]. The degrees of freedom reported are 331. The RMSEA indicates a reasonable fit of the model with the observed data with a value of 0.065 (90% confidence interval ± 0.001). Values less than 0.01, 0.05, and 0.08 indicate excellent, good, and moderate fit respectively [105]. Additionally, the RMSEA is largely invariant with increasing sample size, unlike the chi-square test. For sample sizes of 500 or greater, the RMSEA is sensitive to increasing misfit. Thus it is appropriate to use this supplementary fit statistic in the presence of large sample sizes, to inform if sample size is inflating the chi-square statistic, and hence its significance [106]. The CFI also suggested good fit with a value of 0.947 (acceptable values occur above 0.9 [107]). Finally, an NNFI of 0.939 indicates acceptable fit (in accordance with standard of values greater than 0.9 [107]) and can be influenced by larger sample sizes since it is calculated from the chi-square statistic. Research Questions 1 and 2 can be answered from this model. This model shows how identity in both physics and math as well as students' beliefs about what science/engineering can do for the world (agency beliefs) predict a choice of engineering.

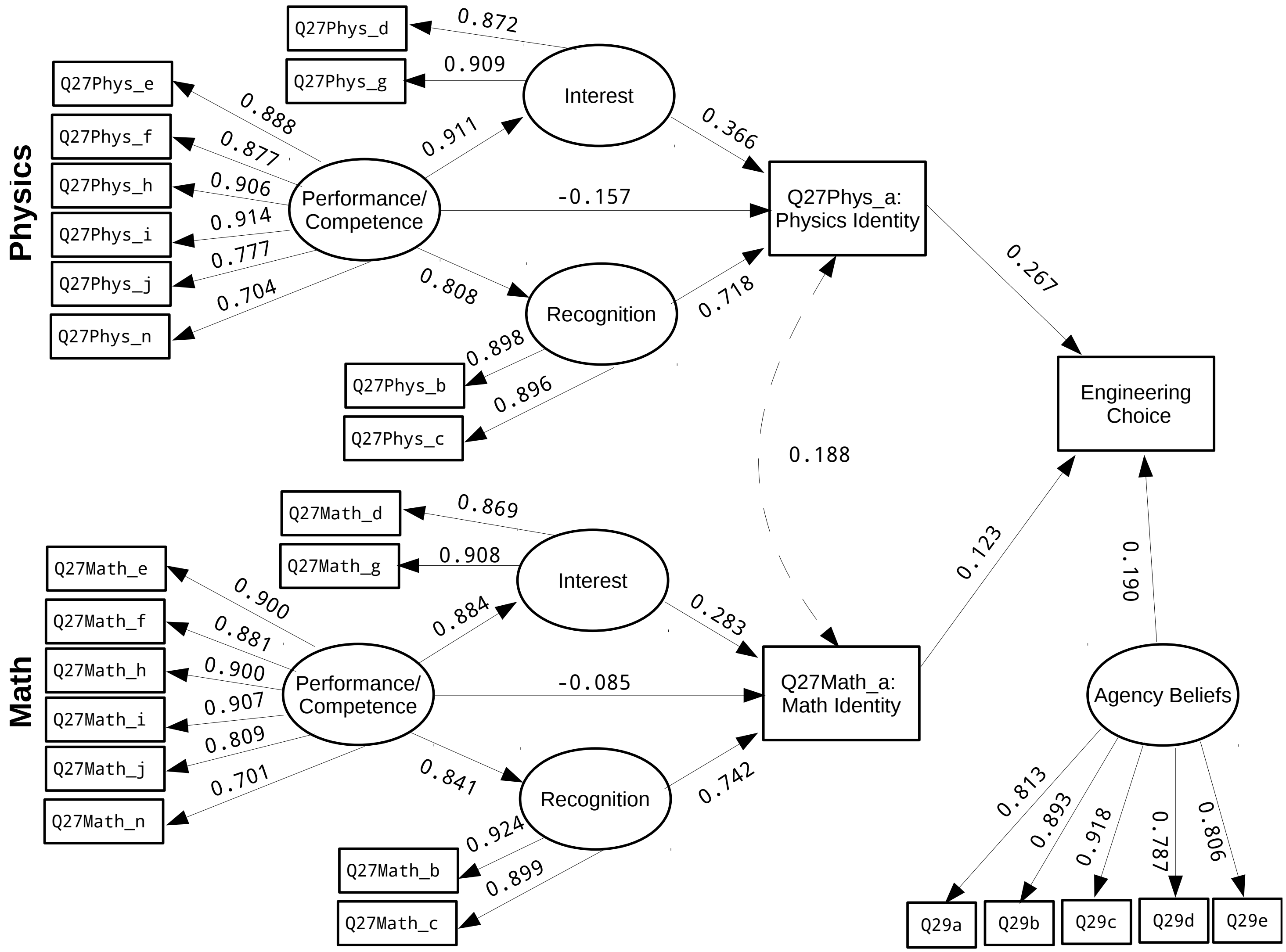

Figure 5.2: Results of final structural equation model for all students. All paths are significant at the p<0.001 level.

To answer Research Question 3, this model was compared for students who identified themselves as either male or female in the SaGE survey. The model invariance tests revealed a few paths that were different between males and females. Both a chi-square difference test and a delta CFI test were conducted to determine model invariance. Cutoffs of 0.01 were used for the delta CFI tests [108]. The parameter estimates have been added in Figure 5.3 for the final trimmed model with differences in freely estimated paths highlighted. The loadings for students' responses to Q27Math_n: "I can overcome setbacks in math" (M= 0.771; F=0.681) were freely estimated while the remaining loadings were constrained to be equal in the measurement model. Additionally, the regression estimates for the paths from physics identity, math identity, and agency beliefs were estimated freely while the rest of the structural model paths were constrained equal. The fit parameters for this model were: a chi-square of 4,389 on 705 degrees of freedom, RMSEA of 0.061 (90% confidence interval 0.059 to 0.063), CFI of 0.954, an NNFI of 0.950, all indicating good fit for the gender comparison model. The total variance explained in the linear engineering choice outcome was 20.2% for the model pictured in Figure 5.2. This result answers Research Question 4 and shows that students' self-beliefs explain just over one fifth of the variance in choice of engineering.

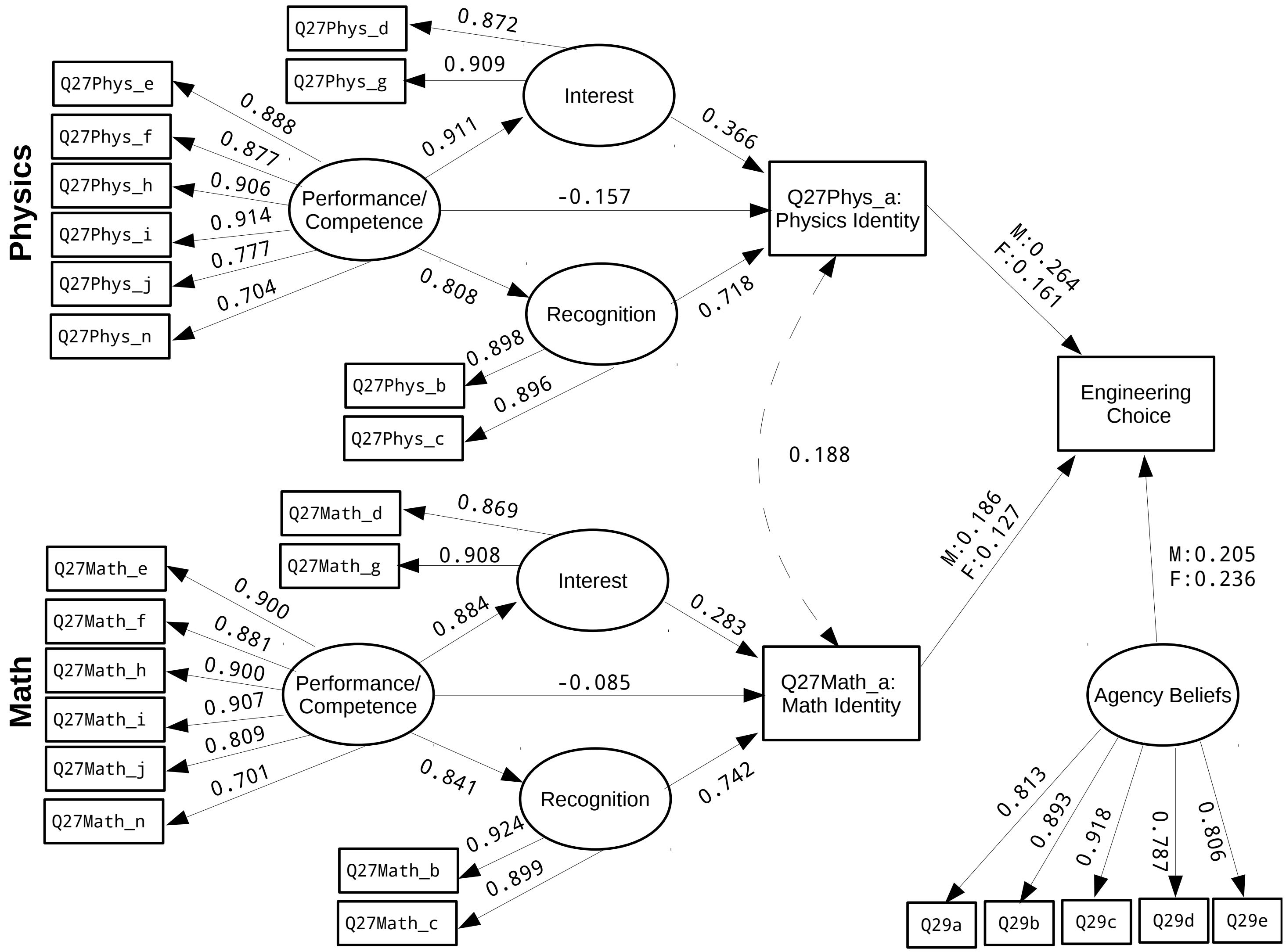

Figure 5.3: Results of final gender comparison structural equation model (F=Female; M=Male). All paths are significant at the p<0.001 level.

Discussion

The results highlight how certain student self-beliefs are important for understanding the choice of engineering as a college major. Engineering identity, a somewhat unclear construct at the juncture of high school and college when students often declare a major of study but before many students have had the opportunity to gain any engineering-related experiences, has been shown to be related to multiple subject-related identities; specifically, physics and math identity. As first identified in previous work [35], a significant, negative direct path from performance/competence to identity was confirmed for both physics and math identities. This indicates that even though performance/competence beliefs are related to the development of an identity in these domains, without interest and recognition as mediating factors, identity development may be substantially hindered. Boaler and Greeno [109, 110] make a similar point about math learners. They argue that the ability to do the math alone is not enough to support strong mathematical identities for students; rather, mathematical identities are tied to understanding and engaging authentic involvement in mathematics and seeing oneself as an effective mathematics learner in the classroom. Thus, if a person feels competent and able to perform in physics or math, both considered difficult topics, but s/he is never recognized or does not develop some interest in the subject, the likelihood of their developing a physics or math identity is depressed. This is an important finding since self-efficacy beliefs, somewhat conceptually similar to performance/competence beliefs in our framing, is often cited as a key factor in persistence [111, 112] without a deeper examination of the ways in which self-efficacy beliefs are related to other important self-beliefs, including identity. Although more nuanced examinations, such as work related to SCCT, identify the moderating effect that interest plays between self-efficacy and goals (and, subsequently, persistence) [70], these studies may not highlight the important role of an individual's beliefs in the recognition they receive from others. In our model, physics and math recognition beliefs each have the largest direct effect on physics and math identity, respectively, and we have seen, therefore, that they are critically important for engineering choice. Although the importance of recognition has been cited in many studies of identity [61, 113], our work confirms its importance in a large scale data set. Furthermore, our work clarifies that performance/competence beliefs are not sufficient to guarantee identity development. In support of this finding, Marra et al. found that female engineering students had positive shifts in self-efficacy beliefs while simultaneously having negative shifts in their feelings of inclusion [111].

In addition, gender differences in physics and math identity were found between women and men. Women had lower estimates for the correlation between seeing themselves as a "physics person" and a "math person" and their choice of engineering. While the estimates for both men and women were positive, seeing themselves as the "type of people" who do physics or math was less important for the choice of engineering for women than for men. This difference may be due to the fact that women identify less with the subjects of math and physics due to lower recognition beliefs [114] and performance/competence beliefs [67], both of which are important for women's identity development [61, 70, 113]. Additionally, studies have shown that women lose interest in math and science early on in their education [9]. This loss of interest may feed into depressed math and physics identities and may lead to fewer women choosing engineering due to the emergent barrier of relating their self-ascribed identity with an identity amenable to considering the pursuit of physics, math, or engineering which is vital to students' actual career choices [34] and later persistence within that chosen career [4].

Agency beliefs, consistent with the theoretical framework of CEA, were also found to be significant in this model. For both men and women, agency beliefs were a significant, positive influence on engineering career choice. This influence was even stronger for women than for men, with loadings of 0.236 and 0.205, respectively. Chinn's study of female students' choice of engineering careers found that agency towards engineering was influenced by powerful adults (such as teachers) and by curricular choices that did not alienate women or minorities but rather incorporate content and strategies personally meaningful to them [115]. The development of agency beliefs are apparently even more important for women to choose engineering than men. Holding empowering agency beliefs, coupled with choosing an engineering-related career is an important first step towards actualizing the potential to create change in the world. The development of agency allows students to act against established social structures and cultural norms within engineering (as, for example, a male dominated field) and without. It also allows them to take action and separate their own actions from what is done to them [116].

However, what students experience (e.g. in a classroom setting) clearly impacts what they intentionally choose for themselves (e.g. their choice of major). Teachers' pedagogical choices can impact students choices and behavior, especially if those pedagogical choices empower students to shape what happens around them or at least to realize that they have the ability to shape what happens in their world. Specific classroom practices including student autonomy and the creation of figured worlds can impact students' agency [32, 40, 117, 118]. A woman who develops agency towards engineering within a science course is more likely to intentionally choose to pursue engineering, going against social norms and structures, than otherwise. Thus, agency has a potential for individual and social transformation [119]. Agency beliefs are an important consideration for men and, especially, for women to understand the affective influences on the choice of engineering.

In the current study, the sample is large and representative of the national college population (including 2- and 4-year institutions) with a typical college population gender distribution (55% female). For student choice of engineering at the critical juncture between high school and college, this model of self-beliefs explains 20.2% of the variance in choice of engineering. A previous study did investigate students' choice of a STEM career [91], difference in career outcomes is important to highlight. While this previous study is somewhat informative on the question of the choice of engineering and is similar in its analytic methodology to the current chapter, it does not directly address students' major choice in engineering. The path between STEM students and non-STEM students is much more clearly defined in high school than differentiating between the many shades of STEM fields. This study investigated the choice of an engineering career which is more nuanced than a

STEM career. Students develop interest and desire to go into a STEM career much earlier than choosing an engineering path [120,121]. Additionally, SCCT directly measures a comparatively narrow set of measures related to self-efficacy beliefs (task-performance). In CEA, self-efficacy is embedded within students' identity beliefs about their performance/competence. While these two constructs are linked conceptually, they are measured somewhat differently and indicate somewhat different ideas about what a student believes s/he can accomplish. Social cognitive career theory also includes direct measures of supports and barriers in its framework. Critical Engineering Agency does not directly measure these ideas, but relies more strictly on a set of self-beliefs, with the effects of supports and barriers that are reflected in students' reported self-beliefs. So while the paper on STEM persistence by Wang [91] clearly contributes insight into how to model students' STEM career choices, it does not directly address the research questions studied in this work and does not explicitly address important affective states that have been found to be important to the choice of and persistence in particular STEM majors that are included in this work [42,45,118,122].

The theory of self-concept is also related to these ideas of self-efficacy and students self-beliefs (identity), but is distinct in a few ways. Self-concept focuses on both affective and cognitive factors for how students view themselves [123]. Additionally, self-concept focuses on how student perceive themselves in relation to others and what others think about them [124]. This study and the framework of CEA focuses solely on students' affective self-beliefs in describing engineering choice.

Implications for Practice

These findings are important for the improved recruitment and retention of a larger, more diverse body of engineering students. Understanding the transition between high school and college is important to address the "leaky STEM pipeline" [7]. As students move through their academic careers from middle school to high school to college, the fraction of students interested in STEM declines, disproportionately so for women, and the pipeline for students choosing STEM careers becomes smaller and less diverse. While prior research has documented student persistence and attrition in engineering majors across the college years [4],the choice of engineering as a major in, or at the end of, high school is not well understood. The self-beliefs model utilizing CEA alone explains one fifth of the variance students' engineering career intentions. It is clear that there are many other potentially predictive factors for engineering choice, including factors identified by SCCT as supports and barriers, prior academic success, and aspects of future goals, to name some prominent examples. These factors were not included in the current study because of the overriding goal to test how the framework of CEA explains engineering choice. Additionally, CEA as we have constructed and tested in this chapter is solely based on students' self-beliefs including identity and agency factors rather than factors external to an individual. Students often cite a "lack of belonging" as a main reason that they leave engineering [125]. Understanding how students identify with engineering at the critical junction between high school and college and how they believe that they can use their engineering degrees is important to understanding the numerous recruitment and retention issues in engineering.

This research represents a validation of CEA as a framework to understand students' affective states in relation to engineering. Students' engineering identity prior to having significant engineering experiences in a community of practice has been found to be comprised of multiple subject-related identities corresponding to students' subject-related experiences in high school. This finding is consistent with previous studies on the "types" of students who choose engineering; specifically, students who excel in math and science and show interest in these subjects [4, 35, 40, 122, 126]. Additionally, recognition beliefs are important for students' identity development [61, 113]. For K-12 teachers and professors who teach courses fundamental to engineering, like math and physics, understanding student identity is important for persistence in engineering. Students who identify with these engineering-related subjects will choose engineering early on at a higher rate than students who do not. Identity is not simply students who are "good at" physics or math homework, tests, or concepts. Identity is more strongly impacted by interest and students' beliefs that they are recognized as the type of person who does these subjects. These paths are consistent for both men and women. Any attempts to develop students identity in these situations will be beneficial for both genders. The direct link between performance/competence and interest is well documented [69, 127]. Students must develop the beliefs that they can accomplish the goals and perform proficiently in a course before an interest in the subject is developed. The link between performance/competence and recognition is more nuanced. Performance/competence predicts students recognition, but students feeling recognized does not predict students' performance/competence. Students who are recognized before they feel competent may not internalize the recognition, and very often teachers do not recognize students who are not excelling in their classrooms. Recognition is the most important part of an identity development in this model. Students who feel recognized by their peers, family, and teachers are more likely to identify as a "math person" or "physics person," and the estimates for these paths in Figure 5.2 are over twice as large as any other direct path to identity. Instructors in engineering, physics, and math courses can positively impact students engineering attitudes by recognizing their students as the kind of people that can do STEM. Giving students the realization that they can hold a STEM related identity can empower them to choose an engineering career.

Students' agency beliefs also play an important role in students' choice of engineering, particularly so for women. The concept of agency beliefs is different from the traditionally defined construct of agency. This belief captures how students feel they are empowered to make changes, not the actions of empowered change which are more readily measured through qualitative techniques. Thus, emphasizing the utility of science and engineering to cause meaningful change in the world and help to make students more critical of themselves and the world around them in high school science and math classrooms and even freshman engineering courses can positively affect students' attitudes and increase the likelihood of them choosing a career in engineering. These endeavors are a valuable use of classroom resources because they are positive for all students, and even more so for women. Demonstrating the positive effects of science and engineering can be accomplished through student-oriented classroom discussions or demonstrations as well as specific case studies of engineering projects. Incorporating such topics will help to increase the number of STEM students which are sorely needed [2], and also increase the proportion of women in engineering which remain a stubbornly persistent underrepresented group in this field [6].

Conclusion

Students affective beliefs are vital to understanding their choice of an engineering career. Identifying with math and physics upon entrance to college predicts engineering major choice. These subject-related identities are the types of identities that students hold prior to having direct experience with engineering. Additionally, students' agency beliefs are also important to their engineering choice. Seeing practical applications for engineering in the world is especially important to women. The framework of CEA can be used to understand the affective states of student who choose engineering and explains over one fifth of the variance in choice of engineering through students self-reflexive beliefs alone. Much research has focused on the external factors that cause students to choose, or not choose engineering [4, 5, 11, 127], but fewer studies focus on students' internal states. These affective beliefs are demonstrably a strong influence of why students choose engineering. Some limitations of this study include the inability to see how the measured constructs interact over time because the data utilized in this analysis are cross-sectional in nature. Without longitudinal data, the ability to see how identity changes and develops over time and how changing agency beliefs influence engineering career choice is limited. Additionally, the items used to measure students' agency beliefs are a first attempt at capturing how students view their choice of a career that uses science can affect their surrounding world. As this concept is better understood, new questions that capture a more diverse aspect of students' agency beliefs can be developed and utilized in the framework of CEA.

Future studies from this work are numerous. While this work has highlighted the need to increase the number of underrepresented groups in engineering we have focused on gender. Race and ethnicity, as well other areas of underrepresentation like sexual orientation, of students should also be investigated using CEA as a lens to understand students' engineering choice. Also, this work has a strong ability to see connections between large-scale constructs, but does not take into account individuals' experiences. Future explanatory studies of how and why these connections are seen are vital to the continuing validation of CEA as an affective model. It is especially important to understand the nuances of how students internalize recognition from teachers, family, and peers into their own identities. Recognition is the most significant predictor of a subject-identity and subsequently, engineering choice. A qualitative follow-up study on how students feel recognized in the classroom is being conducted. Understanding not only how students choose engineering, but how they are reinforced in their engineering identity development through college is vital to begin to address the need for more engineers.

Additionally this study has been framed at the critical transition between high school and college. We have shown that students at this point, with no direct engineering experiences, have multiple subject-related identities. These identities will change over time as students are exposed to engineering communities of practice in college, and may look more like the traditionally studied engineering identity in college. It is unknown whether aspects of these subject-related identities identified will fade or become incorporated into a distinct engineering identity as students complete engineering courses, have direct experience with practicing engineers, and develop the skills needed in an engineering career. Future studies that investigate the experiences and changing attitudes of students throughout college may give insight into how engineering students' CEA changes over time.

Chapter 6

Other Factors Affecting Engineering Choice

While the framework of Critical Engineering Agency (CEA) explains a significant portion of the variance in engineering choice, there are still many other factors that influence students' decisions to choose engineering in college. This chapter includes two studies that describe some of these other factors including other student attitudes and self-beliefs, outcome expectations, classroom experiences, and family influence.

6.1 Student Attitudes and Self-Beliefs

This work explores the breadth of students' attitudes and beliefs influencing their engineering career choice [128]. Efforts have been made to understand students' choice of engineering. This choice, often made at or near the end of high school, is often only a partly-informed decision due to a lack of direct experiences with engineering [1]. The objective of this study is to 1) examine the choice of engineering, 2) to assess the extent to which we could explain it, based upon different categories of factors, which are identified in various choice and persistence frameworks, and 3) to examine gender differences that may exist.

To frame this work, two perspectives that have been argued to have predictive power for choice of engineering as a career; Social cognitive career theory (SCCT) and Critical Engineering Agency (CEA) were considered.

These two frameworks have some similarities in their measurements. Both models measure aspects of self-efficacy beliefs. Social cognitive career theory directly measures a relatively narrow set of self-efficacy measures related to task-performance. In CEA, the idea of self-efficacy is embedded within students' beliefs about their performance/competence. While these two ideas are linked conceptually, they are measured differently and indicate somewhat different ideas about what a student believes s/he can accomplish. Utilizing both of these frameworks allows for the examination of a wider variety of possible factors influencing choice of engineering.

Additionally, students' career interest in addressing sustainability-related issues were included because students have indicated that protecting the environment and having a civic mind-set are important concerns [129, 130]. Sustainability is "meeting the needs of the present without compromising the ability of future generations to meet their own needs" [131]. Students' choice of engineering, as a prototypical "applied science" discipline, may be motivated by these beliefs, and for this reason we chose to include sustainability beliefs.

Methods

Because the SaGE survey used in this analysis was implemented in a course for general education requirements, a representative sample of students was obtained. Of the total student population that completed the demographic portion of the survey, of which 54.7% were female. Of the 814 students who indicated that they were "extremely likely" to choose an engineering career, 19.8% of respondents were female. In total 1319 students indicated that they were either "likely" or "extremely likely" to choose an engineering career, so there were still many students not intending to choose engineering with whom to compare.

The R statistical software system was employed to build a regression model on choice of engineering [75]. A students' likelihood of choosing engineering was assessed in a question that asked "Please rate the current likelihood of your choosing a career in the following:" for science, math, and engineering careers on anchored scales. A student's highest response to any of the eight engineering disciplines was used as a proxy for a student's interest in engineering. This method was used to capture students interested in engineering in general (but undecided on a particular discipline) as well as students with a well-specified engineering interest. Multiple imputation was used to account for missingness in the data using an expectation maximization bootstrapping method from the Amelia II package [132]. Cases that could not be imputed due to inordinate missing responses in the variables under consideration were removed by list-wise deletion for a final sample of 4,453. Blocks of items that measure constructs of SCCT and CEA were input in a least-squares regression [133] to examine the choice of engineering including demographic/background controls, identity, agency beliefs, outcome expectations, participation in engineering/science activities, perceptions of engineering, personal influences on career choice, beliefs about sustainability, and high school science experiences (see Table 6.1). Throughout this analysis, the maximum risk of Type I error was set at 1%.

Results

In this analysis we controlled for gender, race and ethnicity, English as a first language, prior academic performance, family support for science and math, type of high school attended, and college/university attended. Previously validated items of CEA described in Chapter 4 including physics and math interest, recognition, and performance/competence beliefs and agency beliefs were added into the model [122]. These items account for 8.9% of the model variance. Next, items on outcome expectations related to students' overall career and sustainability were added and explain an additional 9.5% of the model variance. Fourth, items about which people or experiences influenced students' career choice and participation in out-of-class activities were added. These items correspond to supports and barriers included in SCCT that may mediate student career choices, and explained less of the variance in choice of engineering than the previous two blocks with an additional R^2 of 0.022. Finally, questions that probed students' high school experiences, including science pedagogies were considered. These items explain only 0.4% of the outcome variance. The final model of engineering career choice explains 41.9% of the variance in students' choice of engineering.

Gender interactions were also tested in this model showing differential effects for men and women in outcome expectations, inventing/designing things, and applying math and science in a career were positively correlated with engineering choice for men but negatively correlated for women. Addressing climate change, poverty and distribution of wealth was a stronger estimate for women. In students' reported career influences, females more often cited their chemistry teacher than males. Speaking with a female engineer or scientist in chemistry was negatively correlated with engineering choice for women but positive for men.

Table 6.1: Block addition model to explain choice of engineering.

	Items	**Estimate**	**Std. Error**	**Significance**[§]
Controls	Family interest in science (0 -“not at all”; 4 - “very much so”)	0.010	0.044	n/s
	Family support of science for career (0 - “not at all”; 4 - “very much so”)	0.014	0.040	n/s
	Family support of math for career (0 - “not at all”; 4 - “very much so”)	0.096	0.039	*
	Family help for math tutoring (0 - “not at all”; 4 - “very much so”)	-0.011	0.041	n/s
	Math Academic Performance (multiple item scale from 0 - 1)	0.123	0.092	n/s
	Gender (0 - Male; 1 - Female)	-0.189	0.076	*
	Caucasian (binary)	-0.109	0.043	*
	English as first language	0.196	0.059	**
	Public charter high school attended (binary)	0.130	0.112	n/s
	Foreign high school attended (binary)	0.140	0.112	n/s

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Table 6.1 – continued from previous page

	Items	Estimate	Std. Error	Significance§
Controls	College attended	Controlled for as a factor		
	Total Adjusted R2: 0.209			
CEA	Physics Interest (multiple item scale from 0 - 4)	0.068	0.021	**
	Physics Recognition (multiple item scale from 0 - 4)	0.088	0.022	***
	Learning science will improve career prospects (0 - "strongly disagree"; 4 - "strongly agree")	0.101	0.015	***
	Added Adjusted R2: 0.089			
	Total Adjusted R2: 0.298			
Career Expectations	*Outcome expectations (0 - "not at all important"; 4 - "very important"*			
	Helping Others	-0.077	0.022	***
	Working with People	-0.101	0.017	***
	Inventing/Designing Things	0.222	0.021	***
	Inventing/Designing Things x *Gender*	-0.075	0.027	**
	Applying Math/Science	0.210	0.022	***
	Applying Math/Science x *Gender*	-0.123	0.025	***

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Table 6.1 – continued from previous page

	Items	**Estimate**	**Std. Error**	**Significance§**
Career Expectations	*Interest in addressing in career (binary)*			
	Energy (supply/demand)	0.502	0.048	***
	Poverty and Distribution of Wealth/Resources	-0.217	0.059	***
	Poverty and Distribution of Wealth/Resources x *Gender*	0.282	0.075	***
	Climate Change	0.102	0.090	n/s
	Climate Change x *Gender*	0.355	0.129	**
	Added Adjusted R2: 0.095			
	Total Adjusted R2: 0.393			
Influence on Career	Participated in engineering/science clubs/camps/-competitions (0 - "never"; 4 - "more than 6 times")	0.074	0.017	***
	Tinkered with Things (0 - "never"; 4 - "more than 6 times")	0.092	0.011	***
	Contributed to Selection of Career (binary)			
	Sibling is an Engineer	0.241	0.077	**
	Contact with Someone in Major/Career	-0.143	0.036	***

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Table 6.1 – continued from previous page

	Items	**Estimate**	**Std. Error**	**Significance§**
Influence on Career	Math Teacher	0.170	0.064	**
	Chemistry Teacher	-0.068	0.103	n/s
	Chemistry Teacher x *Gender*	0.419	0.138	**
	Physics Teacher	0.231	0.078	**
	Participation in Project Lead the Way	-0.465	0.107	***
	Added Adjusted R2: 0.022			
	Total Adjusted R2: 0.415			
Pedagogy	Manipulated physical objects in Biology	-0.091	0.049	n/s
	Manipulated physical objects in Biology x *Gender*	0.176	0.063	**
	Spoke with female engineer/scientist in Chemistry	0.326	0.087	***
	Spoke with female engineer/scientist in Chemistry x *Gender*	-0.406	0.116	***
	Worked on lab/projects in Biology	-0.082	0.020	***
	Added Adjusted R2: 0.004			
	Total Adjusted R2: 0.419			

§The level of statistical significance is coded in the final column: n/s represents a non-significant result, ** represents a statistical significance less than 0.01 but greater than or equal to 0.001, and *** represents a statistical significance less than 0.001.

Discussion

In the resultant model, several factors proved to be significant predictors of engineering choice with some gender differences. Students' self-beliefs beliefs and outcome expectations account for a large portion of the variance in students' choices (8.9% and 9.5%, respectively). In particular, factors assessing students' identity beliefs and agency beliefs account for a substantial fraction of the variance on students' engineering choices. In previous work, students' physics, math, and general science identities were found to be important factors for their engineering identity development [35]. In this model, only physics interest and recognition were significantly correlated with engineering choice. This finding is consistent with previous work which found a stronger connection between physics and engineering identities than with math which is discussed in Chapter 5 [35]. This explanation is likely because engineering and physics content share a paradigm: heavy application of math with science, consistent with the outcome expectations reported by students. Students who see their own identities lining up with specific disciplinary identities persist at a higher rate than those who do not which may help explain this result [4].

For educators, developing students' identity and agency are demonstrably important to choice of engineering and student persistence. Students' beliefs about who they are and the subjects with which they identify are important. Additionally, professors who teach the pre-requisites for engineering, especially physics, may have strong influences on students' desire to pursue a career in engineering. The authoring of an identity is a sustained process rather than a one-time effort [33], and poor classroom experiences could cause have an important deleterious effect on students' intended careers. Focusing on the development of student's interest in a subject and recognition of that student as a member of that community of practice (e.g. as a "physics person") may be very important for future engineers.

Additionally, outcome expectations from SCCT accounted for significant variance in the choice of engineering (9.5%). Bandura delineated several classes of outcome expectations: monetary, social, or self-evaluative which determine a particular set of actions [134].

In this model, expectations towards helping others, working with other people, and addressing poverty and distribution of wealth are examples of outcome expectations that reduce the likelihood of choosing a career in engineering. For women, inventing/designing things and applying math/science in their careers were net negative predictors. Understanding how students perceive engineering as a career and whether or not that career aligns with their outcome expectations is important to help understand engineering choice. These findings are similar to previous work that found that women had lower or negative outcome expectations in regards to engineering [135].

Gender differences for choice of engineering were found in this analysis. Most of these differences were found in outcome expectations as previously described. Two differences were found in females' reported career influences. Females' chemistry teachers had a positive influence for women but a non-significant influence overall. This finding may align with the distribution of women in specific engineering disciplines that utilize more chemistry such as chemical (32.9% women), bio- (39.2% women), environmental (45.5% women), and materials (27.1% women) engineering which all show greater representation than average (18.9%) [6].

Additionally, speaking to a female engineer/scientist was negatively correlated with the choice of engineering for women but positive for men. This finding may be due to female students being unable to identify with women who have overcome the barriers associated to engineering, due to perceived gaps between their identities, outcome expectations and the "role models" presented. Traditional roles for male students and female students create gendered patterns for access to engineering professions and identity. While women bring many skills to engineering disciplines such as managing, planning, organization, coordinating communications, and bringing up different perspective in group discussions, these features are not recognized as fundamental engineering skills. The emphasis falls to technical and analytical skills. While women perform just as well as men in these typical engineering skills, the lack of recognition hinders the formation of an engineering identity and professional role-confidence. Women must not only author their identity as an engineer, but they must contradict the traditional stereotypes surrounding engineering as a masculine field [33]. Women tend to have lower self-concepts and do not feel smart enough in or do not value math and physical science [136]. These gendered stereotypes coupled with this low self-concept may cause women to view these role models as a typical examples of the few and elite who have succeeded rather than an example that they can succeed themselves [137].

In utilizing a cross-sectional study design, the data gathered have some strengths: large statistical power, national representativeness in the sample, and the ability to test hypotheses surrounding events that were introduced to students naturally rather than through an intervention. This study design also has certain weaknesses, notably including the inability to draw causal conclusions. Rather, results are correlational in nature. The results do indicate substantial correlations between student responses and students' choice of major, but further work is necessary to indicate a causal direction to these relationships. For example, students may be interested in physics because of their choice of engineering as a major, or they may choose engineering because of their interest in physics topics. With this limitation in mind, the data should be interpreted as correlational rather than causal.

The choice of engineering is a complicated decision, and students make career decisions for a variety of reasons. The factors included in this work were drawn from some of the existing frameworks used to explain engineering choice from affective, social, and cognitive viewpoints. In our nationally representative data, these factors explain 41.9% of the variance in the choice of engineering. Some of the most important factors to this choice include students' outcome expectations and CEA. Additionally, gender interactions in outcome expectations and career influences were found. Underrepresentation of women in engineering is a persistent issue which hinders the development of the most effective engineering solutions, limits the quality of the engineering field, and restricts accessibility to economic and social status available to engineers [7]. In order to meet one million new STEM graduates needed in the next nine years [2], it is important to not only understand why the majority of students choose engineering, but also reasons why the minority does as well.

6.2 Family Support and Influence

Another study conducted looked at the specific influence of family on students' career choice [138]. This external factor can have a significant influence on which students choose engineering. There are few studies on how a student's choice of engineering is affected by having an engineer as a family member, yet there are persistent hypotheses about these types of familial influences.

Introduction

There is relatively little empirical research on how a student's choice of engineering is affected by having an engineer as a family member, yet many people cite familial influences as a reason for students' choice of engineering. Some prior work on family support has appeared in the SCCT, but it does not directly address the influence of a family member and focuses on engineering persistence rather than engineering choice. This research examines the influence of family on students engineering career choice through a mixed methods study. Quantitative connections between having an engineer as a family member and how influential these members were on students' career choices were examined. While these relationships do give a generalizable connection between engineering choice and family influence, they do not describe how these influences are exerted. A follow-up qualitative analysis was conducted with student interviews to understand how students perceive these family influences on their career choices.

As the oft used saying goes, "like father like son [or, like mother like daughter]," there are established connections between family background and students' educational aims and outcomes [139, 140]. Families are critical to providing support for student attainment through emotional as well as financial dimensions, from purchasing textbooks to paying for college [139, 141]. Parents shape children's attitudes, motivations, values, and aspirations through a socialized family culture and are a locus of control in the education of their children [142, 143]. Social scientists have noted this influence and the patterns by which students "inherit" the occupational status of their parents. This finding, especially true for sons, is referred to as occupational inheritance which operates by two primary mechanisms: 1) socialization of skills [144] and role modeling of parents to children [145]. Kohn found that parents' work environments and the challenges that they face shape how they raise their children [144]. Parents in professional jobs succeed through self-regulatory practices that they pass on to their children. While the focus of this original work was mainly on father-son inheritance patterns, a greater focus on mother's roles came in the 1980s. It was found that mothers provided occupational knowledge to their daughters and played a key role in the transmission of occupational values [146]. Later studies showed that a mother's role is as important as that provided by fathers. Parents play a significant role in the occupational aspirations and career development of their children [147].

One study completed a comparative analysis of how occupational inheritance differentially affects men and women in engineering [148]. This quantitative study examined 861 engineering students from 15 U.S. institutions. Analyses revealed that approximately half of the men and women in the study had an engineer in their family and that women were significantly more likely than men to have an engineering parent. While interesting findings for the engineering education community, these results alone can not conclude that men and women inherit their interest in engineering from family. This work showed a correlation between having an engineering family member and choosing engineering within a sample including only engineers. The final sample featured more women (22.4%) than average in engineering (18.9% [6]) and almost forty percent of the sample came from a single institution which introduces the risk of sampling bias into the findings. While these data pose interesting hypotheses and add to the discussion of "engineers begetting engineers," they open the door to further examination of family role in occupational inheritance. Another preliminary study examined how parents shape their children's exposure to engineering and found that parents do not explicitly teach their children engineering [149]. This finding is consistent with the literature that many parents are not aware of their influence on children's career trajectories [150].

Other work has been conducted in the SCCT literature on family role as a support/barrier to the choice of engineering. Social cognitive career theory has been widely used to investigate the choice of engineering as a career [69]. This theory is based on the social cognitive approach introduced by Bandura [134]. SCCT is founded on the triadic reciprocal relationship between personal and physical attributes, external environmental factors, and overt behavior included in social cognitive theory. One part of this relationship is perceived contextual and distal supports and barriers (including family support across both distal and contextual realms) which is linked to choice goals and actions indirectly thorough self-efficacy beliefs [70, 127]. In this model, supports and barriers play a more prominent role in informing students' self-efficacy beliefs than in directly influencing particular engineering choices [70].

Work by Strayhorn, investigating the role of supportive relationships for African American males' success in college, also highlights the importance of support for retention in college [151, 152]. Supportive relationships are positively associated with students' satisfaction in their college experiences which, in turn, improves retention [4]. These relationships are especially important to retaining talented engineers. Of all underrepresented minorities in engineering, African American males have one of the highest rates of attrition [153]. Understanding how family support can provide an entrance into engineering and how supportive relationships within college improve retention may begin to stem the tide.

An early decision to major in engineering in college is vital for students – especially students from traditionally underrepresented backgrounds (e.g. women and minorities). After the freshman year, it is difficult if not impossible, for students to enter engineering and finish a degree within four years due to the large number of required courses [12]. A four year completion time is important to students with loans or scholarships due to the time-sensitive nature of maintaining funding to achieve a post-secondary degree.

In this study, we examine 1) how having an engineer as a family member facilitates a pathway into engineering, and 2) how family influence affects the choice of engineering as a career.

Methods

The data for this mixed methods triangulation study come from the large nationally representative SaGE survey and interviews of high school science students. One question central to the current analysis asked students to "Please rate the current likelihood of your choosing a career in the following:" on an anchored scale from 0 ("not at all likely") to 4 ("extremely likely"). The various career options were "Mathematics," "Science/math teacher," "Environmental science," "Biology," "Chemistry," "Physics," "Bioengineering," "Chemical engineering," "Materials engineering," "Civil engineering," "Industrial/systems engineering," "Mechanical engineering," "Environmental engineering," and "Electrical/computer engineering." Students who indicated a "3" or "4" as their response to a particular engineering discipline were separated out for further analysis. In all, 814 individuals responded with a "4" in at least one engineering discipline, and a total of 1319 individuals responded with a "3" or greater in at least one engineering discipline and did not indicate a greater likelihood of them pursuing another career.

These students were compared to all other students (non-engineers) using binomial logistic regression to see if having an engineer as a family member or if having parents, siblings, or other relatives influence student career choices, as well as the interaction between these items are predictive of a choice of engineering. The highest level of education of both father/male guardian and mother/female guardian, proxies for socioeconomic status (SES), were input as control variables. Additionally, general family support of math and science as indicated on a variety of items were used to control for families particularly supportive of or interested in STEM. These control variables allowed the isolation of familial engineers and their influence on career choice by accounting for several alternative hypotheses (e.g. the confounding nature of SES on both parents' career choices and on students' interests). Only statistically significant controls were left in the final model (Table 6.3). Additional tests were run to determine if gender differences were seen on the type of career influence or which familial engineer impacted choice of engineering. All data processing, statistical analyses, and figures in this chapter were created using the R statistical language and software system [75]. Throughout this analysis, the α level, the maximum allowed probability of a false positive (Type I error), has been set at 0.01 or 1%.

The qualitative data for this study are derived from interviews of 17 high school students attending two public high schools one in the Midwest and one in Mountain Region. These high schools were recruited based on the project team's identification of teachers in the national SaGE survey who use specific teaching strategies in their classrooms. These teaching strategies included sustainability topics like discussing energy supply and demand and opportunities for future generations that significantly increased the likelihood of women choosing an engineering career. The teaching strategies and their effects were the focus of a different study and are outside the scope of this work.

Students at these high schools took a brief version of the SaGE survey which included their career interests both at the time and retrospectively as well as their attitudes about STEM. Students were selected for interviews based on their survey responses, previously-observed classroom behavior, and teacher recommendations. Selection criteria for student interviews included: interest in engineering (especially for women), high or low physics and/or math identity, changes in attitudes toward science between middle school and high school, observably engaged classroom participation, and students indicated by their teachers as interesting cases on the above criteria. Eight students were selected from each of the two schools. Student interviews were typically 30 minutes in duration. The types of questions included in student interviews asked students about their perceptions of their class and teacher, attitudes about science, beliefs about the type of people who do physics, math, and engineering, career interests, support they receive for their career interests (including family support), and perceptions about school culture. Table 6.2 presents some demographic information as an overview of the interviewed students.

The interviews were analyzed using a constant comparative method. This method describes the process of moving between the data collection and the data analysis to inform additional data collection. This method also involves finding similarities between statements and incidences in the same and different interviews and observations [86]. Open coding was conducted for student's accounts of familial engineers and supports and barriers for their choice of a career. The similarities between the interviews were used to construct overarching themes in student responses. The software used for this coding process was RQDA, an open source qualitative analysis tool [87].

Table 6.2: Demographics of high school students selected for interviews.

High SchoolClassroom	**Gender**	**Self-identified Race/Ethnicity**	**Self-identified Engineering Interest (Low to High)**
Midwest – Mr. A	Male	White	High
	Male	White	Mid-high
	Female	White	Low
Midwest – Mr. B	Female	White	Low
	Female	White	Mid
	Male	White	High
	Female	White	Mid
	Female	White	High
Mountain Region – Mr. C	Male	White	Mid-high
	Male	Hispanic	High
	Female	Hispanic	Mid
	Male	White/Native American	High
	Male	White	High
	Female	Hispanic	High
	Female	Hispanic	High
	Female	White	Low
	Female	Hispanic	High

Results and Discussion

The results of the binomial logistic regression of engineering choice are summarized in Table 6.3. Related variables are grouped together in Table 6.3: first, controls; second, familial engineers and students perceived family influence on career path. Within the control block, family support for science items are grouped together.

Odds ratios are used to compare the relative odds of the occurrence of the outcome of interest (e.g. engineering career choice), given exposure to the variable of interest (e.g.

Table 6.3: Logistic regression of engineering choice. The Estimates are the logit (log of the odds ratio) for each predictor; the Odds ratio is the exponentiation of the Estimate. The Standard error is the error associated to each estimate, and the significance is the p-value estimated for each predictor.

	Estimate	**Odds Ratio**	**Standard Error**	**Significance**§
Controls				
Father's highest level of education	-0.113	0.893	0.03	***
Family Support				
Science was a hobby	0.317	1.372	0.087	***
Science was important for a better career	0.48	1.616	0.082	***
Family helped with schoolwork	0.25	1.284	0.076	***
Family arranged for science tutoring	0.643	1.903	0.19	***
Predictors				
Father – Engineer	-0.507	0.602	0.181	***
Mother – Engineer	-	-	-	n/s
Sibling – Engineer	0.798	2.222	0.142	***
Other relative – Engineer	0.456	1.578	0.094	***
Mother/female guardian contributed to career path	-0.568	0.567	0.087	***
Father/male guardian contributed to career path	0.388	1.473	0.091	***
Father – Engineer x *Father/male guardian contributed to career path*	1.321	3.747	0.221	***

§The level of statistical significance is coded in the final column: n/s represents a non-significant result, ** represents a statistical significance less than 0.01 but greater than or equal to 0.001, and *** represents a statistical significance less than 0.001.

having a familial engineer). The odds ratio can also be used to determine whether a particular exposure is a predictive factor for a particular outcome, and to compare the magnitude of various factors for that outcome [154]. Having a father/male guardian with a higher level of education is a negative predictor of choice of engineering (i.e. reduces the odds of choosing engineering). This finding is consistent with previous work citing that students from high SES that are interested in STEM are less likely to choose engineering than related fields such as science [47]. Another control, family support of science has an average odds ratio of 1.544, meaning that if a student perceived their family to be supportive of science, then they are 1.544 times more likely to choose an engineering career.

Familial engineers other than parental figures are significant positive predictors of engineering career choice. Having a mother that is an engineer is a non-significant predictor of engineering choice, and having a father who is an engineering is actually a negative predictor of the choice of engineering. This finding seems counter to previous work in occupational inheritance in engineering [148]. The current results are from a sample of 6,772 from 50 institutions, a larger, broader sample than previous work. Also, we compare engineering students to non-engineering students, while the previous study compared engineering women to engineering men. Such methodological differences may explain the differences in the results. Within engineering, familial engineers may have a relatively strong impact on why students chose engineering, but when compared to all students, these influences are less significant. The influence of familial engineers within the total student population can be mixed. Simply having a familial engineer may be less significant for students not choosing engineering because of a variety of other influences (e.g. interest in STEM, self-efficacy beliefs, other background influences). The students in this work may cite siblings and other relatives (e.g. cousins, aunts, uncles, etc.) more often due to self-efficacy building vicarious learning experiences [155]. Students who see others that are similar to themselves (closer in age or experience) being successful engineers may enable a re-imagining of their possible selves (i.e. the selves one believes one might become in the near and the more distal future [156]), to more firmly believe that they can succeed in engineering.

Parental influences on engineering career choice are mixed. Students who reported that their mother/female guardian contributed to the selection of their career path are less likely to chose an engineering career. This finding may be consistent with literature finding that parents have unknown, strong influences over their children's career aspirations [149, 150]. Mothers, in particular, may be influencing their children toward careers and values which they find to be important [144]. Since there are more women in a plethora of other fields like business, law, and medicine [8], women may be simply guiding children into fields where they have found success and/or which they find relevant [144]. Having a father/male guardian who contributed to a student's career choice has a positive effect on engineering choice, meaning that a father's influence on a career makes students more likely to choose engineering. However, this finding may be convoluted with the fact that there are an overwhelming number of men in an engineering career [6], rather than male parental figures guiding children into engineering. However, the effect of having fathers who are engineers and also are reported to have contributed to their children's career selection (an interaction effect) has a compounded effect. Such students are 3.747 times more likely to choose a career in engineering. Students reporting that sibling and other relative had an influence on their career choice were non-significant in this model as well as any interactions. These findings may be due to the overwhelmingly strong influence of parents on their children and their career choice [142, 143]. While having a sibling as an engineer is a significant predictor of engineering career choice, students do not report their siblings has having an influence on an engineering career choice. Additionally, all of these findings showed no gender differences. While this work contradicts Mannon and Schreuders [148], it is consistent with other work that children follow their parents into the same field regardless of gender and regardless of field [140]. This latter research examined intragender differences of a female child choosing her father's career versus another field and vice versa for male children. Besides some bias in the study by Mannon and Schruders [148], that study focused on explaining differences between genders within engineering. While we do acknowledge the lack of female role models within engineering to "pass on" occupational inheritance to their children, especially women, there is a positive message in these findings. Occupational inheritance is not a closed feed-back loop for women, fathers who are engineers and who influence students is a large effect for both men and women, and the lack of many women engineers does not widen the representation gap in engineering from a family influence analysis.

Two primary mechanisms appear to be the underlying routes of familial influence on students engineering careers. Firstly, siblings and other relatives who are engineers have a strong influence on students' choice of an engineering career. Vicarious learning leading to self-efficacy building may explain the stronger influence of these individuals on career choice. Self-beliefs about one's efficacy shape the way in which one navigates the world [65]. If a scenario is perceived to be too difficult or exceeds one's capabilities then that scenario, such as the choice of engineering as a college major, may be avoided. Self-efficacy also contributes to the persistence and amount of effort one may put into accomplishing a goal in the face of adversity or obstacles. These self-efficacy beliefs are not determined by one's past experiences alone. Efficacy appraisals are influenced by vicarious experiences [157]. Seeing others whose skills are deemed to approximate one's own can successfully raise the self-efficacy of the observer. For example, a student in our interviews who was interested in majoring in electrical engineering (and is now working on a degree at a prestigious engineering school) describes his career influence thusly:

> *My brother's actually becoming – like – he's going to get his Master Electrician's License and he kind of got me interested, always talking about that stuff and I just kind of decided that would be a good fit.*

This mechanism can also work in reverse. If a student does not identify with a vicarious role model in engineering or that model is not successful, then they may decide that a path into engineering is closed to them. A highly-talented female in physics describes her likelihood of choosing a career in engineering:

> *I feel like they're [engineers] a whole bunch of smart people so I, I have no*

desire to go in engineering...so, I can't.

Several students, including individuals desiring to enter engineering as well as other fields, described the influence of vicarious role models. One student described how she decided to choose accounting:

> *Accounting? Um, I don't know, because, well, my oldest sister, she's kind of like my role model and that's what she did and then like I'm taking an accounting class now and I just thought this is like, um, I just like liked it and I'm going to take another accounting too next year to keep studying and I'm going to go to college for that, too, so.*

Another student described the influence of his uncle on his desire to be an aerospace engineer:

> *Um, well, there are a couple things I've thought about. One is to be a civil engineer with like bridges and roads, but I wasn't too interested in that. Um, I have an uncle that works for Boeing in [a distant city] and he seems to really like his job and he makes pretty good money. I like cars. I could, I enjoy that, something with cars maybe or, um, but mostly with planes because I like planes a lot.*

These vicarious experiences may need to come from people with whom students can identify more effectively than parents. While parents do provide an important role in the development and raising of children, across many cultures, siblings, especially, and other family members may be as or more influential than parents [158]. Additionally, siblings spend a large amount of time together which results in a high degree of mutual imitation [159].

A second mechanism of familial influence is the direct influence of parents on students' career paths. While siblings and other relatives play an important role in vicarious learning, parents, pass on their occupational values and desires through a process known as occupational inheritance. The influence of mothers and fathers on a student's career choices in the quantitative portion of this study is consistent with this literature [139–148], and is supported by students' narratives.

The same student who spoke of his uncle's influence to become an aerospace engineer (quoted above), also talked about the strong influence of his parents. From a discussion of his competing interests, his mother was actively encouraging toward a different career path, based upon her own interests and values:

> *Well, my mom kind of pushes me more towards [being a] psychiatrist because she's a counselor so she likes that, but my dad is more like whichever way you want to go is good for me, both sound like good careers.*

This narrative supports the quantitative finding that if a mother has a reported influence on students' career, it may make them less likely to choose engineering. As expected, other students also reported a parental influence over their career choices. One male student interested in engineering described his parents' influence as supportive of engineering:

> *My mom and my dad helped me a lot, like getting information. And the internet. I look up stuff on the internet. My parents always ask me about it and I'm better than last year. Last year I had no idea. But I'm starting to get a better idea of what I want to do. I'm trying to think of that and research that.*

Another student described her parents's influence on her as a student and in her career path:

> *Yeah, they're very encouraging. They're always talking to me about it [being a radiology technologist], saying is that what I want to do, making me look at different aspects about it, um...I feel like since they didn't go [to college] they feel like that urge to, because they see how their life has been hard and difficult and they don't want ours, mine and my brother's, to be like that, so they urge*

us constantly to do good grades, to like be good in school, go farther than what we can, make life easier on ourselves, I guess. And thats since they didn't have it they want us to have it.

Many students said that their parents wanted them to be happy and to "do what you want, like, do what you love." Some students did not report a direct influence similar to the student with a mother in counseling; the influence of parents on students' values and career aspirations is more subtle. Parents have a strong locus of control in the transmission of values, education, and development of their children [149]. Often, these underlying mechanisms are taken for granted. While this connection is well documented in the literature, often students do not describe this phenomena in their narratives. While parents have been identified as important agents of occupational inheritance, the process of how they transmit their knowledge, values, and behaviors are not well studied [149, 160].

The largest effect found in the quantitative data showed that the interaction of having a father who is an engineer and having reporting an influence from a father on career choice is stronger than the two separate main effects combined. In the interviews, one student described an interest in "radios and electronics." When pushed for an understanding of whether this career interest involved engineering or a technology degree, the student did not offer a clear path but described the influence of his father (who was an state employee who "works on electronics and radios"):

I'll be shipping out this summer for basic training. And ah, I want to go into radios and electronics. I've been around the military my entire life. I've moved around, ah, every three years for the last 18 years, and ah, I'm just kind of used to moving around, bouncing around. I've been around military bases my whole life so its nothing really new to me so ***kind of following in my dad's footsteps****...having the military help me get through ah, college and all that stuff so that I can get out, um, come back to [this state] and work for the state and do electronics and radios for them because that's what my dad does and ah, all* *of it here.*

His father not only had a direct influence on his career, but a direct occupational inheritance was evident in this case. This student did not have a clear path towards achieving his goals beyond joining the military and getting a degree, but he did have a strong commitment to the path he described.

Conversely, another student described a dad who pushed him toward engineering, but was not directly involved in his life. He lived with his mother and only saw his father a few times a year. He had a strong interest in a physics career rather than engineering:

> *Well, my dad, my dad was always, a, talking about how he wanted me to be some sort of engineer or something when I grew up and um, I don't live with him but a, he was definitely interested and we used to argue about science a lot so it was...he wasn't [an engineer]. He was a glass work – an auto glass worker, so.*

This student described a strong push toward engineering by his father, but the transmission of occupation did not seem to be as strong in this case, perhaps because his father was not involved in his daily life. These contrasting cases show how the interaction of having a father in an engineering career who is also influential in your career choice can result in a higher likelihood of choosing an engineering degree, but having a father who is not as influential or is not an engineer may have a different outcome, consistent with the quantitative results.

One of the strengths of the mixed methodology used in this chapter is that solely using students' narratives of career choice and the path and influences that helped them make a decision is oversimplified. Using quantitative data *as well as* qualitative narratives in mixed methods allows a bigger picture of predictive factors for the choice of engineering. For example, a student is not likely to say that because he is male, white, and from a middle class background, that he was influenced to choose engineering. Instead, he may describe an interest in math and science and understanding how things work, and the encouragement of his family or teacher or guidance counselor as well as other critical events/experiences in his path to arrive at a decision of a career in engineering. The qualitative portion of this study gives some insight into why students make their career decisions while the quantitative data give insight into factors previously unlinked to career choices.

Conclusions

Through a mixed methods triangulation study, two particular mechanisms were found for familial influence on engineering career choice. The first is the strong influence of siblings or extended family members as role models (via vicarious learning experiences) on engineering choice. Seeing a person with whom a student can identify succeed and thrive in engineering may contribute to self-efficacy beliefs with respect to an engineering career. Previous work has shown that this type of self-efficacy building is less important than direct experience-derived self-efficacy, but it does have an effect on career choice as see by students' narratives [157]. Many students see a sibling as similar to themselves and can image that if their own brother/sister can do engineering then they can, too. Another student saw engineers as "a bunch of smart people" and developed low self-efficacy beliefs that turned her away from an engineering career.

The second mechanism of familial influence on an engineering career involves occupational inheritance of specific values and beliefs from parents towards their own careers. A large body of literature in child development documents the strong influence of parents on career choices. Our work supports the findings that parents' support (rather than siblings or other relatives) have a stronger influence of students' career aspirations. Mothers tend to pass on their occupations which can steer children away from a degree in engineering, while fathers tend to have a more positive influence on engineering career choice. This finding may be due to the low number of women in an engineering-related occupation to "pass on" that job or due to the values that mothers pass on pushing young women away from engineering, resulting in lower numbers of women in engineering. The data necessary to draw conclusions about the direction of causality of this hypothesis are beyond this study, but it does offer an interesting topic for future research. The interaction of having a father who is an engineer and who has an influence on a students' career has the largest odds ratio towards a choice of engineering. Throughout this study, no gender differences amongst students were found for either parental figure as influences or familial engineers.

As we seek to increase the number and diversity of students in engineering, considering these findings is important not only for engineering education researchers, but also families, teachers, and guidance counselors. Our future work in this area will seek to incorporate into these models greater details about students' engineering choices and how to create positive supports for a career in engineering.

Chapter 7

Qualitative Connections from Structural Equation Model

Chapter 5 highlighted some valuable and interesting connections between math and physics identity constructs, agency beliefs, and the choice of engineering. Additionally, the relative importance of agency beliefs over math and physics identities has been seen for women in their choice of engineering. These connections suggest important implications for the recruitment and retention of women in engineering, but the causal mechanisms which may explain these relations and the development of these affective beliefs can not be determined solely using the cross-sectional quantitative data.

7.1 Explanatory Power

Utilizing qualitative data in addition to the results of SEM can add deeper meaning to the theory of CEA [86]. Qualitative data allows for the researcher to capture the individual's point of view. In quantitative approaches, statistical analyses study the distribution of individuals across an outcome to identify trends. This approach allows for testing the probability that an effect is not due to just chance alone, but such approaches do not necessarily capture the richness of the experiences of any individual students within the sample. Qualitative research can study the individual's perspective and beliefs through detailed interviewing and observation. Additionally, this approach allows the researcher to incorporate a broad range of context and the effects of the social world *writ large* on the data and interpretations. Finally, this approach facilitates the collection of rich, descriptive data, which can explicate theory or develop understanding of how and why the trends seen in quantitative data occur. This data expands on the general findings of Chapters 5 and 6 and allows for a deeper description of CEA and females choosing careers in engineering. Through this process, explanatory links can be understood which would be inaccessible through quantitative methods alone.

7.2 Directed Qualitative Content Analysis

For both qualitative studies conducted, directed qualitative content analysis was used to understand the underlying themes and ways that female students develop CEA. Qualitative content analysis consists of a family of techniques for systematic text analysis developed by Mayring and colleagues 35 years ago in a longitudinal study about psycho-social consequences of unemployment [81]. This technique traditionally analyzed large amounts of text into a number of categories that represent meaning [84]. Qualitative content analysis has moved past its more quantitative origins to the interpretation of content through a systematic process of coding and meaning-making.

Directed content analysis works with previously formulated, theoretically derived aspects of analysis by connecting them with the textual data. The goal of a directed approach to content analysis is to validate or conceptually extend a theoretical framework or theory. Thus, this approach is particularly apropos for understanding CEA in context. Existing theories or research can help focus the research questions addressed in qualitative research. Such a directed approach can provide predictions about the variables of interest or about the relationships among variables, thus helping to determine the overarching themes or relationships between codes [81]. Figure 7.1 illustrates the overarching process of directed qualitative content analysis as described by Mayring [81]. The only part of Figure 7.1 that has changed dramatically over the last 14 years is the type of evidence accepted for qualitative content analysis. Instead of the "quantitative steps of analysis" typically used in traditional qualitative content analysis, excerpts of discourse [85] and conceptual networks can be used [86]. Taking a direct approach means that researchers begin by identifying key concepts or variables as coding categories. Next, operational definitions are determined using theory [84].

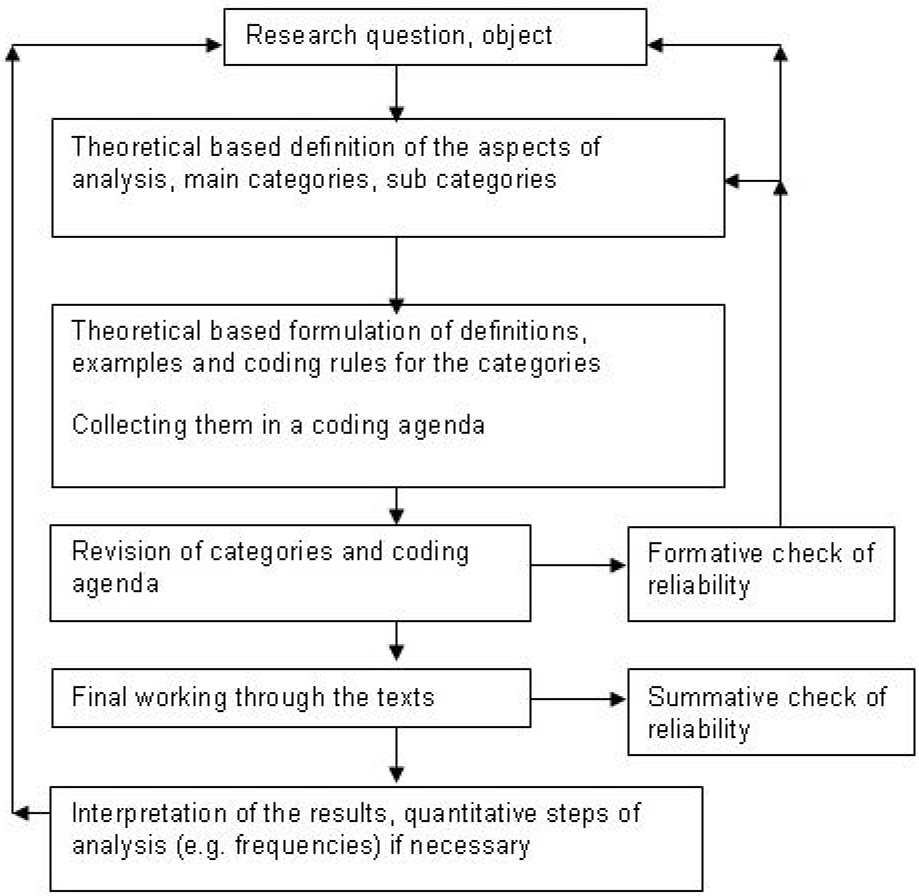

Figure 7.1: Step model of directed qualitative content analysis [81].

The general steps for qualitative content analysis outlined in Chapter 3 are included here [82]:

1. Prepare the data – The choice of the content must be justified by the research questions [83].

2. Defining the unit of analysis – The unit of analysis refers to the basic unit of text to be classified during content analysis. For Study 1, each open-ended survey was one unit. For Study 2, each of the three time points of the longitudinal interviews conducted was a unit of analysis.

3. Develop categories and a coding scheme – This analysis is directed. In this approach, researchers use existing theory or prior research to develop the initial coding scheme prior to beginning to analyze the data. As analysis proceeds, additional codes are developed, and the initial coding scheme is revised and refined. Researchers employing a directed approach can efficiently extend or refine existing theory [84].

4. Test coding scheme on a sample of text – This step involves validating the coding scheme through a detailed code book and conducting inter-rater reliability testing to ensure codes are consistent and reproducible.

5. Code text – The actual coding process uses a constant comparative method (described below). This method is used to prevent "drifting into an idiosyncratic sense of what the codes mean" [85].

6. Assess coding consistency – This step ensures reliability that the entire unit of analysis was coded consistently. Additionally, code meanings may have changed subtly over time and this step works to ameliorate inconsistent coding [86]

7. Draw conclusions from the data – This is the point at which the researcher makes sense of the themes or categories identified, and their properties. Researchers make inferences and present their reconstructions of meanings derived from the data.

8. Report methods and findings – For the study to be replicable, it is necessary to monitor and report the analytical procedures and processes as completely and truthfully as possible [83].

The qualitative analysis of Step 5 consists of a methodologically controlled assignment of a code to a passage of text. The main idea of defining specific steps in this qualitative analysis is to give explicit definitions, examples and coding rules for each deductive category, determining exactly which circumstances under which a passage can be coded [81]. Those category definitions are put together within an *a priori* (see Appendix G). In addition to coding deductively, emergent ideas and connections related to the theory of CEA are developed and understood inductively. These themes are included in the additional code book found in Appendix H.

Data collected in directed qualitative interviews are often comprised of open-ended questions followed by targeted questions about the predetermined codes. To analyze the data, two steps are taken using a constant-comparative method. First, the data are coded with the *a priori* codes. Any other text that was not categorized with the initial coding scheme is examined to see if it is a subcategory of an existing code or it is given a new, emergent code [84]. These findings can offer supportive and non-supportive evidence and connections for CEA. Evidence is usually presented by showing codes with exemplars and by offering descriptive evidence [82]. Newly defined codes can offer a contradictory view of the theory or more fully articulate and extend CEA. The software used for this coding process is RQDA, an open source qualitative analysis tool [87].

Because this approach analyzes the data with *a priori* codes, a significant, interpretive researcher bias could be introduced during analysis. To neutralize the potential for finding only supporting evidence for CEA and/or excluding contextual aspects, an audit trail can be used [84]. By working with other researchers to define the *a priori* codes, establish inter-coder reliability, and come to a consensus on the application and meanings of these codes to the data in context, the accuracy and veracity of the findings can be established and triangulation with other studies can be conducted. Formative assessment of reliability was conducted using the research group to vet *a priori* codes. This process is conducted to ensure that while coding, the codes developed from theory are manifested and defined in an inclusive way. Summative assessment of reliability occurs after coding, this process included inter-coder reliability assessment for dependability with a Cohen's κ of 0.954 and a standard error of 0.045. Additionally, the percent agreement between the coders was 96%. Sections of text from both the open-ended surveys and the case study were checked, and the results ensure that the *a priori* codes were consistent and applicable across both qualitative studies. This values indicate "very good" reliability of the a priori codes and ensure summative reliability [161]. The area in which the coders did not agree was the interpretation of the significance of others asking students for help in a subject. While this code may seem like a recognition experience, it loads onto the performance/competence factor in an exploratory factor analysis [122]. A note was added to the *a priori* code book to clarify this issue for future coding.

Trustworthiness in qualitative research can be established through four criteria: credibility, transferability, dependability, and confirmability [162]. Credibility refers to the "adequate representation of the constructions of the social world under study" and can be assessed both in terms of the process used in eliciting those representations and in terms of the credibility of those representations for the community under study. Activities that work toward credibility include a prolonged stay in the field, persistent observation, triangulation, the search for negative cases (comparators), the establishment of referential adequacy by setting aside some portion of the data for testing of conclusions, discussions or debriefing with peers, and checks of results with members of the community under study. In this work, a prolonged investigation of the case study (occurring over a period of more than one year); triangulation of quantitative and qualitative data as well as several sources of data used; regular discussions within the research team; and checks of the results with the literature and data set were used to establish credibility of the data.

Transferability refers to "the extent that the researcher's working hypotheses about one context apply to another" [162]. The researcher's responsibility is to provide enough data, through rich, ample description, to allow these judgments to be made. In this qualitative work, transferability was addressed by understanding the broad context of CEA constructs in open-ended surveys. These responses give a breadth of answers that may transfer to other cases. In the case study, in-depth understanding of context and descriptions of situations allows for transferable findings.

Dependability refers both to “the coherence of the internal process, addressed primarily through the concept of an internal audit, and to the way the researcher accounts for changing conditions in the phenomena” [162]. Dependability was established by establishing a clear process by which the data were analyzed. Each step of the directed qualitative content analysis was documented.

Confirmability, refers to the extent to which “the characteristics of the data, as posited by the researcher, can be confirmed by others who read or review the research results” [162]. This process has been described as needed explicitness of data collection methods; analytic constructs documented by data; negative instances displayed and accounted for; personal, professional, and theoretical biases discussed; analysis strategies articulated; and documentation of the field decisions that altered research strategies (p. 148) [163]. These two factors were established by creating a clear sense of how the data were analyzed and the specific codes used (Appendices G and H). All data collection methods are included in the appendices. Throughout the process of understanding CEA and analyzing the qualitative data included in this dissertation, the concept of trustworthiness was embedded.

These methods were used for both qualitative studies in Chapters 7 and 8.

7.3 Open-ended Surveys

Data Sources

Women from the SaGE survey who were identified as having engineering career interests (e.g. those indicating either a “3” or “4” on an anchored scale from “0 - not at all likely” to “4 - extremely likely” for the likelihood of choosing a career in engineering) were identified as potential participants for this study. Both students from the initial SaGE survey deployment in Fall 2011 and the additional oversample from nine 4-year engineering schools were used to have the largest number of potential participants. These students were recruited via their provided emails and offered a small incentive to participate in this study. Only female students who indicated interest in engineering on the SaGE survey were sampled, and the framework of CEA was examined for differences in students with the same engineering career goal. These students were asked a variety of questions about their math and physics identities, agency beliefs, perceptions of engineering, and career expectations and influences (see Appendix D). The total number of female engineers who also provided contact information was 302. A total of 46 students responded to the open-ended survey (14% response rate) and this number provided an adequate number of student responses to begin to establish explanatory links from identity and agency to empowerment for women interested in engineering.

Critical Engineering Agency

The open-ended survey responses were examined using the CEA framework. Connections seen in the SEM (Chapter 5) were explored. Students gave examples of how they developed specific identities and how agency beliefs factored into their engineering choice. These data allow a richer picture of the connections of CEA to be developed and the theory expanded and explained.

Agency Beliefs

Students described their agency beliefs with varying degrees of depth and personal affiliation. While almost all students described engineering as a way to benefit the world with specific examples when prompted, some women exhibited stronger agency beliefs even when unprompted. When asked what some of the most important influences on choosing engineering, some women described their desire to pursue an engineering career specifically to make an impact in the world:

> Student 12: *I've also been surrounded by a lot of illness in my family and it has inspired me to devote myself to a career that helps people get over their illnesses*

(in this case, through developing medical devices).

Student 12: *[Engineering will] give me the tools and resources I need to make an impact...*

Student 14: *I'm assuming some science goes into surgery, so when I had my knee surgery a few years back that mattered. I've taken a number of science/-math/computer design courses, so on my way to becoming an engineer [sic] has impacted me. And if I ever develop a mortal sickness then hopefully the field of medicine will have advanced far enough that it isn't so deadly.*

Student 18: *I hope to improve the quality of life within the world.*

These *unsolicited* agency-related responses show students with stronger agency beliefs that directly cite wanting to make a positive change in the world as the reason for choosing engineering. Agency beliefs are not a binary outcome, but are part of a spectrum for how individuals view engineering as a way to change the world. Chapter 5 showed that agency beliefs are more important for women in choosing engineering than for men. Even when asked what engineering can do for the world and for their lives personally, many women responded with answers beyond the identification of new technologies (e.g. cell phones and computers). These responses illustrate the depth to which these students believe their chosen careers can have positive social outcomes:

Student 23: *Science and engineering keep society moving forward, improve quality of life, and can give hope and purpose to a person that uses the science to do work.*

Student 10: *Technology and innovation are the only ways to achieve any progress as a society. Science and engineering can help create vaccines and medicines to cure cancer and other deadly diseases. Science and engineering can discover ways to prevent the negative effects of global warming or find a place where humanity can live if we kill this earth.*

Student 27: *Science and engineering impact my life in so many ways including the buildings that I sleep and study in, and the medicine I take to stay healthy.*

These students spoke about science, engineering, and technology as the way to make life better for people and for themselves. When asked about what science/engineering could do, students spoke about the impact on their career in a variety of ways from social impacts to personal experiences to globally relevant issues. These students showed a breadth of understanding of the possible impacts of engineering. Some of this insight may be due to being involved in an engineering major for some period of time, and it may also indicate a better understanding of what engineers can do.

In previous studies, the measurement items for agency beliefs included "science has taught me to take care of my health," which seemed somewhat different from the rest of the items that loaded onto agency beliefs. From the current data, connecting engineering and science with medical improvements and personal health is a natural extension of the positive impacts of engineering for students. Women describe engineering in this way and have a statistically larger path coefficient between agency beliefs and the choice of engineering in college in the structural equation model. These responses that tie engineering to socially impactful, health-related, and environmental outcomes may explain why women are represented in higher proportions in engineering disciplines that directly address helping people and the environment including biomedical (39% women), chemical (33% women), environmental (46% women), industrial (30% women), and biological (35% women) engineering which are all higher than the national average of 19% [6].

The way in which women speak about their agency beliefs, both prompted and unprompted, gives a deeper understanding how women view their chosen careers and their impacts. Seeing how engineering is involved in everyday aspects of their lives as well as the potential to make large global changes is important for women in their discussions of engineering. These areas highlight ways to get women interested in engineering as well as empower them through a non-traditional career that can address traditional social values of wanting to help people and make an impact. The development of agency beliefs allows individuals to act intentionally against established social structures [30]. These students, especially women, can become empowered to choose engineering as a career despite the lack of women in engineering. Women's discussion of agency beliefs shows the breadth of agency beliefs and illustrates how women describe their beliefs about the potential for engineering to make a difference.

Identities

When students were asked if they saw themselves as a math or physics person on a seven point anchored scale from "no, not at all" to "yes, very much," all students except for a couple indicated a math identity that was equal to or higher than a physics identity. Developing a physics identity was more important than developing a math identity for both men and women in their choice of engineering in the earlier SEM. However, in this data set, only two out of forty-six female students reported higher physics identities than math identities. While the identity estimates were lower for women than for men, these estimates held similar ratios between physics and math identities when compared. This finding may be explained by the fact that students interested in STEM careers were pushed toward physics in high school and high school physics curricula focus on applications of science, similar to the way students conceive of engineering [164]. However, when students took physics in college, it was not necessarily as related to engineering as their math courses. Students in engineering are typically required to take twice as many math courses as physics courses in their degree process [165]. In addition, in many engineering programs, math is regularly used in and explicitly related to engineering courses, while physics focuses on theory and common terms like "energy" do not translate across the curriculum [166]. This difference in exposure and focus on math over physics in the post-secondary engineering curriculum may explain the switch for students from a physics identity emphasis for choice of engineering in the SEM to higher math identities in this study.

Additionally, when asked to describe the ways in which they felt like a "math person" or a "physics person," students had markedly different ideas about what it meant to hold a math identity versus a physics identity.

Math identities were discussed with a wide variety of rich terms including examples of how students were good at solving problems, able to understand the material, enjoyed the subject, received recognition by others, and how math was connected to everyday life. Some examples include:

> Student 21: *I love working out math problems, seeing how you get an answer, and that there is only one right answer, and a specific algorithm for getting the answer*

> Student 22: *Being able to teach someone else the subject*

> Student 42: *Math just tends to click with me, it doesn't take me very long to solve a problem. If I have seen an example of a similar problem, I am usually able to figure it out.*

> Student 6: *Engineering school has opened my eyes as to what math can really explain in the science world. There are so many ways in which scientific topics are modeled through mathematics in order to compute numbers that are extremely close to true value, all through mathematics.*

Physics identities, on the other hand, were discussed in more limited ways. Students spoke about being good at physics, understanding physics, and seeing physics in everyday life. Almost no students spoke about their interest in physics.

> Student 46: *The real world makes more sense with a knowledge of physics.*

> Student 23: *I understand how forces act on a body, I am good a visualizing things, and I am good at problem solving.*

> Student 33: *It helps you understand how to problem solve, such as how much force you need to apply at what angle in order to move/turn/open something.*

Conspicuously, the ways in which students described both their physics identity and their math identity did not include many instances of recognition. Recognition was included a few times when students discussed being a math person, but was never discussed as a part of being a physics person. This lack of recognition experiences in students' narratives may be due to the fact that they have been asked about how they see themselves and, in this reflection, they do not talk about how they feel others view them. Additionally, while the importance of recognition has been shown, students do not explicitly discuss it. They internalize that recognition into who they see themselves to be through external validation. Because this validation process is initiated from others, students may not cite it in their personal narratives about the type of person they see themselves to be. The lack of recognition in student narratives may also be due to the social positioning of the question as ego-centric.

However, when students write about taking on the vital role of feeling like an engineer in identity work, recognition does come out as an important for becoming part of the engineering community and their self-concept. The engineering recognition responses were rich in detail and students emphasized how they felt they belonged in their community through instances of internalized recognition. In understanding the importance of recognition for identity development, the concept of recognition must be probed explicitly because students are not likely to bring up the concept in self-oriented discussions of who they see themselves to be.

Community of Practice

An important difference in these data is the point in the participants' education at which they were collected. Most students were in their second or third year of their engineering studies. In contrast to the earlier surveys, students had been exposed to an engineering Community of Practice and had begun to develop traditionally studied engineering identities. Lave and Wenger described a Community of Practice as:

> An aggregate of people who come together around mutual engagement in an endeavor.

> Ways of doing things, ways of talking, beliefs, values, power relations – in short, practices – emerge in the course of this mutual endeavor. As a social construct, a Community of Practice is different from the traditional community, primarily because it is defined simultaneously by its membership and by the practice in which that membership engages. (p. 464) [167]

From this perspective, constructing knowledge is an inherently social process and involves being a participant in a community, which comes with normative cultural practices. Students become a part of a Community of Practice as they begin the process of learning what it means to be an engineer. Communities of Practice generate and appropriate a shared repertoire of ideas, commitments and memories. Participants also need to develop various resources such as tools, documents, routines, vocabulary and symbols that in some way articulate and carry the accumulated knowledge of the community. While students may not identify as engineers immediately, they are still participating in a "peripheral" way to the Community of Practice. Learning to perform appropriately in a Community of Practice transitions members from participating "at the fringes" to becoming core members in a process of "legitimizing" participation [167]. One may argue that an individual's identity can not be formed without "legitimate" participation in a Community of Practice. Thus, earlier chapters focused on the transition from high school to college when students had not been immersed in an engineering Community of Practice. However, as these students began their college careers, they began to construct knowledge of what it means to be an engineer and how to identify as an engineer as well as practice engineering-related activities. In this process, their engineering identities as a part of this Community of Practice began to develop and interact with previously studied physics and math identities that were so important to their earlier engineering choice. This development steps beyond the previous study utilizing SEM because it is situated within an engineering Community of Practice. For example, one student said that she was engineer because she was "in the process of developing the tools to successfully be an engineer."

Because recognition is so critical to students' identity development, understanding how students feel recognized within the classroom is valuable for informing pedagogy. Students' identities in engineering may be fostered by taking advantage of specific formal and informal education opportunities. When asked how they felt recognized as engineers, female engineering students responded in a variety of ways. Many cited design projects, internships, and other recognizing their talent to problem solve as ways of being seen as an engineer. Some examples of specific situations in which recognition as an engineer was internalized by students spoke about freshmen design projects:

> Student 2: *During my freshman year, the engineering class worked on group projects. We designed a device to save energy and presented it to peers and faculty.*

> Student 24: *In my freshman intro to biomedical engineering class, we had to design an intubation mannequin that met a lot of specifications, and then build a prototype and give an 'elevator speech' to our lab group. My group won, and so we went on to build an entire business plan and present it to the whole class. This meant redesign of a more sophisticated model and looking at markets and calculating return on investment, et cetera. It was a great learning experience, both with regard to engineering and business. I felt recognized when we went on to the final round and got a lot of positive feedback on our prototype.*

> Student 33: *I really felt like an engineer during freshman year of college in which an assignment in my statics class involved designing and building a tower out of wooden dowels that could withhold about 20-30 pounds while also being as light as possible. My partner and I were very successful in this project, and actually won the competition as we were the group that were able to actually take the assignment and think outside of the box.*

These students saw more "legitimate participation" in engineering through pedagogy that can be implemented in the classroom. Instead of learning specific content knowledge or doing problem-solving exercises, these students felt like engineers by "doing." These projects involved designing and actually building specific prototypes based on engineering fundamentals. The recognition component of their identity development was realized through presentation or competition of their results. This external validation of their product is the type of recognition experience that students actually internalize and use in their construction of an engineering identity. This finding is consistent with other work that showed that specific learning setting provide resources for the development of subject-related identities [168].

Other students talked about ways they felt recognized as engineers outside of the classroom:

> Student 28: *When my sorority was setting up for an event, some other members couldn't figure out how to set up the stage and one said "someone go get [name], she's an engineer, she can figure it out." I felt recognized as an engineer because she explicitly said it, and she also was referring to engineering in a positive way which made me fee like my skills were appreciated.*

> Student 41: *I am a Resident Assistant, and among my staff, whenever we have team builders, they always say "the engineer! the engineer can figure it out!"*

When peers saw these female students as a part of the engineering Community of Practice, they felt recognized as engineers. The reputation that they were able to figure out something or fix something based on their chosen career allowed these students to feel liked they were engineers and belonged in that Community of Practice. Recognition of students as engineers by their peers falls outside of their Community of Practice but still has significant impact on how students feel a part of their engineering community. As students internalize what others within and without their engineering Community of Practice say about their identities as engineers, their sense of belonging within engineering develops. This finding shows that when students talk about the influences of their peers in feeling recognized as an engineer, it can be students within their major, or friends that they interact with outside of that community.

Engineering Choice

When describing the most important influences on choosing engineering, most students described an interest in engineering, strong performance/competence beliefs and/or interest in math and science, and the influence of family and teachers. These ideas largely validate the previous findings in Chapters 5 and 6. The importance of math and physics identities and agency beliefs as measures of students' internal self-beliefs are important for students' choice of engineering. Additionally, the influence of family and teachers in women's choice of engineering was discussed in two studies in Chapter 6. Women's physics teachers and, even more than men, their chemistry teacher were important influences on career choice. Additionally, the effects of occupational inheritance from parents and self-efficacy beliefs derived from vicarious learning experiences of siblings which are familial engineers is a significant predictor of engineering choice. Students' qualitative responses triangulate previous quantitative work. For example:

> Student 14: *I liked math and designing 3D models on computers, so it [engineering] seemed like the best fit.*

> Student 15: *I have always loved problem solving and the feeling you get when you help people fix something or make something better. Engineering is a perfect way to implement those skills.*

> Student 6: *I really, really enjoyed chemistry and math in high school. A career that often came up when discussing these topics was chemical engineering. I figured it was probably a good fit.*

> Student 34: *[I chose engineering because of] my strength in mathematics, but desire to apply it to more than teaching.*

Student 35: *My dad is a Civil Engineer and I have always looked up to him as my inspiration. My grandfather is also a Civil Engineer and co-owns a company that my dad and other family members also work at. I have always wanted to work with both my dad and grandpa.*

Student 45: *I look up to my dad and my mom's cousin, who both really encouraged me to be and engineer.*

Discussion

The connections of CEA that were seen in earlier research were validated and expanded upon by the data collected here. Student narratives of their own identities are inherently ego-centric. When asked to discuss how the feel like a "math person" or "physics person," students spoke about their interest, performance/competence, and/or the connections that they saw between that subject and everyday life. Only a few students who had very strong math identities spoke about how they felt that other people saw them in that way. Recognition as an identity construct takes into account a social aspect of identity formation. Students' identity development in STEM is influenced by the ways in which they interact and participate with people and within a community. It is important in the understanding of identity to take into account how students believe other see them. This factor is more important in predicting students' math and physics identities than either performance/competence or interest alone, as demonstrated in Chapter 5. Additionally, the concept of recognition is fundamental to a Community of Practice [169]. Human beings are social creatures who have agency in the world around them. Recognition beliefs capture this social aspect by considering what it means to belong and have a sense of community membership. This membership is integral to part of individuals' sense of affiliation or identification with certain communities and does have great impact on feelings of belongingness and ultimately persistence [4, 42, 170]. However, recognition is not a regular part of students' self-constructed narratives about their own identity formation. This result may be due to the self focus of students' personal narratives or the lack of the metacognitive ability to reflect on how others make them feel a part of a community.

Students who spoke about their identity with respect to interest versus just performance/competence had stronger identities. These narratives mainly occurred in a math rather than a physics context. This finding is different from what was seen in the SEM results. In that case, the path estimates for physics were larger than math for both men and women. Students may have associated physics with engineering in high school since physics is typically branded as a gateway course into engineering and may be presented as applied science similar to students' perceptions of engineering. However, students may find college physics to fall short of these expectations. One student documented that he found physics to be a class in which it is difficult to get a good grade, time consuming, or boring, dull, or simply not fun [171]. These experiences may turn off students previously interested in physics as it related to engineering and reduce their perceived physics identities over time. Additionally, the culture and pedagogy of many physics classrooms turn off women to physics [172]. Math, however, is a different community. Research has shown that women taking mathematics courses are taught similar amounts of mathematics and receive grades that are similar to (or better than) those of their male counterparts [173]. Additionally, women currently comprise $\sim$43% of bachelor's degrees awarded in math which is more than double the fraction of degrees awarded to women in physics, 21% [89]. These representation differences may be a reflection of the differences in attitudes in these two communities and how students speak about who they see themselves as in math and physics. However, it is important to note that tests of statistical difference between the path estimates of physics and math identities predicting choice of engineering for women were not analyzed in the SEM.

Understanding how women see themselves to be a physics person and the channels through which that identity is limited can help address the representation issues of women in engineering. Having a physics identity is important for both men and women to choose engineering as a career, but women's development of these identities seem to be limited by how they discuss what a physics identity means. Lack of interest and recognition in their discourse points to lower physics identities and possibly lower engineering enrollment. Students who desire to be competent in a subject but do not desire to take on subject-related identities associated with membership in these communities often face difficulties in the subject area and are turned off by the subject [174]. Capturing women's interests and beginning to recognize these students in the classroom may improve their identity, which has been shown to have a positive impact on engineering choice. Additionally, increasing the way in which women are recognized and internalize this recognition in math may improve some of the representation issues for women.

Understanding how women feel recognized in engineering, which is also a significantly underrepresented field, offers some practical findings for pedagogical reform in the physics and mathematics classroom. Women describe recognition experiences as legitimate participation in the community through projects in which they take on a leadership role and experiences in which they make a valid contribution to the knowledge base. Because physics and math are courses closely associated with an engineering degree, these ideas could be incorporated into math and physics curricula with engineering-related projects that incorporate the more abstract science and math being learned. This work addresses Research Question 5 by describing *how* women identify with physics and math.

Women interested in engineering have more complex and varied agency beliefs than previously identified. Agency beliefs in CEA are inherently social, as is identity, and having agency within a Community of Practice allows students to not only craft who they see themselves to be in a community but also imagine their intentional participation within that community. Agency is at once the possibility of imagining and asserting a new self in a community at the same time as it is about using one's identity to imagine a new and different community that is improved through one's own legitimate participation [118]. Many individuals described these beliefs about their future participation in an engineering Community of Practice to improve the world. This empowerment was involved in how students described their reasons for choosing engineering as well as what they wanted to do with their intended careers. The concept of who women saw themselves as in the future, as engineers, was aided and cemented by their beliefs that choosing a vocation in engineering would fulfill their beliefs that they could make a positive change through their own actions. These beliefs may be placed on a spectrum ranging from the broad, global impact of engineering to the specific understanding of how choosing a career in biomedical engineering can improve solutions for a sick mother.

The relationship between identity, agency, and Figured Worlds, of which a Community of Practice is a specific type, has been documented by Holland and colleagues and is shown in Figure 7.2 [117]. Figured Worlds are "socially and culturally constructed realm[s] of interpretation in which particular characters and actors are recognized, significance is assigned to certain acts, and particular outcomes are valued other others" (p. 52) [117]. This definition is an expansion of Lave and Wenger's definition of a Community of Practice as a way to identify social groups on the basis of participation in particular activities or practices [167]. A Community of Practice is a type of Figured World because actors within this group **do** define their membership by their culturally constructed and accepted practices of dialogue, actions, and values. However, a Figured World also emphasizes the abilities of actors to "innovate, improvise and reconfigure the norms, the tools, the practices and all aspects of their social and cultural lives" [117]. This work looks at a specific Community of Practice, within engineering, and how students become a part of engineering culture and reproduce community products, but also examines how agency plays a role in participation and change in engineering.

Communities of Practice utilize students agencies to transform their identities. Their identities, in turn, create possibilities for asserting changes in their Community of Practice through agency. Agency in this conceptualization functions as an agential bridge between identity and a Community of Practice. This concept has emerged in how student describe who they see themselves to be within a context. Students who describe themselves as recognized as engineers (i.e. participation in engineering Community of Practice) speak of how they see engineering as a practical way to make the world better (i.e. agency).

This idea, in turn, also feeds into who they see themselves to be and how they describe themselves as engineers (i.e. identity). This agential bridging occurs in how students speak about their recognition beliefs. These developed engineering identities have the potential to empower students (e.g. agency) to change their Community of Practice for the better. This agential bridging may be the mechanism by which students who develop a subject-related identity begin to participate in a Community of Practice. Students form agency beliefs about their chosen careers in nuanced ways, and many students speak of out of classroom experiences as ways in which they form agency beliefs. While students form CEA within a Community of Practice, their emergent agency beliefs are informed by their Community of Practice and how involved they become. As students become more central players in a Community of Practice, in part through recognition, their ability to envision participation in the community in a meaningful way to change the world outside that community increases. This positive feedback loop between students' CEA and Community of Practice through agential bridging emphasizes the importance of understanding a sociocultural perspective in self-concept research.

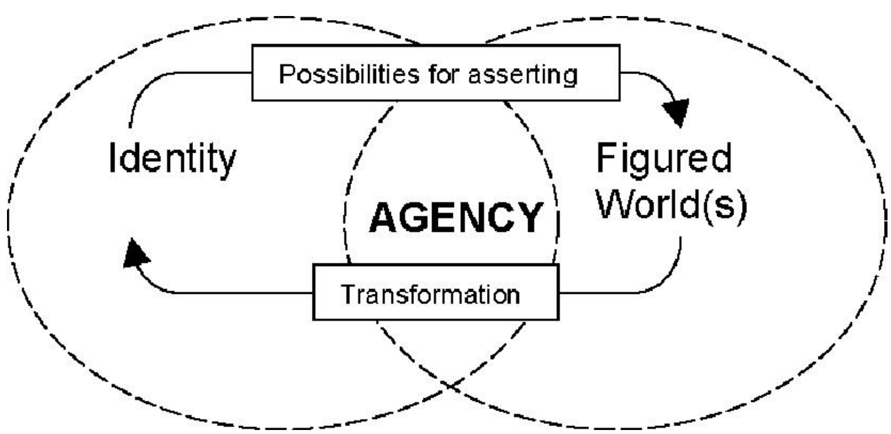

Figure 7.2: Figure of agential bridging between Figured Worlds (Community of Practice) and identity [117].

Specific examples of how this plays out in student narratives is through the ways in which students describe feeling recognized as engineers. Women describe situations in which others say they are an engineer because they can “fix” or “do” something. Women also felt recognized by being involved with engineering projects or working in an engineering industry. Students also spoke of being prepared to do “real” engineering. The overarching theme of these descriptions is participation in the vocation of engineering. Students who felt that they legitimately participated in engineering felt a part of that community. These students also became empowered in engineering through their participation of seeing themselves as engineers, an example of agential bridging.

This idea of how identities and Communities of Practice are linked is similar to findings by Barton et. al on how identities are formed over time [175]. The process of identity formation involves

> the actions that individuals take and the relationships they form (and the resources they leverage to do so) at any given moment and as constrained by the historically, culturally, and socially legitimized norms, rules, and expectations that operate within the spaces in which such work takes place (p. 38) [175].

Identity involves interacting within a Community of Practice with culturally normative behaviors. The negotiation of self-concepts must occur within these spaces which may be supportive towards forming an identity or may deter identity development. Students' agency beliefs are not only a way in which identity formation occurs, but it is the empowerment which allows women to form identities within a Community of Practice that may have normative values and culture that do not promote the identities of underrepresented groups. In turn, agency beliefs can empower students to make change within a Community of Practice to improve the culture for future underrepresented students.

Conclusions

Critical Engineering Agency goes beyond an individual's sense of self as a person whose actions can make a difference to include actions aimed at social transformation that are informed by engineering understandings and practices. The connections seen in the

SEM in Chapter 5 have been triangulated through this study. Students who have improved identities in math and physics speak more often about their interest than performance/competence beliefs. While recognition is extremely important to identity development, students do not intentionally discuss others in their own narratives. When asked explicitly about recognition these students give deep and meaningful insight into how they feel recognized, especially in engineering. Agency beliefs do play an important role in women's engineering choice, and the rich descriptions of how students view engineering as a way to make change in the world is more meaningful and varied than previous measurements. Future work will include creating new measurement items for agency beliefs that capture this diversity.

This chapter lends some insight into Research Questions 6 and 7. Women began to describe how they viewed agency and what they could do with a career in engineering. The breadth of student responses of ways in which women discuss agency beliefs and the connections between identity and Communities of Practice create new insight into how agency plays a role in the CEA framework. Women discuss in a limited way how they formed their agency beliefs. Students who provided unsolicited discussions of agency beliefs speak about how life experiences impacted their view of engineering as a way to make a positive impact in the world. Follow up work with the case study in the next chapter will lend deeper insight into how specific experiences may engender agency beliefs.

This chapter has shown that agency beliefs are more central to students' CEA than previously hypothesized. Agency beliefs function as a bridge between students' identity and involvement within a Community of Practice. Communities of Practice were previously thought to facilitate identity formation, but student narratives have shown that students connect their vocational community with their already held identities through their agency. The findings of this work deepen the understanding of CEA and how the constructs of identity, agency, and being a critic interplay with students in context. This context – participation within an engineering community – was not captured in the model of how identity and agency predict engineering choice. The lack of context in the quantitative work simplifies the story of how students choose engineering based on high school subject-related identities and perceptions about what engineering can do for the world. This follow up contextualizes student responses within engineering and gives deeper understanding to how CEA empowers women to not only choose engineering but remain in engineering. Fostering this this empowerment and self-beliefs in female students can begin to stem of tide of underrepresentation of women in engineering.

Chapter 8

Qualitative Case Study

In addition to exploring the paths seen in the SEM model in Chapter 5, a qualitative case study was conducted to see how a female student, Sara, identified at the end of her high school studies as having high Critical Engineering Agency (CEA) navigates her engineering studies and develops as an engineering student in college. Sara is an exemplar of a female in engineering with high math identity and a strong belief that engineering can make a positive change in the world. Understanding how she chooses engineering as a college major and navigates her identity development and agency beliefs in engineering can provide a transferable example of how this framework can be utilized to improve female students' recruitment and retention in engineering.

Methods and Data Sources

The data for this study come from multiple sources and perspectives. This case study provides insight into a particular issue, in this case, female choice of engineering, and builds upon the theory of CEA [86]. Data were collected at three time points (Spring 2013, Fall 2013, and Spring 2014) as "snapshots" of Sara and her journey from high school to an engineering major in college. During her senior year of high school, Spring 2013, an abridged version of the SaGE survey and a face-to-face interview was collected (see Appendix F). After beginning college, another interview was conducted towards the end of Fall 2013 (Sara's first semester in college). Finally, a third interview was collected at the end of her freshman year in the spring of 2014. Additionally, interviews with her high school chemistry teacher (in Spring 2013 and Spring 2014) were collected. The interview protocol for all of these interviews are contained in Appendix E. The methods for analyzing these data sources is Directed Qualitative Content Analysis as described in Chapter 7. The difference in this approach for Study 2 is the unit of analysis. Rather than concise questions about the pathways seen in the SEM analysis, this data is a case study of Sara's experiences.

In the engineering and science education research literature there are precedents for the single case study approach [60, 170, 176]. A case study allows the reader "to experience vicariously unique situations and unique individuals within our own culture" [177]. Case studies emphasize detailed, contextual analysis of a limited number of events or conditions and their relationships. A holistic, in-depth investigation can give an example of a how the theory of Critical Engineering Agency actually affects the empowerment and decision-making process of a single student. By understanding the exemplar, the theory can be articulated and explicated.

8.1 Sara

Sara[3] is an average height female with sandy blond, shoulder-length hair, brown eyes, and a dry sense of humor. She comes from a rural town in the Midwest with fewer than 4,000 residents. The population is predominately white with roots in a Swiss/German heritage. The surrounding community consists of a proportionately large population of Amish people. Sara fits within this conservative community as a wholesome teenager who swam on her high school team. Her high school consists of approximately 400 students and is housed in the same building as the middle school and elementary school. Trade classes are offered through this rural high school as well and the percentage of students who qualify for free/reduced lunch is 39%.

Additionally, her high school runs a unique integrated service project that helps to

[3] All names (persons and places) used in this analysis are pseudonyms used to protect participant identity.

provide clean water to a developing nation. This program was started in response to an urgent need for clean water in the wake of a devastating natural disaster which happened around five years ago and was initiated by the students at her high school. One instructor allowed two sections of his combined chemistry and physics class to develop committees to address the research about why the water in this country was polluted, how to raise money for this project, how to develop a system for creating clean water, and how to raise awareness for this project. Over three semesters, the students researched and innovated upon an existing membrane technology to create a portable water purifying system that uses electro-chemistry to filter and purify 55 gallons per minute with chlorine made from salt water, water, and solar energy. For the previous three summers before initially interviewing Sara, this school had gone to this country to distribute the water purification devices and train people how to use them.

This program has grown out of two sections of science classes to the entire curriculum and culture of the school and community. Walking down the hallways, posters and bulletin boards are displayed with members of the summer teams, support for this program, and cultural descriptions in the social science halls. The science department head described the involvement:

> *And so we started to see every discipline focus on water as kind of an anchoring thread or on the [local] culture as kind of an anchoring thread....So the whole community has gotten involved. Elementary kids, they learn about, um, sanitation and hygiene and so on from our high school kids who go into [country]. So it's like oh, you're doing that, well, then I'll listen to you. My teacher I wouldn't listen to, kids, you know, I'll listen to them. That celebrity kind of, you know, impact. Um, and so our kids have become experts in water. They've become experts in [country] and in cross-cultural stuff. And honestly we probably have people here, particularly some of our Amish probably have some water issues that would still benefit from us, but sometimes you kind of have to do it elsewhere before you bring it home because now you own the problem, you know,*

you're willing to kind of come out of your comfort zone and go to your next door neighbor and help out where maybe beforehand you wouldn't so.

In this school context and environment, Sara developed an interest in engineering that began late in her high school career – halfway through her Junior year. Originally, she planned on finishing her high school degree a year early and directly entering the workforce. She saw no point in getting an education and was uninterested in pursuing higher education. She points to her AP Chemistry teacher, Michael, as the main influence on her decision to major in engineering in college. Her teacher indicated that early in her high school career she was an "at risk" student with a disrupted family life who was uninterested in learning, especially in science. Through her interaction with the clean water program at her school over three years and this teacher, she developed an interest in science and decided to finish out her high school degree and pursue a college degree in engineering. Her case illustrates how a student can develop CEA beliefs situated in context. This case is especially interesting because of the significant changes in her attitudes, desires, and goals through her empowerment. Her story, incorporating her decision to choose engineering, choice of college, and her freshman year experiences and reflections, gives insight into how CEA can be developed in women previously uninterested in engineering, even late in high school.

Choosing Engineering

Initial contact with Sara was suggested by her high school AP chemistry teacher, Michael. He identified her as a student of interest to our research team because she had become interested in engineering through her experiences in the clean water program and her math and science classes. In her initial interview, Sara told me that she choose her career in engineering because she liked chemistry and wanted to do something with it. By talking to her chemistry teacher she figured out that she wanted to do engineering. She stated, "I guess like for narrowing my, what I wanted to do, [Michael] was definitely like the biggest factor in it."

Michael began teaching at her high school four years prior to our interview to fill a gap in the chemistry department. The school had planned to change the chemistry program to a computer based program or distribute it across the two science teachers already at the high school. The superintendent told him that he could teach since he had a degree in chemistry and worked in industry for 23 years. He agreed to fill the position temporarily until someone could be hired, but ended taking the position permanently. He explained how he guided Sara into her current engineering trajectory based on her interests and experiences in the clean water program at her high school:

> *Sara, who I think you're going to interview, she started out leaning towards, um, quitting school and going into some sort of charitable work. Um, but she realized that, well, she still wants to do that, but if she goes into the engineering side, um, she thinks she can be much more effective. Like become a chem– she's looking at chemical engineering. So if I go in as a chemical engineer, I can still do the charitable work but I can do my chemical engineering in a third world country helping them develop their water systems which will affect many more people and so, um, you know, so those types of conversations happen almost daily really.*

I asked him if he specifically guided students into engineering and science careers and he stated:

> *I won't say 'I think you should be an engineer'. But I will say, 'you know, hey, there's an opportunity here and then, um, [a nearby engineering university] has a lot of engineering career days. Um, we've taken students over there to do, just to see what it's like, um, we just sent some kids to summer programs just again to encourage them to see, you know, check this out, it might be something you're interested in.' Last year I sent three, Sara was one of them, three girls to the School of Technology at [this university], Engineering Technology, um, and they spent three days. It was through the Women in Engineering program. Um, so they spent three days there exploring technology careers. Um, so it was*

just the, so we encourage it [engineering careers], I guess, and support it and that type of thing. We arrange funding if it's needed. Um, many times we can get scholarships for them from, the community here is just greatly supportive. For instance, the [clean water] program, I've been told by three or four different people in the community if a student can't go because of money let us know. You know, the career day, the last [engineering university] Career Day costs each student $100, it goes more than a day, it's a long weekend. Um, and there were three students that probably wouldn't have gone if somebody, you know, that someone in the community has told us that anytime you need something just let us know we'll support that so. So it's really been supportive and it's good for the, great for the kids, great for the community.

Sometimes, the argument is made by educators (especially post-secondary educators) that studying the choice of engineering in high school is "too late" for students, especially women. Sara's story illustrates that the choice of engineering is sometimes made even in the last few months of a high school career. Her teacher, Michael, described how her experiences with the clean water program at her high school sparked her interest in a science-related career. She took on a leadership role in the clean water program, training new students and working to solve installation issues. Each site offered a different challenge of installing the piping correctly and ensuring that the system would work. These hands-on and design experiences initiated the desire to use science in a positive way and motivated Sara to begin to excel in school science. She saw her experiences as "practice" for her future career.

When she took chemistry during her sophomore year with Michael, she "just got it" and began to be interested in science and excelling in the course. This course changed her attitudes towards learning, and she began to see knowledge as a way to better herself. Through multiple conversations with her teacher, she developed an interest in learning. She approached Michael in her junior year with the desire to pursue a degree in some "scientific thingy" and through his influence, she explored the options available to her in science and engineering programs. She wanted to take the parts of high school that she was enjoying and use them in her life. She decided to choose engineering in her senior year based on her discussion of Michael's career in the manufacturing sector and her experiences in the clean water program. By the time I met her in her senior year, she had chosen to pursue chemical engineering and had applied to several engineering colleges.

Her teacher played a unique role in her choice of engineering. Michael was not simply a science teacher at her school. He crossed traditional boundaries by being involved in Sara's life in formal education, the clean water program, and in Sara's personal life. Michael knew Sara from the summer after her freshman year in high school through the clean water program and the two subsequent summer trips as well as functioning as her chemistry teacher her sophomore and senior year of high school. Sara came from a disrupted family and Michael became a father figure in her life. Michael had a daughter close in age to Sara and she began to spend time at their house on a regular basis. He identified with her struggles and desires to quit school. His life story paralleled hers in many ways. At sixteen years old he wanted to drop out of high school but became interested in chemistry and pursued a degree in it. He said that she was a unique case when she got excited about chemistry and it just made sense to her. In other ways, she was a typical high school student who enjoyed learning about things in which she was interested and did not enjoy or put time into learning things she did not care about, like English. His influence in her life and abilities to cross boundaries helped develop specific values and empowerment in Sara.

8.2 Identities

Sara excelled in her AP Chemistry class, making a 98 in her fall semester. She spoke of her interest in chemistry as a deeper part of her enjoyment of learning that she had developed:

> *I like chemistry as a whole so like there's not like a particular, because like each new thing I just like learning more about it. I like being in AP Chem now*

> *because we like go more into depth of where like chemistry was more just like on the surface.*

Additionally, her performance/competence beliefs were evident in her description that chemistry "just comes really natural." She also felt recognized by her classmates, saying:

> *. . . everyone would come like the day before the test and like so 'how do you do this?' And I was like okay, but, so I mean I guess I teach kids sometimes if they need help.*

Sara also spoke explicitly about her identity in math. When asked if she saw herself as a math person, she replied, "Definitely." On an abridged version of the SaGE survey, Sara scored high (3 and 4 on an anchored scale from 0 to 4) for all of the math identity variables including, "I see myself as a math person." These constructs manifested themselves in her discussion. She talked about her interest in math in several different ways. She enjoyed doing the calculations for her chemistry lab group in class and said, "Personally, I like doing more like the calculation deal."

She took a leadership role in her chemistry lab group in carrying out the calculations because she understood them and was recognized by her group as the best math person.

> *. . . we normally do groups of three like we did today and like those two typically work on that and then tomorrow [she was missing class because of a swim meet] I would've basically done all like the calculations and stuff because like I just get it and then they'll like looking at it and they'll like I do not get this at all. So then, then I help out a lot of times.*

Sara spoke of how she became interested in math and science in her interview. On her survey, she marked that she was was less confident in math and science (3's on an anchored scale of 1 to 6) and less interested in math (2 on an anchored scale of 1 to 6) and science (3 on an anchored scale of 1 to 6) in middle school (Appendix F). Her narrative about how she became more interested in science and math illustrates the process of forming the identities discussed:

> *I used to get like B's in math and science and I was like okay at it. And I felt like I was decent but I just, it never fully, like I never just liked it a lot. And I guess it was more like in middle school they taught you like yeah, the earth is, has so many layers and you have rock soil and all this stuff and I was like I don't care what the soil is, like I do, but I don't....And by the time I got into eighth grade it was just like I know I should know this but I don't. And then whenever I got into high school it was just like oh, this is a different way to look at things. This is like you can use math to like figure out things and you can see how things move and work and function and like whatnot. So I guess, I was just a lot more interested and whenever I'm interested then I like put my time in like, like everyone does and so, I mean, I guess that's what the difference is. I don't know. In eighth grade our math teacher was really good so then like I started liking math like a lot better then. And then, like algebra came really easily to me and then after that I just started excelling both in the science and math department so. And then once I started excelling then I like liked it a lot better because I don't like to do things that I'm not good at so.*

This cycle illustrates the paths seen in the SEM in Chapter 5 and the connections seen in the open-ended surveys in Chapter 7. A lack of interest in middle school in her science courses prevented an identity development in science. As the content of her courses changed in high school to become more interesting to Sara, her desire to be that type of person increased. She did better in those courses, increased in her confidence in learning the material and developed specific science and math identities. This narrative also shows that while identity is a quasi-trait that is relatively stable over time, it can be influenced and changed as a result of experiences in and out of the classroom. The snapshot of identity and it's effect on choice of engineering in the CEA framework captures the relationships between interest, performance/competence, and recognition in identity.

Sara had not taken physics in high school. When asked about what it means to be a physics person she told me:

I guess how things work and move. I don't know, I don't know too much about physics since I have never taken it, but I don't know. I've heard about things that they do and just how reactions and stuff and how things actually, the physics of them or whatnot, I don't know. As I am, I don't know too much. I mean, I don't know. I obviously don't know too much about physics because, yeah, I mean, I'm going to have to take it someday and then I'll learn.

Her plans were to take a physics course in college as a part of her engineering degree. While she did not take a physics course during this study, future time points can illustrate how she forms a physics identity alongside her chemistry, science, and math identities while forming an engineering identity.

8.3 Agency Beliefs

Because of her involvement in the clean water program at her high school, Sara desired to pursue a career that would make a difference in the world. The influence of her high school chemistry teacher steered her toward engineering as a career that would allow her to pursue a college degree and fulfill that purpose. This desire to affect positive change in the world and empower a choice of engineering is a prime example of how agency beliefs can empower women to choose a career in engineering.

Sara discussed her experiences in the clean water program and how that impacted her view of people and their needs:

I went twice now to [country of the clean water project] with our school and, um, we installed water purification systems there. And it was really neat because like, I mean, I guess neat's like, I don't know, but I just, I was really impacted by like how people live with, without water and stuff and like they just drink this like dirty disgusting water and they think it's okay. And like they stopped using our purifiers for awhile because it didn't taste the same because the water was clean and just, it kind of amazed me in that. And then also how trashed it was. Like *there was trash and just gross stuff all over. And it was devastating, like how, I don't know how people live, but I don't even know where I would start to clean that up because it's everywhere and like the poverty and everything is terribly sad to see.*

This experience created the desire to address some of the needs that she saw through this program in her career:

It [experience with the clean water program] definitely led me to like want to do something and like especially with the water purification system, like we created, like we didn't create the system but we definitely like renovated it and made it better and more efficient, like it purifies water a lot faster and better and lasts a lot longer. And we figured out ways to, um, make the battery work like solar panel stuff. So I mean, it kind of just showed me that I like doing that kind of things and figuring out, and then like I can still help people but then design things through my like ***potential career*** *or science or what ever.*

When asked about what she wanted to do with a career in engineering, Sara told me that she wasn't exactly sure what she wanted to do. She had considered a career in chemical engineering due to the influence of her chemistry teacher:

And so I kind of was like okay, I want to do something in chemistry and then like I talked to [Michael] some about what things I could do. And then, um, I just, like I just kind of eventually through talking to [Michael] and stuff figured out that I kind of want to do that [chemical engineering].

Sara also considered majoring in environmental engineering as a way to connect her experiences in the clean water program with her plans for a future career:

I was thinking about doing the whole environmental engineer, I was thinking maybe I could make something with wind mills and how they work efficiently and like just making things. I mean, and it could be something even more complex like, I don't know, some, I don't know.

Her desire to be an engineer derived from what she could *do* with that career and not necessarily for the career in and of itself. This manifestation of agency beliefs leading to engineering choice shows in context how seeing engineering as a practical way to change the world can increase female interest in an engineering career.

Additionally, Sara tied her science and engineering to the every day world. She saw connections in how these interests and identities shaped the world around her:

> *I mean, most people don't realize that like this is science or this is engineering or this math or whatnot, but I mean, what I might be using is like someone had to make a chair. They had to like engineer it, they had to use science and chemicals making it. And so I think when you think about it, everything has to do with science and math and whatnot.*

Relating her science and engineering interests to her life and seeing these ideas as a route to make an impact on the world is a rich and detailed example of how agency beliefs can make engineering more attractive to students. The importance of agency beliefs for this one woman corroborates the findings in Chapters 5 and 7. Sara's story is a detailed example of how this difference between men and women in choice of engineering can be manifested.

8.4 Mastery Orientation

In addition to the constructs seen from the CEA framework, other themes emerged in Sara's data. One of these themes was Sara's mastery orientation. This orientation, drawn from goal orientation theory in education psychology [178], is associated with an enjoyment of learning and is a typeof intrinsic motivation. Students with a mastery orientation believe that they have some control over factors related to learning. They believe that they can learn, that hard work and efforts pays off, and that they have or can acquire strategies that will help them learn. They do not give up easily when a learning task challenges them.

This theme emerged as essential to Sara's success. Sara repeatedly talked about her love of learning and interest in understanding how things work in real life. She speaks to the idea that if she works hard enough, she will eventually succeed. This sentiment is connected to the idea of grit. Grit is the tendency to sustain interest in and effort toward long-term goals. Students who develop grit are more resilient in the face of failure or adversity [179]. The emergence of these themes results from this particular student and the desire to fully understand her affective states in relation to her engineering choice. Motivation and grit are not the primary lenses used to analyze this work, but do add insight into the context of Sara's story. The development of a mastery orientation and grit towards science and engineering has a positive impact on Sara's potential success as she enters her first year of engineering in college. She shows examples of her mastery orientation through her interview:

> *I mean, I'm not the kind of student that just takes something and then like forgets about it. Like I actually want to learn everything because I do love learning. I mean, I know high schoolers aren't supposed to admit that or whatever, but I mean, I like to learn more things, see how like why things happen, why they are what they are... like a person's never going to be mad about learning more things. Like you can't get upset that you know more stuff.*

In order to satisfy this desire for knowledge, Sara spoke of her enjoyment of teaching herself. Her high school chemistry classroom has a unorthodox model of learning: instead of Michael disseminating knowledge in a teacher-centric style, he viewed himself as a guide to learning and allows students to work through learning modules self-paced. This pedagogy emphasized student responsibility for learning. Sara told me that she preferred this way of learning:

> *I love it, like because I can come in here [the classroom], I don't feel pressured to get my work done but I, like I'm this type of student that like I will get my stuff done, like I don't know why it matters when I get it done as long as I do. And that's what I've never understood and [Michael] gets that. Like he says if you want to fail this class you can fail it. But if you don't then you better do your packet, you better take the test and ask me questions... that's probably my*

favorite part, the like freedom that, and like lack of, by having like lack of control gives it more control I guess.

This desire to learn and persevere towards her goals allowed Sara to see engineering as a viable choice of career even late in high school. Her desire to learn more connects to the grit she possesses to passionately pursue her long-term goals. Being intrinsically motivated rather than looking for outside approbation also let Sara choose a career in engineering by seeing the connection between her interests, abilities in math and science, and desire to use her experiences in clean water to make a change in the developing world. The connection between these CEA constructs that unites her self-concept to her goals is her mastery orientation.

8.5 Summer Experiences

During the summer between high school and college, Sara had two experiences that helped cement her desire to continue engineering in college. First, she participated in the clean water program with her high school for the third consecutive summer. She also participated in an internship at her grandfather's engineering company.

Sara's experiences with the clean water program were formative in developing her agency beliefs about a career in engineering. Part of her summer was spent bringing clean water technology and training individuals in a more remote part of the country the project works in than in previous trips. Sara described how this experience affected how she viewed engineering in college:

> *Even though it was a very science [oriented trip], like it was with our science department, I just wanted to go there to help people out. So, I mean it taught me just like once again to like be thankful for what I have, and that you should always help people, and, and then they liked helped me out with they changed me and made me a better person, and like yeah. It's a really neat thing.*

Additionally, Sara's grandfather was a mechanical engineer who owned an engineering business in a nearby city. Sara spent part of her summer working at the firm and seeing how engineering designs were conceptualized and fabricated into actual parts for cars. She said that she was responsible for mostly office work and "menial tasks," but that she did obtain an understanding of what engineering was like which made her excited about starting engineering in the fall:

> *It was really neat to see them [engineers] like you could actually see that they were the ones who created it [part designs] and they were the ones who made this and if they would like mess up or something then like something, like the part wouldn't be correctly made. Like it was cool to actually see how their work was put into place. And so, that encourage me to keep going on to engineering.*

She complained about having to be involved with all of the tedious tasks of standards and just wanted to "do something." When she spoke with Michael about this struggle and how she just wanted to "do" engineering, he informed her that she was doing the job of a first-year engineer. He explained how she had to do tasks that would help her understand the industry and design process before she would be trusted with more responsibility. Her grandfather additionally gave her similar advice. Over time, Sara began to see the value in her experience and became excited about engineering through her internship. She summed up her summer experiences by saying:

> *Going to [country with clean water program] definitely made me like start to [want to be an engineer] and also my class in high school with Michael that made me like just interested into it, and working like at the internship further continued it, and then actually just being in college and experiencing it makes me want to keep going.*

8.6 Pursuing Engineering in College

First Semester Fall 2013

The second interview with Sara took place near the end of her first semester in college (Fall 2013). Originally, Sara had talked about pursuing a degree in chemical engineering at a large, engineering-focused school. She ended up attending a small, private, religious school. When asked why she chose this school instead of the one she had discussed earlier, she described her competing interests. Sara wanted to continue her competitive swimming in college. However, she was unable to compete on the team at the large, engineering college. The school that she ended up choosing to attend offered her a full swimming scholarship that made it possible to swim while pursuing an engineering degree and be cost effective. Sara's competing interests in her extra-curricular activity and interest in engineering caused her to change her choice of college. She primarily chose the small college because she was able to swim, not because of financial reasons. Additionally, the small college that she did choose to attend did not have chemical engineering and had only a limited choice of engineering programs. Sara was willing to compromise her intended major and pursue a degree in geological engineering in order to pursue her competitive swimming.

This case illustrates how a student develops a variety of identities, not only school subject-related identities. While subject-related identities in math and physics do statistically predict a choice of engineering, the findings for the SEM does not capture individual experiences but rather the average effects for a broad population. Sara negotiated her identity as a swimmer in balance with her identity as a math and science person and a desire to be an engineer. This case illustrates how the constructs of CEA do predict of choice of engineering, but the quantitative measures do not richly capture the breadth of experiences of individuals. The idea of competing interests is discussed tangentially in Osborne, Simon, and Collins' work. The authors state that behavior "may be influenced by the fact that attitudes other than the ones under consideration may be more strongly held" (p. 1055) [52]. Sara's identity as a swimmer competed with her identity as an engineering student that led to a compromise in her choice of college.

Her choice to attend a different school than initially intended did significantly affect Sara's experiences in college. Because of the nature of the institution, she had to follow certain procedures of attending chapel twice a week, following a dress code, adhering to a curfew, and requesting to leave campus on the weekend. She did not expect to have limited freedom in college, but rather to have the opportunity to make her own choices. While she felt that she was getting a wonderful education and loved the opportunity to pursue swimming in college, she did make some sacrifices to balance her competing interests. She acknowledged that the stricter environment was "also probably good for me, just cause even though rules can get really annoying it does keep me on task, keeps me out of trouble, and stuff and whatnot." She struggled with following the rules early on, but over time, developed friendships and connections.

Since her college did not offer chemical engineering, Sara had to decide on a different engineering discipline. She chose geological engineering, which is a new major at her college because "I might as well try it out and see if I like it and I'm pretty much enjoying it." In her mind, geological engineering was the closest option to chemical engineering. This choice of major may not be as spontaneous as may initially appear. Sara spoke often of her experiences in the clean water program at her high school and how it affected her job choice. She saw geological engineering as a way to bridge her college choice and interest in using her high school experiences while attending a school that allowed her to swim:

> *I'm hoping to branch maybe off of geological engineering and kind of go into environmental, but I mean I'm not fully positive that that's what I want to do, but right now that's what my plan is. And just, maybe, maybe do something like with the water part of it cause of like going to [country] and all that stuff cause I really loved that. But, I'm not fully, completely positive yet, but that's kind of the plan.*

She viewed her major choice not as the most important decision for her career, but it meant choosing an engineering discipline that she liked and would allow her to make a difference.

Some of the themes seen in Sara's high school interview continued on into her first interview in college. She showed a sustained strong math identity, agency beliefs, and mastery orientation. Sara began taking calculus in college and, for the first time, struggled with math concepts. She spoke about "actually having to study." When asked about her identity as a "math person" she responded:

> *I've been really struggling [in] my calculus class. So, this year has been like a really big struggle for me in the math department which has been kind of like confusing because I have always, like math has always been my strong suite, and I'm like I'm not doing as well as I normally would, and then, it's not necessarily, and then I'm like trying and like studying hours upon hours for a test and stuff which I have never done in math ever because I never had to, but I mean I still think of myself as a like a math-based person it's just been a lot harder.*

Her description of struggling in math but still being a "math-based person" lends validity to the idea of studying identity constructs longitudinally. Even though her performance/competence in math has been challenged through her calculus course, her math identity remains relatively intact. These observations show how identity can be thought of as a quasi-trait which is more deeply held over time. Sara's role identity does not fluctuate substantially from moment to moment, but can still change over time.

When asked if she saw herself as an engineer, Sara responded that she was not "smart enough as [she] needs to be." Sara saw being an engineer as having the requisite knowledge to function like the engineers at her grandfather's company. While she was developing as an engineer, she did not yet see herself as an engineer. This discussion is consistent with conclusions drawn from the qualitative open-ended survey that students do not regularly feel recognized as engineers through traditional coursework, but through design and internship experiences where they function as engineers.

Sara continued to tie her engineering degree to her experiences with the clean water program, showing her strongly-held agency beliefs about her choice of an engineering career and specific coursework:

> *And so I think whenever I do that [take a water-related class in geological engineering] because I do know like some stuff from the past two years about just the purification process and whatnot and how water works and, so I think whenever I get to like those classes involving more of the like geological aspects that I think that it will be more like relevant or whatever.*

Seeing the connection between her coursework and her future career gave Sara the desire to continue in engineering even though college was harder than she anticipated. She continued to show her mastery orientation in the way she spoke about working to do well in all aspects of her degree process:

> *I've like realized that if you are struggling in something, you just can't stop and not do anything, if I want to succeed I'm going to have... like even, even if I am really good at a subject there's always going to be something I don't understand that someone else might understand, and so I mean there's nothing wrong with going to get help. Like there's... everyone struggles in parts of your major, I mean, like that's going to happen.*

She also found the strength to continue in engineering despite adversity, a strong example of grit:

> *Just cause I mean it's one of my goals in life [being an engineer]. It's something that I think I would enjoy to do, and I could just see myself doing it and so, like I guess, just because like I know that I can do it and like I'm not just gonna give up on it.*

The constructs and themes that cause Sara to be interested in engineering – her identity in math and science, agency beliefs, and mastery orientation – also contributed to her desire to stay in engineering. These themes of her narrative contribute to the holistic picture of how CEA can not only empower women to choose engineering, but also empower women to *stay* in engineering.

Second Semester Spring 2014

In her second semester of college, Sara seemed less sure of her current situation at her college. She ended up retaking her calculus class in the spring because she was not happy with her grades in the course. She also said that her professor had a big influence on her ability to understand the material:

> *I understand math really well, so I never have a problem. I just have to make sure that I get someone who can teach me in a way that I can best understand... Um, my other professor kind of assumed that we knew things and it's one of his first years teaching, so he still hasn't, I don't think fully learned, how to teach. So this professor, he's been teaching for like 20 years or something and he shows like step by step things like shows exactly how to do it, gives lots of help and like goes over homework, fully answers questions and stuff like that, so it's been really helpful.*

Sara ended up taking chemistry instead of physics in the spring semester. Even though her interest in chemistry initially sparked her desire to go into engineering, she said that her chemistry courses in college were not what she expected. The professor did not live up to her experiences in chemistry with Michael,

> *All the stuff, like I took chem and AP chem in high school and like a few weeks ago I learned stuff that I was learning like the first or second week of Chem I in high school, so like it's kind of hard to remember all the way back then and I do things harder than I mean to because I know more that what I'm supposed to, but I'm doing alright.*

She cited having more experience in chemistry as being frustrating her in current classes because she over-complicated the problems with her advanced understanding. The lack of rapport with her college professor also added to the disconnect between the subject material learned in class and her deep love and interest of the subject when she took it in high school.

In addition to math and chemistry, Sara took courses in engineering design and computer programming. Despite having trouble with engineering software in the past, Sara said that learning programming was more interesting than she expected and that she was doing better in the course than she expected. However, her engineering design course did not foster her interest in engineering. Instead, Sara viewed her engineering design course as a barrier to overcome in order to reach the more interesting and relevant engineering courses in her future:

> *I've heard that once I get past these introductory level classes they [upper level engineering courses] are a lot different and better. It's just kind of boring right now. Cause I think it's just the information and stuff. So, apparently it gets better (laughs)*

Despite the fact that she disliked her courses in engineering and thought that they were boring, Sara was still set on continuing in engineering. She did admit thinking about switching out of engineering, but dismissed that idea by focusing on the promise of future engineering classes that she was told "will get better, so I am kind of stressing that." The reasons that she cited for thinking about leaving were the difficulties that she had in learning the engineering design software that she was required to use as well as lack of interest in her engineering design courses (which seemed focused on mechanical and electrical engineering). Her focus on the other subjects that she enjoyed like geology and chemistry as well as her desire to do something with a career in engineering prevented her from seriously considering leaving. Additionally, the community that she had built with her swim team and her engineering professors and students helped create a bond with her school environment. She spoke about liking "the challenge" of engineering and how it "keeps me working to be better and study more and stay on top of things." Her grit and mastery orientation helped keep her on an engineering path despite the difficulties she encountered.

When Michael was asked about where he saw Sara in the next couple of years, he said that he did not expect her to continue her degree at the small engineering school in the next year, but that she would probably transfer to a different school and major in chemical engineering rather than geological engineering. He also said that he did not see her being an engineer in the "long-term." As she started her major-specific courses with all of the technical material, he expected her to be less interested in those areas. He saw her becoming a high school chemistry teacher. One of the reasons he gave was when she was taking a leadership role in the clean water program she would show students what she was saying rather than telling them what to do. While Sara did explore this option in high school, she rejected the idea, saying "I was worried about like money making, like I don't want to just be a teacher and stuff." Michael said that he could see her being an engineer, but that he had the feeling that she would end up in teaching eventually. In the future, continuing to follow her career will offer additional information on these speculations about her future.

While her decision to stay in engineering seemed firm, Sara's intentions to stay at her college were more tenuous. She said that she was "kind of 50/50 right now. I am not completely positive. I keep changing my mind to be honest. The chances are that I will probably stay here, but I don't fully know yet." She struggled with her desire to continue swimming and the deep friendships that she had made through that sport and her desire to experience a "real college environment." She spoke again about the possibility of switching to a large engineering university in her home state but was torn because she "wouldn't be able to swim, but then [the engineering university] would be a really good academic college, you know?" Sara had also developed close ties to her classmates and swim team in her first year. These relationships along with her strong CEA, mastery orientation and grit increased her desire to stay in engineering at her school.

When asked if she felt like an engineer, Sara said that she did not "know enough" to be an engineer. Her discussion of what it meant to be an engineer involved a threshold of knowledge that was important to the community. She said that compared to other "kids" who had experience in programming or Autocad design, she was just a "newbie." She defined being an engineer as having a specific amount of knowledge measurable by successful completion of certain coursework. While Sara did not feel like an engineer, she talked about her contributions to engineering group design projects. While she appreciated her group members' "different attributes coming together and things that are their strengths in different group projects," she felt that she specifically contributed to being "better at the whole drawing parts and stuff and just like conceptual things like being able to see the bigger picture of it." When asked to reflect on her future track for engineering, Sara did not have a clearer picture of what she wanted to accomplish. She just pictured herself working in industry, creating and designing things with her requisite engineering knowledge.

Sara reflected back on possible barriers to her choice of engineering and how she overcame some of the issues she saw as difficult for women in engineering. In her discussion, she kept coming back to the influence of her chemistry teacher, Michael, on her choices:

> *I think that if I never would have gotten into chemistry I wouldn't have gotten as close with my chemistry teacher and that wouldn't have happened I could have been on a totally different path. . . I mean he helped me like chemistry a lot and then just talking to him and then like well that and the influences of the clean water program I knew I wanted to do something with geology or helping people. And that and [Michael] helped connect those cause he like he has a degree in chemical engineering and I was going to go for that*

Sara's connection with her chemistry teacher and his ability to connect her experiences in the clean water program with her desire to help people and her enjoyment of chemistry was the single most important influence on Sara in her career. When asked about other influences like family or friends, having an engineer for a grandfather, money, or moving from a small town, Sara did acknowledge those as important to her, but no one else had the same impact on her as Michael did. She even spoke about how she felt different in his classes and was not like the other women who were not interested in engineering. His class structure fostered a crossing of the traditional barriers between student and teacher to a mentoring relationship. Sara captured this in her description:

> *I was able to grasp onto that aspect of learning and that style of learning and I just kind of thrived and what not. And, by doing that I had more time to get to*

know [Michael] better, and so I got to now more about him and engineering and he told me that he thought I would be good at it.

Michael's recognition of Sara as a student who "got it" and would be good at engineering set her on a path to pursue a degree in engineering. He not only gave her the recognition that she needed, but tied her desired outcome expectations to an engineering career. He has repeatedly been cited as the pivotal player in her career choice and empowerment.

In the process of conducting research, the influence of the researcher on a participant is an important aspect to consider. Did Sara's reflection on her engineering identity, choice, and progress affect those areas of her life? As a part of elucidating potential bias in the data as well as member checking, Sara was asked if the researcher or research has had an influence on her. Sara reflected by saying:

I mean like it's [the research] made me, I guess, realize why I am in this field and what I am doing and made me thing about if this is really what I want to do and just like different aspects – that you can do something but not realize things about why you are doing it, so there's that. It kind of made me question it to make sure that I fully want to do it? Am I going to be good at this? Is this what I am going to be interested and enjoy going to work? I guess is this I want to do?

She also said that while she questioned her choices, she felt that she was left with fewer questions in the end than more.

Discussion

The study of Sara is a compelling case because it illustrates how fostering specific self-beliefs and interactions can attract a women into engineering, even as late as the senior year of high school. While this is one particular case than may not be exactly representative of all students, it highlights one story of student success in the face of adversity. This story has implications for how engineering is represented as a discipline, what could make engineering attractive for women, and the struggles students face in the first year of engineering in college.

In this work, several different factors emerged as important for Sara's empowerment to change her course from potential dropping out after high school to choosing and remaining in engineering in college. CEA played an important role in Sara's engineering choice as a major. Her interest in engineering and her decision-making process were propelled by her interest in math and science, specifically chemistry in this case, as well as her desire to help people and make a difference in the world through her actions. Her chemistry teacher crossed boundaries from just being a high school teacher in the classroom setting to being a mentor, clean water project leader, and father figure in Sara's life. She credits him with connecting her newly fostered interest in chemistry with her desire to help people with a career in engineering. Not only did Michael give Sara counsel to find engineering, but he fostered her interest and recognized her as a student capable of achieving great things. In her life, Sara had not been recognized as a talented student interested in science, but Michael gave Sara that kind of recognition. It went beyond simple acknowledgement of being able to complete the work required for good grades. The recognition that Sara received involved connecting her out-of-class experiences in the clean water program with her classroom experiences and outcome expectations to tell her that she would "be good at it." Michael was a change agent for Sara to leverage her identities in math and chemistry with her agency beliefs about engineering into an empowered choice. While the measured constructs of math and science identities and agency beliefs were high for Sara on a quantitative scale, Michael tied together these constructs and helped Sara actualize these ideas into an engineering major choice.

Not only did Michael act as a change agent in Sara's life for empowerment by connecting her self-concept, he changed the positionality of his relationship in and out of the classroom. By changing the power structure of how his class was taught in a guided inquiry way, Michael became a guide in learning rather than the source of knowledge. He allowed students to participate in their knowledge acquisition and construction and broke down the typical power structures of a classroom. This difference is evidenced by how students address him, by his first name or even by nicknames, rather than "Mr." and his last name. The construction of this positionality within the classroom and the connections drawn across students lives can be viewed through the lens of hybrid spaces.

Drawing from hybridity theory which "posits that people in any given community draw on multiple resources or funds to make sense of the world" and that being "in-between several different funds of knowledge and Discourse can be productive and constraining in terms of one's literate, social, and cultural practices," Moje et. al [180] created the theory of third or hybrid spaces in education. The third space is a crossing of the boundaries between traditional school science and home or out-of-school experiences into a new hybrid space. Hybrid spaces build bridges between the ways they know the world and the ways others know the world. It also allows everyday resources to be integrated with disciplinary learning to construct new literacy practices, ones that merge the different aspects of knowledge and ways of knowing offered in a variety of different spaces. With the development of these literacies, which can be related to performance/competence constructs, students can begin to identify with disciplinary knowledge through their own experiences. These connections foster student interest in the knowledge as well. Research on hybrid spaces has shown these types of classroom environments foster hybrid identities and students' agency to enact knowledge for change within their communities [55, 118, 181].

Michael unconsciously created a hybrid space in his classroom through the integration of the clean water program and student autonomy in learning. His classroom prompted students to negotiate their own learning and relate their experiences outside of the classroom with canonical knowledge found in high school classroom environments. He also asked students to take their learned knowledge and apply it to big picture problems such as bringing fresh water to developing countries. The integration of the school, community, and curriculum with the clean water program in a small town in the Midwest made for a unique environment in which to study CEA. His unique role in Sara's life allowed him to guide her in her identity and agency beliefs development within this hybrid space as well as act as a role model for her empowerment and eventual choice of engineering. Sara plans to use engineering to make an impact in the world directly due to her experiences at her high school and within her chemistry classroom.

Similar to the findings of Chapter 7, other factors influenced Sara's plans to stay in engineering. The factors included competing interests, peripheral participation in a Community of Practice, her mastery orientation, and her grit. While Sara had a strong desire to choose engineering and the grit to persist in the program through her first year, her love of swimming dictated the type of school she attended. She created deep friendships with her swim team and valued the financial support that a swimming scholarship gave her at a small, private religious school. However, she also chafed against the numerous rules imposed on campus and felt that she was not having the college experience she expected to have. Additionally, she changed her intended major from chemical engineering to geological engineering based on the limited available programs at the school she attended. When understanding engineering choice, it is important to understand other factors that may pull students away from engineering or from their intended engineering plans. A strong physics and math identity as well as highly developed agency beliefs may empower the choice of engineering for women, but other interests may be stronger than those of engineering or compete with a traditional engineering choice. Sara compromised and found an option that let her pursue a degree in engineering while swimming in college.

Additionally, it is worth noting that Sara did not describe her first year as exciting or interesting. She saw her first year engineering and math courses as stepping stones to more interesting courses later in her major. Her lack of interest in many of the classes caused her to put less effort into these activities and decreased her motivation to continue in engineering. She did not have an identity as an engineer or engineering person from her first interactions with an engineering Community of Practice. This finding does not mean that engineering identity development can not occur in the first year of engineering courses, but illustrates that students must have legitimate participation within a Community of

Practice to come to identify with it. All of Sara's descriptions about her participation and recognition within her classes were devoid of true participation and only involved peripheral activities. The lack of a sense of belongingness adds to many students decisions to leave STEM [4]. Emphasizing projects in which students can feel like they are acting as engineers in the first year may be vitally important to retaining students in engineering. Projects that involve students' agency beliefs as a part of that participation may have even more impact for female students.

While Sara's identity and enjoyment of engineering in her first year did not immediately develop, she was determined to complete her degree in engineering. Despite many women leaving engineering, she was not one of the students planning on exiting her degree program. Sara's focus on the ultimate outcomes of her degree (helping people and providing clean water solutions) as well as her mastery orientation to learn everything contributed to her determination to finish. She showed grit to stick with her choice of engineering. While Michael voiced some doubts about whether she would complete her degree and in which field that degree would be, Sara seemed resolute in her original decisions.

Sara's case does illustrate how a student previously uninterested in STEM can become empowered to pursue a career in engineering through the mechanisms found in CEA. Future work to this study includes following Sara and other women through their trajectories in engineering in college to better understand how discipline-specific identities in science and math as well as agency beliefs influence their experiences in engineering. Additionally, more work into understanding how these self-beliefs morph into engineering self-beliefs over time can help educators and researchers find ways to not only attract but retain women in engineering.

Conclusion

This case study of Sara leaves us with unanswered questions. Although I believe that the case study approach is important, I also believe that a wide-scale yet richly descriptive picture of the beliefs and experiences of women in situations like Sara is critical. This is the story of how **one** woman's experiences shaped her decision of engineering. Sara's case illustrates the power of identities, agency beliefs, and the role of change agents in students' lives. It also shows that while many students are tracked into a STEM career as early as middle school and many girls lose interest in math and science early [9], high school is not too late for students to make engineering career decisions.

Furthermore, what might a science, math, or engineering class look like if we were to take into account our understandings about female empowerment in engineering? How might change the actors, the script, and the stage in STEM teaching and learning settings? The role of Michael in Sara's decision to choose engineering in college gives a powerful example of how hybrid spaces can be created in a high school settings to empower women in engineering. While this case is not generalizable to all students, it does give an example of interventions that might be transferable to other cases.

Chapter 9

Conclusions and Discussion

This chapter discusses the overall findings of this dissertation, their implications for high school and college educators, and possible directions for future research. There are three main outcomes of this research. The first is the development and validation of an explanatory structural equation model for Critical Engineering Agency (CEA). This model provides a framework and lens for educators and researchers to understand how students' self-beliefs influence engineering choice and how to interpret the relationship between their identities and other self-beliefs. The second outcome is a model to understand how gender influences students' CEA. Gender differences in student perceptions about math and physics identities and agency beliefs may provide researchers and educators an improved understanding of why gender gaps continue to persist in engineering. Finally, the transferable lessons from the qualitative studies add depth and explanatory power in understanding how CEA empowers women to choose and persist in engineering within specific contexts. These results provide a comprehensive picture of how this framework can be utilized in understanding student self-beliefs for engineering choice. The following sections provide a detailed outline of these outcomes and provide implications for researchers and educators.

9.1 Addressing the Research Questions

This work addresses several research questions centered around empowering women to choose and persist in engineering. Increasing the number of engineering graduates who enter the work force by improving the college persistence rate, from ∼40% to 50% can provide the one million new STEM graduates needed in the next decade. Increasing the number of women who choose and remain in engineering can provide the changes required to fill this gap [2]. Additionally, recruiting more underrepresented groups into engineering can begin to add new and innovative insights into engineering design solutions. Women who have become empowered and have developed their agency beliefs may be even more poised to add to this active improvisation of cutting edge engineering solutions.

The first three research questions were answered by the quantitative components conducted for this study. Supporting evidence and additional research questions were answered by the qualitative components of this dissertation.

Research Question 1: What are the relationships among students' identities in high school that predict the choice of engineering?

Physics and math identities have a mediated structure in the structural equation models in Chapter 5 (Figure 5.2). Performance/competence beliefs are a direct negative predictor of subject-related identity but, by being mediated by interest and recognition, there is a significant, positive path. Interest and recognition beliefs are important in predicting a subject-related identity. Recognition beliefs are the single strongest predictor of identity. Physics identity is stronger in predicting the choice of engineering than math identity, consistent with prior work that shows that physics identities are the strongest predictor of engineering persistence in comparison to chemistry, biology, or math identities [43].

Research Question 2: How do students' beliefs about how science and technology can impact the world predict a choice of engineering?

Students' agency beliefs are direct, significant, and positive predictors of the choice of an engineering major (Figure 5.2). These estimates are similar in magnitude to the estimates for physics and math identities predicting choice of engineering.

Research Question 3: Are these beliefs (identity and agency) different for men and women?

While physics and math identities are important for both male and female students in choosing engineering, they play a larger role for men than for women with estimated coefficients in the structural equation model for men almost twice as large as the estimates for women (Figure 5.3). Additionally, students' beliefs about how science and technology can impact the world (i.e. agency beliefs) are more important for women than for men. As discussed previously, coupled with the finding from Research Question 1, this has implications for how engineering is represented to potential students. Instead of marketing engineering simply as being for students good at math and science, the conversation needs to center around how an engineering career can impact the world. This finding is consistent with calls to "change the conversation" about engineering [182].

Research Question 4: How well does Critical Engineering Agency as an explanatory framework describe students' choice of engineering?

Critical Engineering Agency explains a large portion of the variance, 20.1%, in the choice of engineering (Chapter 5). Comprised of students' self-beliefs alone with no other background factors (e.g. prior experiences and performances) or other motivational constructs included, it has been shown that this theory can lend insight into how students' affective states are important in their career choices. As educators, there are many factors in students' lives we can not influence: socioeconomic status, race/ethnicity, gender, family support of STEM, familial engineers, etc. While these factors do influence students in their engineering choice, students' self-beliefs can be influenced both in the classroom and in the hybrid spaces that sit at the intersection of traditional pedagogical and external experiences (Chapter 7 and 8). By understanding how CEA plays into engineering choice for students, practical interventions can be designed to positive influence students' identities and agency beliefs which have a proven effect on engineering choice.

Research Question 5: How do women identify with physics and math?

Women identify with physics and math in different ways. Nearly all female engineering students in the open-ended surveys (Chapter 7) displayed stronger math identities than their physics identities. When describing how they felt like they were a "math person" or a "physics person," students talked about different subconstructs of identity (performance/competence beliefs, interest, and recognition beliefs). Students describe their math identities in terms of performance/competence beliefs and interest. When describing physics identities, students focus more on performance/competence beliefs while some spoke about connecting topics to everyday life. Interest was missing from students' narratives about physics identities. Conspicuously, recognition beliefs are missing from students' narratives about both math and physics identities. This finding is surprising given the results to Research Question 1 showing recognition beliefs as the most important component of identity. Since students' narratives are inherently self-focused and without direct questioning, recognition is often not explicitly discussed.

Research Question 6: What do women believe they can do with engineering/science as a career?

Women in engineering display strong agency beliefs. This finding in the qualitative work is consistent with the SEM that predicts the choice of engineering will be made at a higher rate for women with these beliefs. Students described their agency beliefs with varying degrees of depth and personal affiliation (Chapter 7). While almost all students described engineering as a way to benefit the world with specific examples when prompted, some women exhibited stronger agency beliefs even when unprompted. Agency also played a central role in Sara's decision to choose engineering in college so she could continue to make a positive change in the world (Chapter 8).

Research Question 7: What factors influence women's identities and agency beliefs?

Women cited a variety of reasons for forming their agency beliefs. Some of the most powerful examples were from women who saw engineering as a way to improves others' lives like it did their own (Chapter 7). One woman talked about her mother's health and how she chose biomedical engineering because her career could help other people like her mom. Another woman described how she wanted to improve living conditions for people in developing countries. These short accounts, along with Sara's story, show how personal experiences with transformative engineering examples can help develop these beliefs. These experiences typically involved students operating in hybrid spaces between their school learning and their home learning. Sara developed agency for choosing and improving engineering through her experiences with the clean water program at her school (Chapter 8). She saw that her individual contributions could make a difference in people's lives and wanted to continue that service in her career.

Identities were shown to be formed in ways that are consistent with the framework. Students mainly discussed interest and performance/competence beliefs when discussing their math and physics identities (Chapter 7). When describing the ways in which they felt like engineers, students most often described instances of recognition by peers or faculty. These experiences of recognition occurred when students felt they had legitimately participated in an engineering Community of Practice. Additionally, agential bridging, as described by Holland and colleagues [117], occurred between students' identities and their engineering Community of Practice.

9.2 Theoretical Implications

The Critical Engineering Agency framework has been successfully adapted from Critical Science Agency. Critical Engineering Agency is important for understanding students', especially women's, affective states and the process of choosing an engineering major. Women's retention in engineering is just as good or better than their male peers [3]. The metaphor of a leaky STEM pipeline with talented students being lost at every transition point has been used for years to describe attrition and underrepresentation in engineering. In the last decade, the pipeline in engineering at the college level seems to have been patched. However, the attraction of women into engineering is still a vital need. Critical Engineering Agency helps to explain how engineering can be made more attractive for women by helping them match their agency beliefs with an engineering future can begin to stem that loss. Additionally, while it is important to recognize that math and physics are important for engineers, realizing that too much of this messaging can turn off female students is also important for increasing the number of women in engineering.

Despite this emphasis on recruitment, attending to the retention of women is still vitally important for gaining new and talented engineering graduates. Their retention can be better encouraged through the intentional development of a sense of belongingness within engineering [34, 113, 175] rather than their agency beliefs. This identity development seems to occur through core involvement within an engineering Community of Practice. Additionally, many students describe the development of their agency beliefs as occurring in hybrid spaces that bridge their school environment and their community outside of school.

The concept of Figured Worlds focuses on understanding an individuals' practice of improvisation and innovation (e.g. agency, or students' abilities to make choices or changes) [183]. When studying CEA in situated contexts, people are actors who can author their identities in specific Figured Worlds. For example, Sara authored her identity and agency beliefs in a hybrid space of classroom experiences and her participation in her high school's clean water program. This development of her CEA was vitally important to her choice of engineering. However, becoming a part of an developing a sense of belonging within engineering after the decision to choose engineering in college is centered around becoming a part of a Community of Practice. This finding emerged from students' open-ended responses to how they felt like they were engineers. The practice and education of engineering students emphasizes professional training, and acquiring the specific knowledge, discourse, and expertise to be an engineer is central for students. Sara emphasized this point by saying that she did not feel like an engineer during her first year of coursework because she doesn't "know very much stuff yet" and is "not even close to as smart as I need to be."

9.3 Practical Implications

Through this study, some practical implications for educators at the secondary and post secondary levels have arisen. Additionally, some policies could be enacted at the university level to improve the recruitment of women into engineering. Finally, future work is highlighted by questions that are left unanswered by this work.

Students typically do not develop agency beliefs through traditional classroom pedagogy. Students need to interact within hybrid spaces that bridge their classroom knowledge of science and math with their community, home life, and out-of-class experiences. Additionally, while students within engineering begin to have more learning experiences that tie their classroom knowledge with their everyday experiences due to the nature of living and learning within an university or college community, they are missing the deep, participatory experiences within engineering Communities of Practice.

Allowing students to have authentic participatory experiences in engineering early on is crucial for developing this identity. Often, students do not have these design, internship, or “application of knowledge” experiences until late in college. By that time, many of the students who had tenuous ties to engineering may have already left the field [3, 4, 153]. By understanding how CEA functions in situated contexts, targeted interventions into engineering Communities of Practice can be developed.

Increasing the number of STEM graduates is important for the United States’ economic growth and success as well as the development of new and innovative engineering solutions in a global economy. Specific branding for recruitment into engineering that is especially helpful for women, and does not harm their male counterparts, has been found in this work. Focusing on engineering as a career and way to change the world can help people align engineering careers more with women’s outcome expectations. The SEM (Chapter 5) and large multinomial regression model predicting engineering choice (Chapter 6) show the need for developing this view of engineering.

9.4 Limitations and Recommendations for Further Research

This work draws data from a variety of sources to examine the full complexity of CEA and affect on women’s empowerment to choose engineering. However, both the quantitative and qualitative parts of this research have limitations due to the methodology and types of data collected. All analyses and claims have been filtered through these limitations.

In utilizing a cross-sectional survey design, the data gathered have some strengths: large statistical power, national representativeness in the sample, and the ability to test hypotheses surrounding events that were introduced to students naturally rather than through an intervention. This study design also has certain weaknesses, notably including the inability to draw causal conclusions. Rather, results are correlational in nature. The results do indicate significant correlations between students' responses and their choice of major, but further work is necessary to develop a causal understanding of these relationships. For example, in Chapter 6, students who indicated that they tinkered with things were more likely to choose engineering. Students may see tinkering with things as important in retrospect because of their interest in engineering as a major, or they may be led to choose engineering because of their prior enjoyment of tinkering. The SEM model allows for structured regression that does put some directionality to the relationships between math and physics identities, agency beliefs, and choice of engineering, but even this analysis can not fully establish causality.

To address causality issues, qualitative follow-up studies were conducted. The open-ended survey responses were often short and the data collection methodology did not allow for the researcher to probe the answers. Only 46 students responded to the survey which did not allow for the full breadth of student experiences to be cataloged. In the case study, a rich and detailed narrative did emerge, but it was from the perspective of two individuals on one students' empowerment and choice of engineering. While Sara's story is powerful, it is not necessarily representative of an entire population. Insights into how to create hybrid spaces to encourage interest in science and math and identity and agency beliefs development can empower female students to choose engineering may be gleaned from this work. The results may be transferable to other cases, but what worked in this narrative may not necessarily work for many other individuals. This point is illustrated by other female students in Sara's chemistry class that participated in the clean water program and had high math identities but did not choose engineering in college.

Finally, this work has a limited definition of diversity and gender. The construct of gender is not a binary male or female in how students identify themselves. Instead, it is a complex expression of one's identity. The survey and subsequent identification of students was based on a binary measure of biological sex (male or female) and not a more nuanced measure of gender expression. Additionally, while increasing the number of women in engineering is vital, all women are not the same and should not be treated as homogeneous. For example, the experiences of a black woman in engineering may be different than the experiences of a white or Hispanic woman in the same program. Future work in identity development and CEA should include an analysis of students at the intersections of race/ethnicity, gender, and sexual orientation. Considering inequalities along multiple dimensions of race, class, gender, sex, and sexual orientation, it has been shown that systems of oppression interlock and interweave and that not all people who fall within these intersections experience stigma and oppression the same way [184]. It has been noted that it is difficult for individuals to separate issues from what are traditionally considered (by others) to be two distinct aspects of their identity [185]. It is important to not only understand general trends of how women choose engineering, but the experiences of individuals. In Chapter 6, the large model built for engineering choice explained 42% of the outcome's variance, but much of the remaining 58% can be ascribed to the differences in individuals through their personal experiences and decisions. A deeper understanding that goes beyond the traditional definitions of gender is important future work precipitated by this study.

While CEA does explain a large portion of the variance in students' engineering choice (over one fifth), this theory solely using students' self-beliefs does not explain all of the factors that must influence students' choices. Engineering choice has been shown to be related to other background factors like family support for math and science, socioeconomic status, and academic preparation in Chapter 6. These factors are important for understanding how students choose engineering, however, the factors are difficult to change. Students' self-concepts can be influenced by the types of environments, pedagogy, and recognition in which they learn. Understanding CEA development over time within these situated contexts is an important aspect of CEA that has not yet been investigated. Most of the work in Critical Science Agency has occurred at the middle school level [30, 31, 118, 175] within science classrooms. To understand how engineering students develop CEA, future work needs to focus on how students' high school science and math identities and agency beliefs are affected by their engineering pedagogy and Communities of Practice.

Critical Engineering Agency as a framework is a useful affective lens for understanding engineering-related behaviors and choices. With the focus of engineering education being discussed by some educators and researchers as being equated with issues of equality, it is imperative to understand how students are developing a sense of identification with engineering both in high school and in college. This need is especially dire for students who have been traditionally marginalized. The development of the CEA model and application in mixed methods research adds to the current understanding how students, especially women, choose engineering between high school and college and begin to develop an engineering identity within a Community of Practice. Because of the complexity of students' engineering choice in college, many avenues of research can be expanded through this framework. As these areas of research grow, ways that educators and researchers can empower women to choose engineering can be explored. Through these efforts and future research, the issues of representation in engineering and the need for new STEM graduates can be addressed and meet the NSF's vision to "capitalize on the rich diversity of human resources by increasing the number of women, underrepresented minorities, and persons with disabilities who participate fully in engineering education, research, and practice" [73].

Appendices

Appendix A SaGE Survey

Clemson University

Engineering and Science Education

SaGE:

Sustainability and Gender in Engineering

Information Regarding Participation

We are interested in your experiences learning science. By filling out this questionnaire, you will help us find ways to improve science education for future students. Please make your best estimate for each item and answer as many questions as possible. There are no right or wrong answers; just do your best. Some questions will not apply to your experiences and can be left blank (e.g. questions about a course you have not taken). Please note:

- You must be 18 years or older to participate.
- The survey will take approximately 20 minutes to complete.
- Participation is voluntary. You may withdraw at any time.
- Participation will NOT impact your grade in this course in any way.
- You will be asked for contact information (email) in case we want to follow-up on some of your survey responses. This information is voluntary and will not be shared with any third party.
- If you have any questions or concerns, please contact Leidy Klotz (leidyk@clemson.edu), Geoff Potvin (gpotvin@clemson.edu), or Zahra Hazari (zahra@clemson.edu).
- You may contact the Clemson University Office of Research Compliance at 864-656-6460, toll-free at 866-297-3071, or irb@clemson.edu if you have any questions regarding your rights as research participants.

Enter your English course name/number on the line below.

Contact:
Leidy Klotz, Ph.D.

leidyk@clemson.edu

This project is funded by the National Science Foundation, grant number NSF 1036617.

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SECTION 1: YOUR CAREER GOALS

1. **How important are the following factors for your future career satisfaction?**

	Not at all important 0	1	2	3	Very important 4
Making money	○	○	○	○	○
Becoming well known	○	○	○	○	○
Helping others	○	○	○	○	○
Supervising others	○	○	○	○	○
Having job security and opportunity	○	○	○	○	○
Working with people	○	○	○	○	○
Inventing / designing things	○	○	○	○	○
Developing new knowledge and skills	○	○	○	○	○
Having lots of personal and family time	○	○	○	○	○
Having an easy job	○	○	○	○	○
Being in an exciting environment	○	○	○	○	○
Solving societal problems	○	○	○	○	○
Making use of my talents and abilities	○	○	○	○	○
Doing hands-on work	○	○	○	○	○
Applying math and science	○	○	○	○	○

2. **Which BEST describes what you want(ed) to be in middle school, high school, and college?** *(Mark only ONE choice per column)*

	Middle school	Beginning of high school	End of high school	In college
Medical professional (e.g. doctor, dentist, vet.)	○	○	○	○
Health professional (e.g. nursing, pharmacy)	○	○	○	○
Engineer	○	○	○	○
Environmental scientist	○	○	○	○
Chemist	○	○	○	○
Physicist	○	○	○	○
Biologist	○	○	○	○
Computer scientist/Information technologist	○	○	○	○
Social scientist (e.g. sociologist, anthropologist)	○	○	○	○
Other science-related career	○	○	○	○
Mathematician	○	○	○	○
Science/Math teacher	○	○	○	○
Other teacher	○	○	○	○
Other non-science related career	○	○	○	○

3. **Please rate the current likelihood of your choosing a career in the following:**

	Not at all likely 0	1	2	3	Extremely likely 4
Mathematics	○	○	○	○	○
Science/Math teacher	○	○	○	○	○
Environmental science	○	○	○	○	○
Biology	○	○	○	○	○
Physics	○	○	○	○	○
Chemistry	○	○	○	○	○
Bio-engineering	○	○	○	○	○
Chemical engineering	○	○	○	○	○
Materials engineering	○	○	○	○	○
Civil engineering	○	○	○	○	○
Industrial/Systems engineering	○	○	○	○	○
Mechanical engineering	○	○	○	○	○
Environmental engineering	○	○	○	○	○
Electrical/computer engineering	○	○	○	○	○

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4. **Which of these topics, if any, do you hope to directly address in your career?** *(Mark ALL that apply)*

- ◯ Energy (supply or demand)
- ◯ Disease
- ◯ Poverty and distribution of wealth and resources
- ◯ Climate change
- ◯ Terrorism and war
- ◯ Water supply (e.g. shortages, pollution)
- ◯ Food availability
- ◯ Opportunities for future generations
- ◯ Opportunities for women and/or minorities
- ◯ Environmental degradation

SECTION 2: YOUR HIGH SCHOOL EXPERIENCES

5. **What type of high school did you attend?** *(Mark ALL that apply)*

- ◯ Private
- ◯ Public
- ◯ Public charter
- ◯ Private religious
- ◯ Magnet school
- ◯ Vocational
- ◯ Baccalaureate
- ◯ Home-schooled
- ◯ All male or female
- ◯ Foreign high school

6. **How many students were in your high school biology, chemistry, and physics courses?** (If you took multiple courses in a subject, please answer questions in this survey based on the LAST version of the course you took.)

Biology:	◯ 1–10	◯ 11–20	◯ 20–30	◯ More than 30
Chemistry:	◯ 1–10	◯ 11–20	◯ 20–30	◯ More than 30
Physics:	◯ 1–10	◯ 11–20	◯ 20–30	◯ More than 30

7. **Please estimate the distribution of males and females in your last high school biology, chemistry, and physics courses.**

	All females	More females than males	About equal	More males than females	All males
Biology:	◯	◯	◯	◯	◯
Chemistry:	◯	◯	◯	◯	◯
Physics:	◯	◯	◯	◯	◯

8. **In terms of learning the material, these courses required:**

	Very little memorization 0	1	2	3	4 A lot of memorization
Biology:	◯	◯	◯	◯	◯
Chemistry:	◯	◯	◯	◯	◯
Physics:	◯	◯	◯	◯	◯

9. **In terms of learning the material, these courses required:**

	Very little conceptual understanding 0	1	2	3	4 A lot of conceptual understanding
Biology:	◯	◯	◯	◯	◯
Chemistry:	◯	◯	◯	◯	◯
Physics:	◯	◯	◯	◯	◯

10. **Please indicate whether you did the following as part of your last high school science courses.** *(Mark ALL that apply)*

	Biology	Chemistry	Physics
Used the internet for blogging, twitter, or other social media	◯	◯	◯
Watched science videos	◯	◯	◯
Went on field trips	◯	◯	◯
Participated in outdoor activities	◯	◯	◯
Participated in debates, games, or contests	◯	◯	◯
Kept an organized binder/notebook that the teacher checked periodically	◯	◯	◯
Used clickers or other automated response systems	◯	◯	◯
Completed online assignments	◯	◯	◯
Used computer simulations or applets	◯	◯	◯
Manipulated physical objects (e.g. used model kits)	◯	◯	◯
Spoke with female engineer/scientist visitors	◯	◯	◯
Spoke with male engineer/scientist visitors	◯	◯	◯

Please continue to the next page

11. Please indicate how often the following occurred in your LAST high school science courses.

		Never	Rarely	Monthly	Weekly	Daily
Biology	The teacher lectured to the class	○	○	○	○	○
	We spent time doing individual work in class	○	○	○	○	○
	Concepts/ideas were introduced before formulas/equations	○	○	○	○	○
	We spent time doing small group activities	○	○	○	○	○
	We worked on labs or projects	○	○	○	○	○
	Classmates taught each other	○	○	○	○	○
	Whole-class discussions were held	○	○	○	○	○
	The teacher did demonstrations	○	○	○	○	○
	Topics were relevant to my life (e.g. chemistry at home, physics of sports)	○	○	○	○	○
	You asked questions, answered questions, or made comments	○	○	○	○	○
	Other students asked questions, answered questions, or made comments	○	○	○	○	○
	Teacher called on students for responses (not voluntary)	○	○	○	○	○
Chemistry	The teacher lectured to the class	○	○	○	○	○
	We spent time doing individual work in class	○	○	○	○	○
	Concepts/ideas were introduced before formulas/equations	○	○	○	○	○
	We spent time doing small group activities	○	○	○	○	○
	We worked on labs or projects	○	○	○	○	○
	Classmates taught each other	○	○	○	○	○
	Whole-class discussions were held	○	○	○	○	○
	The teacher did demonstrations	○	○	○	○	○
	Topics were relevant to my life (e.g. chemistry at home, physics of sports)	○	○	○	○	○
	You asked questions, answered questions, or made comments	○	○	○	○	○
	Other students asked questions, answered questions, or made comments	○	○	○	○	○
	Teacher called on students for responses (not voluntary)	○	○	○	○	○
Physics	The teacher lectured to the class	○	○	○	○	○
	We spent time doing individual work in class	○	○	○	○	○
	Concepts/ideas were introduced before formulas/equations	○	○	○	○	○
	We spent time doing small group activities	○	○	○	○	○
	We worked on labs or projects	○	○	○	○	○
	Classmates taught each other	○	○	○	○	○
	Whole-class discussions were held	○	○	○	○	○
	The teacher did demonstrations	○	○	○	○	○
	Topics were relevant to my life (e.g. chemistry at home, physics of sports)	○	○	○	○	○
	You asked questions, answered questions, or made comments	○	○	○	○	○
	Other students asked questions, answered questions, or made comments	○	○	○	○	○
	Teacher called on students for responses (not voluntary)	○	○	○	○	○

12. Please indicate whether the following occurred in any projects or labs for these courses. *(Mark ALL that apply)*

	Biology	Chemistry	Physics
I picked the topic	○	○	○
I designed/built something	○	○	○
I orally presented my work to the class	○	○	○
It addressed a community and/or family issue	○	○	○
I integrated ideas and information from various sources	○	○	○

Please continue to the next page

13. **Please indicate whether the following topics were covered in your last high school courses.** *(Mark ALL that apply)*

	Biology	Chemistry	Physics	Other Course(s)
Energy supply (e.g. fossil fuels, nuclear, solar, wind)	○	○	○	○
Energy demand (e.g. in buildings, transportation)	○	○	○	○
Climate change	○	○	○	○
Terrorism & war	○	○	○	○
Water supply (e.g. shortages, pollution, conflict)	○	○	○	○
Population growth	○	○	○	○
Food availability	○	○	○	○
Disease	○	○	○	○
Poverty and distribution of wealth and resources	○	○	○	○
Sustainable development	○	○	○	○
Life cycle analysis	○	○	○	○
Biomimicry	○	○	○	○
Environmental degradation	○	○	○	○
Providing opportunities for future generations	○	○	○	○
Work of female engineers/scientists	○	○	○	○
Under-representation of females in engineering/science	○	○	○	○
Engineering careers, stages, or options	○	○	○	○
Benefits of becoming an engineer	○	○	○	○
Students' stories about engineering/science	○	○	○	○
Teachers'stories about their engineering/science experience	○	○	○	○

14. **How many MINUTES did you spend doing work outside of class each day, on average, for your last high school science courses?**

Biology:	○ 0	○ 5	○ 15	○ 30	○ 45	○ 60 or more
Chemistry:	○ 0	○ 5	○ 15	○ 30	○ 45	○ 60 or more
Physics:	○ 0	○ 5	○ 15	○ 30	○ 45	○ 60 or more

15. **Which, if any, of the following resources did you use during class in your LAST high school science courses?** *(Mark ALL that apply)*

	Biology	Chemistry	Physics
Computer	○	○	○
Graphing calculator	○	○	○
Project supplies/equipment	○	○	○
Non-textbook reading materials (e.g. newspapers, magazines)	○	○	○

16. **What types of questions were you required to answer in your last high school science courses?** *(Mark ALL that apply)*

	Biology	Chemistry	Physics
Required several steps of calculations	○	○	○
Required written explanations/essay responses	○	○	○
Required graphing	○	○	○
Required drawing or sketching	○	○	○
Involved data presented in tables	○	○	○
Involved data analysis	○	○	○
Required new insight and creativity	○	○	○
Had more than one correct response	○	○	○

17. **How interested were most students in the content/topics in your last high school science course?**

	Not at all interested 0	1	2	3	4 Very interested
Biology:	○	○	○	○	○
Chemistry:	○	○	○	○	○
Physics:	○	○	○	○	○

Please continue to the next page

18. How would you rate your LAST high school BIOLOGY teacher on the following characteristics?

	Low 0	1	2	3	4	5	High 6
Enthusiasm for biology	○	○	○	○	○	○	○
Treated all students with respect	○	○	○	○	○	○	○
Explained ideas clearly	○	○	○	○	○	○	○
Explained problems and answered questions in several different ways	○	○	○	○	○	○	○
Was able to organize lessons and classroom activities	○	○	○	○	○	○	○
Was able to handle discipline and manage the classroom	○	○	○	○	○	○	○
Was available to help students outside of class	○	○	○	○	○	○	○

19. How would you rate your LAST high school CHEMISTRY teacher on the following characteristics?

	Low 0	1	2	3	4	5	High 6
Enthusiasm for chemistry	○	○	○	○	○	○	○
Treated all students with respect	○	○	○	○	○	○	○
Explained ideas clearly	○	○	○	○	○	○	○
Explained problems and answered questions in several different ways	○	○	○	○	○	○	○
Was able to organize lessons and classroom activities	○	○	○	○	○	○	○
Was able to handle discipline and manage the classroom	○	○	○	○	○	○	○
Was available to help students outside of class	○	○	○	○	○	○	○

20. How would you rate your LAST high school PHYSICS teacher on the following characteristics?

	Low 0	1	2	3	4	5	High 6
Enthusiasm for physics	○	○	○	○	○	○	○
Treated all students with respect	○	○	○	○	○	○	○
Explained ideas clearly	○	○	○	○	○	○	○
Explained problems and answered questions in several different ways	○	○	○	○	○	○	○
Was able to organize lessons and classroom activities	○	○	○	○	○	○	○
Was able to handle discipline and manage the classroom	○	○	○	○	○	○	○
Was available to help students outside of class	○	○	○	○	○	○	○

21. How frequently have you done the following activities outside of formal courses?

	Never in my life	1–2 times	3–4 times	5–6 times	More than 6 times in my life
Participated in engineering/science clubs, camps, or competitions	○	○	○	○	○
Tinkered with things (e.g. motors, mechanical devices)	○	○	○	○	○
Built things (e.g. structures, houses)	○	○	○	○	○
Participated in other science/engineering hobbies	○	○	○	○	○
Read/watched science/engineering programs or literature	○	○	○	○	○
Read/watched science-fiction programs or literature	○	○	○	○	○
Presented or gave a poster on science/engineering content	○	○	○	○	○
Explained science/engineering topics to experts (e.g. professionals, teachers)	○	○	○	○	○
Explained science/engineering topics to non-experts (e.g. relatives, peers)	○	○	○	○	○

Please continue to the next page

SECTION 3: SUSTAINABILITY AND YOU

When answering the following question, consider that the term sustainability is defined as "meeting the needs of the present without compromising the ability of future generations to meet their needs."

22. To what extent do you disagree or agree with the following:

	Strongly disagree 0	1	2	3	Strongly agree 4
We can pursue sustainability without lowering our standard of living	○	○	○	○	○
Human ingenuity will ensure that we do not make the earth unlivable	○	○	○	○	○
I feel a responsibility to deal with environmental problems	○	○	○	○	○
Environmental problems make the future look hopeless	○	○	○	○	○
I can personally contribute to a sustainable future	○	○	○	○	○
Pursuit of sustainability will threaten jobs for people like me	○	○	○	○	○
Sustainable options typically cost more	○	○	○	○	○
Nothing I can do will make things better in other places on the planet	○	○	○	○	○
I have the knowledge to understand most sustainability issues	○	○	○	○	○
Climate change is caused by humans	○	○	○	○	○
I think of myself as part of nature, not separate from it	○	○	○	○	○
We should be taking stronger actions to address climate change	○	○	○	○	○

23. How likely are you to do the following:

	Not at all likely 0	1	2	3	Extremely likely 4
Put on more clothes rather than turn up the heat when I'm cold	○	○	○	○	○
Use less water when taking a shower or bath	○	○	○	○	○
Evaluate the necessity of things I buy	○	○	○	○	○
Consider the energy/carbon/ecological impact of my food choices	○	○	○	○	○
Reuse bottles for water, coffee, or other drinks	○	○	○	○	○
Choose public transportation, carpool, bicycle or walk as a means of transportation	○	○	○	○	○
Buy a product because it is environmentally friendly	○	○	○	○	○
Take sustainability related courses in my area of academic interest	○	○	○	○	○
Contribute time or money to an environmental group	○	○	○	○	○
Educate others about the importance of these or similar actions	○	○	○	○	○

SECTION 4: ABOUT YOU

24. To what extent do you disagree or agree with the following:

	Strongly disagree 0	1	2	3	Strongly agree 4
I prefer to focus on details and leave the big picture to others	○	○	○	○	○
I hope to gain general knowledge across multiple fields	○	○	○	○	○
I often learn from my classmates	○	○	○	○	○
I prefer to focus on the big picture and leave the details to others	○	○	○	○	○
I hope to develop my expertise in one specific field	○	○	○	○	○
I identify relationships between topics from different courses	○	○	○	○	○
I analyze projects broadly to find a solution that will have the greatest impact	○	○	○	○	○
I seek input from those with a different perspective from me	○	○	○	○	○
I seek feedback and suggestions for personal improvement	○	○	○	○	○
When problem solving, I focus on the relationships between issues	○	○	○	○	○
I live in the moment	○	○	○	○	○
I plan ahead	○	○	○	○	○
When problem solving, I optimize each part of a project to produce the best result	○	○	○	○	○

Please continue to the next page

25. Please rate your general interest in the following areas.

	Not at all interested 0	1	2	3	Very interested 4
Understanding natural phenomena	○	○	○	○	○
Understanding science in everyday life	○	○	○	○	○
Explaining things with facts	○	○	○	○	○
Telling others about science concepts	○	○	○	○	○
Making scientific observations	○	○	○	○	○

26. How confident are you in your ability to do the following:

	Not at all confident 0	1	2	3	Very confident 4
Design an experiment to answer a scientific question	○	○	○	○	○
Conduct an experiment on your own	○	○	○	○	○
Interpret experimental results	○	○	○	○	○
Write a lab report/scientific paper	○	○	○	○	○
Apply science knowledge to an assignment or test	○	○	○	○	○
Explain a science topic to someone else	○	○	○	○	○
Get good grades in science	○	○	○	○	○

27. To what extent do you disagree or agree with the following statements.

	PHYSICS					MATH				
	Strongly disagree 0	1	2	3	Strongly agree 4	Strongly disagree 0	1	2	3	Strongly agree 4
I see myself as a ______ person	○	○	○	○	○	○	○	○	○	○
My parents/relatives/friends see me as a ______ person	○	○	○	○	○	○	○	○	○	○
My _____teacher sees me as a _____ person	○	○	○	○	○	○	○	○	○	○
I am interested in learning more about this subject	○	○	○	○	○	○	○	○	○	○
I am confident that I can understand this subject in class	○	○	○	○	○	○	○	○	○	○
I am confident that I can understand this subject outside of class	○	○	○	○	○	○	○	○	○	○
I enjoy learning this subject	○	○	○	○	○	○	○	○	○	○
I can do well on exams in this subject	○	○	○	○	○	○	○	○	○	○
I understand concepts I have studied in this subject	○	○	○	○	○	○	○	○	○	○
Others ask me for help in this subject	○	○	○	○	○	○	○	○	○	○
I wish I didn't have to take this subject	○	○	○	○	○	○	○	○	○	○
This subject makes me nervous	○	○	○	○	○	○	○	○	○	○
I feel invisible in classes for this subject	○	○	○	○	○	○	○	○	○	○
I can overcome setbacks in this subject	○	○	○	○	○	○	○	○	○	○

28. In your opinion, to what extent are the following associated with the field of engineering?

	Not at all 0	1	2	3	Very much so 4
Creating economic growth	○	○	○	○	○
Preserving national security	○	○	○	○	○
Improving quality of life	○	○	○	○	○
Saving lives	○	○	○	○	○
Caring for communities	○	○	○	○	○
Protecting the environment	○	○	○	○	○
Including women as participants in the field	○	○	○	○	○
Including racial and ethnic minorities as participants in the field	○	○	○	○	○
Addressing societal concerns	○	○	○	○	○
Feeling a moral obligation to other people	○	○	○	○	○

Please continue to the next page

29. To what extent do you disagree or agree with the following:

	Strongly disagree 0	1	2	3	Strongly agree 4
Learning science will improve my career prospects	○	○	○	○	○
Science is helpful in my everyday life	○	○	○	○	○
Science has helped me see opportunities for positive change	○	○	○	○	○
Science has taught me how to take care of my health	○	○	○	○	○
Learning science has made me more critical in general	○	○	○	○	○
Science and technology make our lives healthier, easier and more comfortable	○	○	○	○	○
Technology is a solution to nearly all problems	○	○	○	○	○
I use technology more than my peers	○	○	○	○	○
Science and technology are the cause of most environmental problems	○	○	○	○	○
A country needs science and technology to become developed	○	○	○	○	○
The scientific method always leads to correct answers	○	○	○	○	○
Scientists are completely neutral and objective	○	○	○	○	○
Science and technology will provide greater opportunities for future generations	○	○	○	○	○
The benefits of new technologies greatly outweigh the risks	○	○	○	○	○
Science and technology are helping the poor	○	○	○	○	○
We should trust what scientists have to say	○	○	○	○	○
Scientific theories develop and change all the time	○	○	○	○	○

30. How many college credit hours did you complete before starting college (e.g. AP credits, IB, dual credit)?

○ 0 ○ 1–3 ○ 4–6 ○ 7–9 ○ 10–12 ○ 13–15 ○ >15

31. What was the highest level of education for your parents/guardians?

	Less than high school diploma	High school diploma/GED	Some college or associate/trade degree	Bachelor's degree	Master's degree or higher	Don't know
Male parent/guardian	○	○	○	○	○	○
Female parent/guardian	○	○	○	○	○	○

32. Are any members of your family employed in the following professions? *(Mark ALL that apply)*

	Mother/female guardian	Father/male guardian	Siblings	Other relative
Medical/health professional	○	○	○	○
Scientist	○	○	○	○
Engineer	○	○	○	○
Teacher	○	○	○	○
Other science, technology, or math related career	○	○	○	○
Non-science related career	○	○	○	○

33. Which of the following people have contributed to your selection of a career path? *(Mark ALL that apply)*

- ○ Mother/female guardian
- ○ Father/male guardian
- ○ Siblings
- ○ Other relative
- ○ Coach
- ○ Contact with someone in that major/career
- ○ School counselor
- ○ Math teacher
- ○ Biology teacher
- ○ Chemistry teacher
- ○ Physics teacher
- ○ Other teacher

34. Have you participated in Project Lead the Way?

○ Yes ○ No

Please continue to the next page ➡

35. Which of the following statements describes your family's interest in science and math? *(Mark ALL that apply)*

	Science	Math
This topic was a diversion or hobby	◯	◯
This topic was a way for me to have a better career	◯	◯
My family helped me with my schoolwork in this topic	◯	◯
My family arranged for tutoring in this topic	◯	◯
This topic was a series of courses that I had to pass	◯	◯
This topic was not a family interest	◯	◯

36. Which of the following math courses did you take in high school? *(Mark ALL that apply)*

◯ Algebra I
◯ Algebra II
◯ Geometry
◯ Integrated Math
◯ Pre-Calculus
◯ Non-AP Calculus
◯ AP Calculus AB
◯ AP Calculus BC
◯ Statistics
◯ Trigonometry/Analytical Geometry

37. For each of the following standardized tests, please indicate the highest score you earned on that test.

SAT: _____ Total _____ Math _____ Critical Reading _____ Writing ◯ Don't know ◯ Did not take

ACT: _____ Total _____ Math _____ English _____ Science Reasoning _____ Reading ◯ Don't know ◯ Did not take

38. Please answer the following for the high school courses you took. *Mark only ONE level, year, grade, and gender per row.*

HS course subject	Course level: Regular	Honors	AP	IB	Other advanced	Year taken HS	Final grade	Teacher gender
Physical Science	◯	◯	◯	◯	◯	8 9 10 11 12	A+ A A- B+ B B- C D F	M F
Environmental Science	◯	◯	◯	◯	◯	8 9 10 11 12	A+ A A- B+ B B- C D F	M F
Earth Science	◯	◯	◯	◯	◯	8 9 10 11 12	A+ A A- B+ B B- C D F	M F
1st Biology	◯	◯	◯	◯	◯	8 9 10 11 12	A+ A A- B+ B B- C D F	M F
2nd Biology	◯	◯	◯	◯	◯	9 10 11 12	A+ A A- B+ B B- C D F	M F
1st Chemistry	◯	◯	◯	◯	◯	9 10 11 12	A+ A A- B+ B B- C D F	M F
2nd Chemistry	◯	◯	◯	◯	◯	9 10 11 12	A+ A A- B+ B B- C D F	M F
1st Physics	◯	◯	◯	◯	◯	9 10 11 12	A+ A A- B+ B B- C D F	M F
2nd Physics	◯	◯	◯	◯	◯	9 10 11 12	A+ A A- B+ B B- C D F	M F
Math (most advanced)	◯	◯	◯	◯	◯	9 10 11 12	A+ A A- B+ B B- C D F	M F
English (most advanced)	◯	◯	◯	◯	◯	9 10 11 12	A+ A A- B+ B B- C D F	M F

39. For any AP exams you took, please indicate your test score.

	AP Test Score				
AP Calculus AB	1	2	3	4	5
AP Calculus BC	1	2	3	4	5
AP Biology	1	2	3	4	5
AP Chemistry	1	2	3	4	5
AP Physics B	1	2	3	4	5
AP Physics C	1	2	3	4	5
AP Environmental Science	1	2	3	4	5

Please continue to the next page

SECTION 5: DEMOGRAPHIC QUESTIONS

40. What is your gender? ◯ Female ◯ Male

41. With which racial group(s) do you identify? *(Mark ALL that apply)*

◯ African-American or Black
◯ South Asian (e.g. Indian, Pakistani, Bangladeshi, Sri Lankan, etc.)
◯ Other Asian
◯ American Indian or Alaskan Native
◯ Caucasian or White
◯ East Asian (e.g. Chinese, Korean, Japanese, etc.)
◯ Native Hawaiian or Pacific Islander
◯ Other ______________________

42. Please indicate if you are of Hispanic origin: ◯ Yes ◯ No

43. Which category best fits you and your parents' or guardians' background?

	Born in United States	
Me	◯ Yes	◯ No
Male Parent or Guardian	◯ Yes	◯ No
Female Parent or Guardian	◯ Yes	◯ No

44. Was English the primary spoken language in your household? ◯ Yes ◯ No

45. To help us estimate the size of the community you come from, please provide your home ZIP Code. ⟶

0	0	0	0	0
1	1	1	1	1
2	2	2	2	2
3	3	3	3	3
4	4	4	4	4
5	5	5	5	5
6	6	6	6	6
7	7	7	7	7
8	8	8	8	8
9	9	9	9	9

46. What year are you in college? ◯ 1st year ◯ 2nd year ◯ Other

47. We would like to contact the high school science teachers of some students participating in this survey (your teachers will not know your survey responses).
Please provide the following for your most advanced high school science courses:

Teacher's Name:

Biology	Chemistry

Physics	Math

Name of High School: ______________________________

City: ______________________ State: ______________

We may contact some students to ask follow-up questions. All communications will be confidential and your email will NOT be disclosed to any third party.

Your email address: ______________________________

Note: By completing this survey, you attest that you are 18 years of age or older and that you agree to participate in this research study.

You have reached the end of the survey.
Thank you for your time.
It is our goal that many science educators will benefit from the insights you have provided!

Appendix B R Code for all Quantitative Statistical Analyses

```
load("/home/agodwin/Dropbox/Work In Progress/SaGE Data Round 01 (
   Finalized May 10 2013).RData")
names(SaGE)
library(car)
library(psych)
library(sem)
library(polycor)
library(lavaan)

### Test construct of personal/societal agency
attach(SaGE)
Agency2 <- as.data.frame(cbind(Q29a, Q29b, Q29c, Q29d, Q29e, Q29f
   , Q29j, Q29m, Q29n))
detach(SaGE)
Agency2 <- na.omit(Agency2)
FactorAgency2 <- factanal(Agency2, 2, rotation="promax")
FactorAgency2


### Creating Identity Composites
Q27PhysRec=(SaGE$Q27Phys_b+SaGE$Q27Phys_c)/2
Q27PhysInt=(SaGE$Q27Phys_d+SaGE$Q27Phys_g)/2
Q27PhysCom=(SaGE$Q27Phys_e+SaGE$Q27Phys_f+SaGE$Q27Phys_h+SaGE$
   Q27Phys_i+SaGE$Q27Phys_j+SaGE$Q27Phys_n)/6
```

```
SaGE=cbind(SaGE, Q27PhysRec)
SaGE=cbind(SaGE, Q27PhysInt)
SaGE=cbind(SaGE, Q27PhysCom)

Q27MathRec=(SaGE$Q27Math_b+SaGE$Q27Math_c)/2
Q27MathInt=(SaGE$Q27Math_d+SaGE$Q27Math_g)/2
Q27MathCom=(SaGE$Q27Math_e+SaGE$Q27Math_f+SaGE$Q27Math_h+SaGE$
    Q27Math_i+SaGE$Q27Math_j+SaGE$Q27Math_n)/6

SaGE=cbind(SaGE, Q27MathRec)
SaGE=cbind(SaGE, Q27MathInt)
SaGE=cbind(SaGE, Q27MathCom)

Q35Sci_ar <- recode(SaGE$Q35Sci_a, "1=1; else=0")
Q35Sci_br <- recode(SaGE$Q35Sci_b, "1=1; else=0")
Q35Sci_cr <- recode(SaGE$Q35Sci_c, "1=1; else=0")
Q35Sci_dr <- recode(SaGE$Q35Sci_d, "1=1; else=0")
Q35Sci_er <- recode(SaGE$Q35Sci_e, "1=-1; else=0")
Q35Sci_fr <- recode(SaGE$Q35Sci_f, "1=-1; else=0")

Q25SciInt=(SaGE$Q25a+SaGE$Q25b+SaGE$Q25c+SaGE$Q25d+SaGE$Q25e)/5
Q26SciCom=(SaGE$Q26a+SaGE$Q26b+SaGE$Q26c+SaGE$Q26d+SaGE$Q26e+SaGE
    $Q26f+SaGE$Q26g)/7
Q35SciRec=(Q35Sci_ar+Q35Sci_br+Q35Sci_cr+Q35Sci_dr+Q35Sci_er+
    Q35Sci_fr)/6

SaGE=cbind(SaGE, Q25SciInt)
```

```
SaGE=cbind(SaGE, Q26SciCom)
SaGE=cbind(SaGE, Q35SciRec)

### Test construct of personal/societal agency
attach(SaGE)
Agency3 <- as.data.frame(cbind(Q29a, Q29b, Q29c, Q29d, Q29e, Q29f
    , Q29j, Q29m, Q29n))
detach(SaGE)
Agency3 <- na.omit(Agency3)
FactorAgency3 <- factanal(Agency3, 2, rotation="promax")
FactorAgency3

### Creating Agency Composites
Q29PerAg=(SaGE$Q29a+SaGE$Q29b+SaGE$Q29c+SaGE$Q29d+SaGE$Q29e)/5
Q29GlobAg=(SaGE$Q29f+SaGE$Q29j+SaGE$Q29m+SaGE$Q29n)/4
Q29NatureSci=(SaGE$Q29k+SaGE$Q29l+SaGE$Q29p)/3
Q29Tech=(SaGE$Q29g+SaGE$Q29h)/2

SaGE=cbind(SaGE, Q29PerAg)
SaGE=cbind(SaGE, Q29GlobAg)
SaGE=cbind(SaGE, Q29NatureSci)
SaGE=cbind(SaGE, Q29Tech)

### Controls
Q40_r <- recode(SaGE$Q40, "1=1;2=0")
Q31a_r <- recode(SaGE$Q31a, "1=1;2=2;3=3;4=4;5=5;6=NA")
Q31b_r <- recode(SaGE$Q31b, "1=1;2=2;3=3;4=4;5=5;6=NA")
```

```
###Create binary outcome of being and engineering (1) or a
    scientist (0)
temp1 <- recode(SaGE$Q3g, '4=1; else=0') + recode(SaGE$Q3h, '4=1;
     else=0') +
  recode(SaGE$Q3i, '4=1; else=0') + recode(SaGE$Q3j, '4=1; else=0
     ') +
  recode(SaGE$Q3k, '4=1; else=0') + recode(SaGE$Q3l, '4=1; else=0
     ') +
  recode(SaGE$Q3m, '4=1; else=0') + recode(SaGE$Q3n, '4=1; else=0
     ')
eng <- recode(temp1, '0=0; 1:8=1')
table(eng)

temp2 <- recode(SaGE$Q3d, '4=1; else=0') + recode(SaGE$Q3e, '4=1;
     else=0') + recode(SaGE$Q3f, '4=1; else=0')
sci <- recode(temp2, '0=0; 1:3=1')
table(sci)

###Assumption if said eng and others still counted as eng
compare <- c(1:6772)
compare[sci==1] <-0
compare[eng==1] <-1
compare[sci==0 & eng==0] <-NA
table(compare, useNA='always')
table(eng, sci)

### ABOVE analysis is not mutually exclusive
```

```r
rm(compare)
compare <- c(1:6772)
compare[sci==1] <-0
compare[eng==1] <-1
compare[sci==0 & eng==0] <-NA
compare[sci==1 & eng==1] <-NA
table(compare, useNA='always')
table(eng, sci)

####Regression with engineering scale
engsc <- pmax(SaGE$Q3g, SaGE$Q3h, SaGE$Q3i, SaGE$Q3j, SaGE$Q3k,
    SaGE$Q3l, SaGE$Q3m, SaGE$Q3n)
table(engsc, useNA='always')

#Including all "identity" pieces with gender interactions
summary(glm(engsc ~ Q40_r + Q31a_r + Q31b_r + Q27PhysRec +
    Q27PhysInt + Q27PhysCom + Q27PhysRec:Q40_r + Q27PhysInt:Q40_r
    + Q27PhysCom:Q40_r
            + Q27MathRec + Q27MathInt + Q27MathCom + Q27MathRec:
                Q40_r + Q27MathInt:Q40_r + Q27MathCom:Q40_r
            + Q25SciInt + Q25SciInt:Q40_r + Q26SciCom + Q26SciCom
                :Q40_r + Q35SciRec + Q35SciRec:Q40_r, data=SaGE,
                family=gaussian))

#Including just significant items with gender
summary(glm(engsc ~ Q40_r + Q27PhysRec + Q27PhysInt + Q27PhysInt:
    Q40_r + Q27MathRec + Q27MathInt + Q27MathCom + Q27MathInt:Q40_
    r + Q25SciInt + Q26SciCom, data=SaGE, family=gaussian))
```

```r
#without gender
summary(glm(engsc ~ Q27PhysInt + Q27PhysRec + Q27MathRec +
    Q27MathInt + Q27MathCom + Q25SciInt  + Q26SciCom, data=SaGE,
    family=gaussian))

#Only identity pieces that show significance with career goals
summary(glm(engsc ~ Q40_r + Q31a_r + Q27PhysInt + Q27PhysRec +
    Q27MathRec + Q27MathInt + Q27MathCom + Q25SciInt  + Q1b+Q1c+
    Q1f+Q1g+Q1o, data=SaGE, family=gaussian))

#New model choice of engineering with Q1 career goals
summary(glm(engsc ~ Q1a+Q1b+Q1c+Q1d+Q1e+Q1f+Q1g+Q1h+Q1i+Q1j+Q1k+
    Q1l+Q1m+Q1n+Q1o, data=SaGE, family=gaussian))

#Including only significant career goals
summary(glm(eng~Q1b+Q1c+Q1f+Q1g+Q1o, data=SaGE, family=gaussian))

#Only identity pieces that show significance with career goals
summary(glm(engsc ~ Q40_r + Q31a_r + Q27PhysInt + Q27PhysRec +
    Q27MathRec + Q27MathInt + Q27MathCom + Q25SciInt  + Q1b+Q1c+
    Q1f+Q1g+Q1o, data=SaGE, family=gaussian))

#Now add in agency items
summary(glm(engsc ~ Q40_r + Q31a_r + Q31b_r + Q27PhysInt +
    Q27PhysRec + Q27MathRec + Q27MathInt + Q27MathCom + Q25SciInt
     + Q1b+Q1c+Q1f+Q1g+Q1o + Q29PerAg + Q29GlobAg, data=SaGE,
    family=gaussian))
```

```
#Try sci scale
scisc <- pmax(SaGE$Q3d, SaGE$Q3e, SaGE$Q3f)

#create identity constructs
mathid <- (SaGE$Q27MathInt + SaGE$Q27MathCom + SaGE$Q27MathRec)/3
physid <- (SaGE$Q27PhysInt + SaGE$Q27PhysCom + SaGE$Q27PhysRec)/3
sciid <- (SaGE$Q25SciInt + SaGE$Q26SciCom + SaGE$Q35SciRec)/3

###Rerun models omitting career outomes
summary(lm(engsc ~ Q40_r + Q31a_r + Q31b_r + mathid + physid +
    sciid + Q29PerAg + Q29GlobAg, data=SaGE))
summary(lm(scisc ~ Q40_r + Q31a_r + Q31b_r + mathid + physid +
    sciid + Q29PerAg + Q29GlobAg, data=SaGE))

###Removing n/s items
summary(lm(engsc ~ Q40_r + Q31a_r + mathid + physid + sciid +
    Q29PerAg, data=SaGE))
summary(lm(scisc ~ Q40_r + physid + sciid + Q29PerAg + Q29GlobAg,
    data=SaGE))

###Find Beta coefficients
engmodel<-lm(engsc ~ SaGE$Q40_r + SaGE$Q31a_r + SaGE$Q31b_r +
    mathid + physid + sciid + Q29PerAg + Q29GlobAg)
lm.beta(engmodel)

scimodel<-lm(scisc ~ SaGE$Q40_r + SaGE$Q31a_r + SaGE$Q31b_r +
    mathid + physid + sciid + Q29PerAg + Q29GlobAg)
```

```
lm.beta(scimodel)

#Recode
SaGE$Q40_r <- recode(SaGE$Q40, "2=0;1=1")

SaGE$eng <- pmax(SaGE$Q3g, SaGE$Q3h, SaGE$Q3i, SaGE$Q3j, SaGE$Q3k
    , SaGE$Q3l, SaGE$Q3m, SaGE$Q3n)

SaGE$Q35Sci_ar <- recode(SaGE$Q35Sci_a, "1=1; else=0")
SaGE$Q35Sci_br <- recode(SaGE$Q35Sci_b, "1=1; else=0")
SaGE$Q35Sci_cr <- recode(SaGE$Q35Sci_c, "1=1; else=0")
SaGE$Q35Sci_dr <- recode(SaGE$Q35Sci_d, "1=1; else=0")
SaGE$Q35Sci_er <- recode(SaGE$Q35Sci_e, "1=-1; else=0")
SaGE$Q35Sci_fr <- recode(SaGE$Q35Sci_f, "1=-1; else=0")
SaGE$Q41a_r<-recode(SaGE$Q41a, "1=1; else=0")
SaGE$Q41b_r<-recode(SaGE$Q41b, "1=1; else=0")
SaGE$Q41c_r<-recode(SaGE$Q41c, "1=1; else=0")
SaGE$Q41d_r<-recode(SaGE$Q41d, "1=1; else=0")
SaGE$Q41e_r<-recode(SaGE$Q41e, "1=1; else=0")
SaGE$Q41f_r<-recode(SaGE$Q41f, "1=1; else=0")
SaGE$Q41g_r<-recode(SaGE$Q41g, "1=1; else=0")
SaGE$Q41h_r<-recode(SaGE$Q41h, "1=1; else=0")


#Pull data for just sem
attach(SaGE)
engmodel1<-as.data.frame(cbind(Q27Phys_d, Q27Phys_g, Q27Phys_b,
    Q27Phys_c, Q27Phys_e, Q27Phys_f, Q27Phys_h, Q27Phys_i, Q27Phys
```

```
_j, Q27Phys_n, Q27Phys_a, Q27Math_d, Q27Math_g, Q27Math_a,
   Q27Math_b, Q27Math_c, Q27Math_e, Q27Math_f, Q27Math_h, Q27Math
   _i, Q27Math_j, Q27Math_n, Q25a, Q25b, Q25c, Q25d, Q25e, Q26a,
   Q26b, Q26c, Q26d, Q26e, Q26f, Q26g, Q29a, Q29b, Q29c, Q29d,
   Q29e, Q29f, Q29j, Q29m, Q29n, eng, Q40_r, Q31a, Q31b, Q41a_r,
   Q41b_r, Q41c_r, Q41d_r, Q41e_r, Q41f_r, Q41g_r))

attach(engmodel1)
names(engmodel1)
table(engmodel1$eng, useNA='always')

#MI for missingness
library(Amelia)
a.out <- amelia(engmodel1, m = 1)
summary(a.out)
imputeddata <- a.out$imputations[[1]]
naimputed <- na.omit(imputeddata)
save(naimputed, file = "/home/agodwin/Dropbox/Work In Progress/
   SEM/imputations.RData")

EngID.modelf <- '
#build latent variables
Pinterest =~ Q27Phys_d + Q27Phys_g
Precognition =~ Q27Phys_b + Q27Phys_c
Pcompetence =~ Q27Phys_e + Q27Phys_f + Q27Phys_h + Q27Phys_i +
   Q27Phys_j + Q27Phys_n
physid =~ Q27Phys_a
Minterest =~ Q27Math_d + Q27Math_g
```

```
Mrecognition =~ Q27Math_b + Q27Math_c
Mcompetence =~ Q27Math_e + Q27Math_f + Q27Math_h + Q27Math_i +
    Q27Math_j + Q27Math_n
mathid =~ Q27Math_a
AB =~ Q29a + Q29b + Q29c + Q29d + Q29e

#Latent variable regressions
Pinterest + Precognition ~ Pcompetence
physid ~ Pinterest + Precognition + Pcompetence
Minterest + Mrecognition ~ Mcompetence
mathid ~ Minterest + Mrecognition + Mcompetence

#Regressions
eng ~ mathid + physid + AB

#Covariances
physid ~~ mathid
Pinterest ~~ Precognition
Minterest ~~ Mrecognition
'


fitengf <- sem(EngID.modelf, data=naimputed, std.lv=TRUE,
    estimator="MLM")
summary(fitengf, fit.measures=TRUE, standardized=TRUE)
fitMeasures(fitengf, fit.measures="all")
inspect(fitengf, what="r2")
modindices(fitengf)
```

```
#gender testing looking for mod indices > 3.841
fitgender <- sem(EngID.modelf, data=engmodel1, std.lv=TRUE,
    missing="fiml", group="Q40_r")
summary(fitgender)
fitMeasures(fitgender)
fitgender2 <- sem(EngID.modelf, data=engmodel1, std.lv=TRUE,
    missing="fiml", group="Q40_r", group.equal="loadings")
summary(fitgender2)
mi <- modindices(fitgender2)
mi[mi$op=="=~",]
fitgender3 <- sem(EngID.modelf, data=engmodel1, std.lv=TRUE,
    missing="fiml", group="Q40_r", group.equal="loadings", group.
    partial=c("physid =~ Q27Phys_a", "mathid =~ Q27Math_a", "
    Mcompetence =~ Q27Math_n"))
summary(fitgender3)
fitgender4 <- sem(EngID.modelf, data=engmodel1, std.lv=TRUE,
    missing="fiml", group="Q40_r", group.equal=c("loadings","
    regressions"), group.partial=c("physid =~ Q27Phys_a", "mathid
    =~ Q27Math_a", "Mcompetence =~ Q27Math_n"))
summary(fitgender4)
mi2<-modindices(fitgender4)
mi2[mi2$op=="~",]
fitgender5 <- sem(EngID.modelf, data=engmodel1, std.lv=TRUE,
    missing="fiml", test="satorra.bentler", group="Q40_r", group.
    equal=c("loadings","regressions","lv.covariances"), group.
    partial=c("physid =~ Q27Phys_a", "mathid =~ Q27Math_a", "
    Mcompetence =~ Q27Math_n", "eng ~ physid", "eng ~ mathid", "
```

```
    eng~AB"))
summary(fitgender5, fit.measures=TRUE, standardized=TRUE)
inspect(fitgender5, what="r2")
mi3<-modindices(fitgender5)
mi3[mi3$op=="~~",]
measurementInvariance(EngID.modelf, data=engmodel1, group="Q40_r"
    )
#All covariances are not significantly different therefor the
    fitgender5 gives the correct model
```

R output for final model for all students

```
lavaan (0.5-13) converged normally after  56 iterations

  Number of observations                          6772

  Estimator                                         ML      Robust
  Minimum Function Test Statistic            12506.057   10062.808
  Degrees of freedom                               331         331
  P-value (Chi-square)                           0.000       0.000
  Scaling correction factor                                  1.243
    for the Satorra-Bentler correction

Model test baseline model:

  Minimum Function Test Statistic           192685.724  181464.885
  Degrees of freedom                               378         378
  P-value                                        0.000       0.000

Full model versus baseline model:

  Comparative Fit Index (CFI)                    0.937       0.946
  Tucker-Lewis Index (TLI)                       0.928       0.939

Loglikelihood and Information Criteria:

  Loglikelihood user model (H0)             -237505.132  -237505.132
  Loglikelihood unrestricted model (H1)     -231252.103  -231252.103

  Number of free parameters                        103         103
  Akaike (AIC)                              475216.263  475216.263
  Bayesian (BIC)                            475918.780  475918.780
  Sample-size adjusted Bayesian (BIC)       475591.471  475591.471

Root Mean Square Error of Approximation:

  RMSEA                                          0.074       0.066
  90 Percent Confidence Interval          0.073  0.075       0.065  0.067
  P-value RMSEA <= 0.05                          0.000       0.000

Standardized Root Mean Square Residual:

  SRMR                                           0.036       0.036

Parameter estimates:

  Information                                 Expected
  Standard Errors                           Robust.sem

                   Estimate  Std.err  Z-value  P(>|z|)   Std.lv  Std.all
Latent variables:
  Pinterest =~
    Q27Phys_d         0.517    0.013   39.206    0.000    1.253    0.872
    Q27Phys_g         0.524    0.013   39.022    0.000    1.269    0.909
  Precognition =~
    Q27Phys_b         0.705    0.011   64.792    0.000    1.196    0.898
    Q27Phys_c         0.705    0.011   65.837    0.000    1.196    0.896
```

```
  Pcompetence =~
    Q27Phys_e         1.247    0.011  116.100    0.000    1.247    0.888
    Q27Phys_f         1.223    0.011  112.238    0.000    1.223    0.877
    Q27Phys_h         1.248    0.010  120.656    0.000    1.248    0.906
    Q27Phys_i         1.263    0.010  123.331    0.000    1.263    0.914
    Q27Phys_j         1.085    0.013   84.653    0.000    1.085    0.777
    Q27Phys_n         0.944    0.014   68.237    0.000    0.944    0.704
  physid =~
    Q27Phys_a         0.559    0.010   58.659    0.000    1.331    1.000
  Minterest =~
    Q27Math_d         0.590    0.013   44.249    0.000    1.263    0.869
    Q27Math_g         0.616    0.014   44.239    0.000    1.317    0.908
  Mrecognition =~
    Q27Math_b         0.751    0.012   60.690    0.000    1.388    0.924
    Q27Math_c         0.695    0.012   60.430    0.000    1.285    0.899
  Mcompetence =~
    Q27Math_e         1.229    0.011  115.843    0.000    1.229    0.900
    Q27Math_f         1.231    0.011  116.185    0.000    1.231    0.881
    Q27Math_h         1.204    0.010  116.815    0.000    1.204    0.900
    Q27Math_i         1.208    0.010  115.863    0.000    1.208    0.907
    Q27Math_j         1.168    0.012   94.597    0.000    1.168    0.809
    Q27Math_n         0.900    0.014   65.057    0.000    0.900    0.701
  mathid =~
    Q27Math_a         0.590    0.010   58.699    0.000    1.481    1.000
  AB =~
    Q29a              1.075    0.012   91.800    0.000    1.075    0.813
    Q29b              1.078    0.011  100.795    0.000    1.078    0.893
    Q29c              1.106    0.010  108.367    0.000    1.106    0.918
    Q29d              0.926    0.012   74.518    0.000    0.926    0.787
    Q29e              0.971    0.012   83.376    0.000    0.971    0.806

Regressions:
  Pinterest ~
    Pcompetence       2.207    0.066   33.517    0.000    0.911    0.911
  Precognition ~
    Pcompetence       1.370    0.029   46.475    0.000    0.808    0.808
  physid ~
    Pinterest         0.360    0.024   15.284    0.000    0.366    0.366
    Precognition      1.008    0.033   30.353    0.000    0.718    0.718
    Pcompetence      -0.373    0.057   -6.525    0.000   -0.157   -0.157
  Minterest ~
    Mcompetence       1.890    0.052   36.393    0.000    0.884    0.884
  Mrecognition ~
    Mcompetence       1.554    0.034   45.387    0.000    0.841    0.841
  mathid ~
    Minterest         0.332    0.024   13.896    0.000    0.283    0.283
    Mrecognition      1.008    0.034   29.401    0.000    0.742    0.742
    Mcompetence      -0.213    0.054   -3.912    0.000   -0.085   -0.085
  eng ~
    mathid            0.072    0.007    9.850    0.000    0.181    0.123
    physid            0.164    0.008   19.514    0.000    0.391    0.267
    AB                0.279    0.017   16.169    0.000    0.279    0.190

Covariances:
  physid ~~
    mathid            0.188    0.020    9.582    0.000    0.188    0.188
```

Intercepts:

Q27Phys_d	1.556	0.017	89.177	0.000	1.556	1.083
Q27Phys_g	1.566	0.017	92.419	0.000	1.566	1.122
Q27Phys_b	1.233	0.016	75.523	0.000	1.233	0.925
Q27Phys_c	1.326	0.016	81.052	0.000	1.326	0.993
Q27Phys_e	1.845	0.017	108.129	0.000	1.845	1.314
Q27Phys_f	1.660	0.017	97.972	0.000	1.660	1.191
Q27Phys_h	1.759	0.017	104.991	0.000	1.759	1.276
Q27Phys_i	1.757	0.017	104.625	0.000	1.757	1.271
Q27Phys_j	1.417	0.017	83.525	0.000	1.417	1.015
Q27Phys_n	1.938	0.016	118.852	0.000	1.938	1.444
Q27Phys_a	1.278	0.016	78.578	0.000	1.278	0.960
Q27Math_d	1.912	0.018	109.162	0.000	1.912	1.316
Q27Math_g	1.951	0.017	111.782	0.000	1.951	1.346
Q27Math_b	1.962	0.018	107.392	0.000	1.962	1.307
Q27Math_c	1.879	0.017	108.017	0.000	1.879	1.314
Q27Math_e	2.338	0.017	140.792	0.000	2.338	1.711
Q27Math_f	2.144	0.017	126.278	0.000	2.144	1.535
Q27Math_h	2.256	0.016	138.807	0.000	2.256	1.687
Q27Math_i	2.295	0.016	141.819	0.000	2.295	1.723
Q27Math_j	2.065	0.018	117.693	0.000	2.065	1.430
Q27Math_n	2.314	0.016	148.250	0.000	2.314	1.802
Q27Math_a	1.896	0.018	105.488	0.000	1.896	1.280
Q29a	2.407	0.016	149.492	0.000	2.407	1.819
Q29b	2.336	0.015	158.967	0.000	2.336	1.935
Q29c	2.276	0.015	155.084	0.000	2.276	1.888
Q29d	2.452	0.014	171.259	0.000	2.452	2.084
Q29e	2.234	0.015	152.419	0.000	2.234	1.854
eng	1.247	0.018	69.781	0.000	1.247	0.849
Pinterest	0.000				0.000	0.000
Precognition	0.000				0.000	0.000
Pcompetence	0.000				0.000	0.000
physid	0.000				0.000	0.000
Minterest	0.000				0.000	0.000
Mrecognition	0.000				0.000	0.000
Mcompetence	0.000				0.000	0.000
mathid	0.000				0.000	0.000
AB	0.000				0.000	0.000

Variances:

Q27Phys_d	0.496	0.014			0.496	0.240
Q27Phys_g	0.340	0.011			0.340	0.174
Q27Phys_b	0.344	0.013			0.344	0.194
Q27Phys_c	0.353	0.013			0.353	0.198
Q27Phys_e	0.417	0.011			0.417	0.211
Q27Phys_f	0.447	0.012			0.447	0.230
Q27Phys_h	0.341	0.010			0.341	0.180
Q27Phys_i	0.314	0.010			0.314	0.165
Q27Phys_j	0.773	0.019			0.773	0.397
Q27Phys_n	0.909	0.020			0.909	0.505
Q27Phys_a	0.000				0.000	0.000
Q27Math_d	0.517	0.016			0.517	0.245
Q27Math_g	0.367	0.013			0.367	0.175
Q27Math_b	0.329	0.013			0.329	0.146
Q27Math_c	0.394	0.013			0.394	0.193

```
    Q27Math_e          0.356    0.010                          0.356    0.190
    Q27Math_f          0.437    0.012                          0.437    0.224
    Q27Math_h          0.339    0.010                          0.339    0.190
    Q27Math_i          0.314    0.009                          0.314    0.177
    Q27Math_j          0.720    0.019                          0.720    0.345
    Q27Math_n          0.839    0.020                          0.839    0.509
    Q27Math_a          0.000                                   0.000    0.000
    Q29a               0.595    0.015                          0.595    0.340
    Q29b               0.295    0.010                          0.295    0.202
    Q29c               0.229    0.008                          0.229    0.158
    Q29d               0.527    0.012                          0.527    0.380
    Q29e               0.508    0.013                          0.508    0.350
    eng                1.741    0.026                          1.741    0.808
    Pinterest          1.000                                   0.170    0.170
    Precognition       1.000                                   0.348    0.348
    Pcompetence        1.000                                   1.000    1.000
    physid             1.000                                   0.176    0.176
    Minterest          1.000                                   0.219    0.219
    Mrecognition       1.000                                   0.293    0.293
    Mcompetence        1.000                                   1.000    1.000
    mathid             1.000                                   0.159    0.159
    AB                 1.000                                   1.000    1.000

                   fmin                           chisq
df                             pvalue
                        0.923                       12506.057
331.000                        0.000
                 chisq.scaled                       df.scaled
pvalue.scaled          chisq.scaling.factor
                    10062.808                         331.000
0.000                        1.243
               baseline.chisq                     baseline.df
baseline.pvalue         baseline.chisq.scaled
                   192685.724                         378.000
0.000                   181464.885
           baseline.df.scaled        baseline.pvalue.scaled
baseline.chisq.scaling.factor                             cfi
                      378.000                           0.000
1.062                        0.937
                          tli                            nnfi
rfi                          nfi
                        0.928                           0.928
0.926                        0.935
                         pnfi                             ifi
rni                    cfi.scaled
                        0.819                           0.937
0.937                        0.946
                   tli.scaled                     nnfi.scaled
rfi.scaled                   nfi.scaled
                        0.939                           0.939
0.937                        0.945
                   ifi.scaled                      rni.scaled
logl                unrestricted.logl
                        0.945                           0.949
-237505.132                  -231252.103
```

```
                         npar                          aic 
bic                        ntotal 
                      103.000                   475216.263 
475918.780                   6772.000 
                         bic2                        rmsea 
rmsea.ci.lower                rmsea.ci.upper 
                   475591.471                        0.074 
0.073                         0.075 
                 rmsea.pvalue                 rmsea.scaled 
rmsea.ci.lower.scaled         rmsea.ci.upper.scaled 
                        0.000                        0.066 
0.065                         0.067 
          rmsea.pvalue.scaled                          rmr 
rmr_nomean                           srmr 
                        0.000                        0.066 
0.069                         0.036 
                  srmr_nomean                        cn_05 
cn_01                           gfi 
                        0.037                      203.751 
214.230                         0.919 
                         agfi                         pgfi 
mfi                           ecvi 
                        0.894                        0.701 
0.407                            NA 
```

R output for gender comparison model

```
lavaan (0.5-13) converged normally after  60 iterations

                                                  Used       Total
  Number of observations per group
  0                                               1283        2523
  1                                               1536        3041

  Estimator                                         ML      Robust
  Minimum Function Test Statistic             5857.105    4389.716
  Degrees of freedom                               705         705
  P-value (Chi-square)                           0.000       0.000
  Scaling correction factor                                  1.334
    for the Satorra-Bentler correction

Chi-square for each group:

  0                                           2734.041    2049.078
  1                                           3123.064    2340.638

Model test baseline model:

  Minimum Function Test Statistic            84569.654   80420.050
  Degrees of freedom                               756         756
  P-value                                        0.000       0.000

Full model versus baseline model:

  Comparative Fit Index (CFI)                    0.939       0.954
  Tucker-Lewis Index (TLI)                       0.934       0.950

Loglikelihood and Information Criteria:

  Loglikelihood user model (H0)             -95841.337  -95841.337
  Loglikelihood unrestricted model (H1)     -92912.785  -92912.785

  Number of free parameters                        163         163
  Akaike (AIC)                              192008.674  192008.674
  Bayesian (BIC)                            192977.569  192977.569
  Sample-size adjusted Bayesian (BIC)       192459.662  192459.662

Root Mean Square Error of Approximation:

  RMSEA                                          0.072       0.061
  90 Percent Confidence Interval          0.070  0.074       0.059  0.062
  P-value RMSEA <= 0.05                          0.000       0.000

Standardized Root Mean Square Residual:

  SRMR                                           0.054       0.054

Parameter estimates:

  Information                                 Expected
  Standard Errors                             Standard
```

```
Group 1 [0]:

                   Estimate  Std.err  Z-value  P(>|z|)   Std.lv  Std.all
Latent variables:
  Pinterest =~
    Q27Phys_d         0.526    0.014   37.408    0.000    1.219    0.865
    Q27Phys_g         0.539    0.014   37.950    0.000    1.249    0.908
  Precognition =~
    Q27Phys_b         0.658    0.014   48.142    0.000    1.137    0.885
    Q27Phys_c         0.665    0.014   47.976    0.000    1.150    0.892
  Pcompetence =~
    Q27Phys_e         1.229    0.020   61.842    0.000    1.229    0.897
    Q27Phys_f         1.189    0.020   59.769    0.000    1.189    0.878
    Q27Phys_h         1.215    0.020   62.249    0.000    1.215    0.910
    Q27Phys_i         1.236    0.019   63.955    0.000    1.236    0.923
    Q27Phys_j         1.057    0.021   49.557    0.000    1.057    0.766
    Q27Phys_n         0.935    0.021   43.468    0.000    0.935    0.733
  physid =~
    Q27Phys_a         0.554    0.012   46.162    0.000    1.340    1.000
  Minterest =~
    Q27Math_d         0.599    0.015   40.927    0.000    1.278    0.882
    Q27Math_g         0.629    0.015   41.566    0.000    1.343    0.911
  Mrecognition =~
    Q27Math_b         0.718    0.015   48.437    0.000    1.388    0.913
    Q27Math_c         0.670    0.014   47.809    0.000    1.297    0.900
  Mcompetence =~
    Q27Math_e         1.275    0.020   63.191    0.000    1.275    0.909
    Q27Math_f         1.240    0.021   60.458    0.000    1.240    0.884
    Q27Math_h         1.246    0.020   62.955    0.000    1.246    0.918
    Q27Math_i         1.234    0.019   63.457    0.000    1.234    0.918
    Q27Math_j         1.196    0.022   53.326    0.000    1.196    0.822
    Q27Math_n         1.009    0.028   36.583    0.000    1.009    0.771
  mathid =~
    Q27Math_a         0.585    0.012   48.287    0.000    1.501    1.000
  AB =~
    Q29a              1.102    0.021   53.607    0.000    1.102    0.833
    Q29b              1.105    0.018   61.316    0.000    1.105    0.904
    Q29c              1.119    0.017   64.116    0.000    1.119    0.919
    Q29d              0.917    0.019   49.522    0.000    0.917    0.789
    Q29e              0.976    0.019   51.413    0.000    0.976    0.806

Regressions:
  Pinterest ~
    Pcompetence       2.089    0.066   31.490    0.000    0.902    0.902
  Precognition ~
    Pcompetence       1.410    0.041   34.548    0.000    0.816    0.816
  physid ~
    Pinterest         0.398    0.033   12.174    0.000    0.381    0.381
    Precognition      0.986    0.040   24.937    0.000    0.705    0.705
    Pcompetence      -0.376    0.073   -5.154    0.000   -0.156   -0.156
  Minterest ~
    Mcompetence       1.884    0.057   33.263    0.000    0.883    0.883
  Mrecognition ~
    Mcompetence       1.656    0.046   35.807    0.000    0.856    0.856
  mathid ~
    Minterest         0.357    0.031   11.585    0.000    0.297    0.297
```

```
    Mrecognition      0.972    0.039   25.154    0.000    0.733    0.733
    Mcompetence      -0.222    0.068   -3.276    0.001   -0.086   -0.086
  eng ~
    mathid            0.113    0.016    6.881    0.000    0.290    0.186
    physid            0.170    0.018    9.323    0.000    0.411    0.264
    AB                0.320    0.042    7.578    0.000    0.320    0.205

Covariances:
  physid ~~
    mathid            0.179    0.024    7.406    0.000    0.179    0.179

Intercepts:
    Q27Phys_d         1.785    0.039   45.373    0.000    1.785    1.267
    Q27Phys_g         1.827    0.038   47.574    0.000    1.827    1.328
    Q27Phys_b         1.512    0.036   42.161    0.000    1.512    1.177
    Q27Phys_c         1.571    0.036   43.673    0.000    1.571    1.219
    Q27Phys_e         2.143    0.038   56.045    0.000    2.143    1.565
    Q27Phys_f         1.983    0.038   52.430    0.000    1.983    1.464
    Q27Phys_h         2.035    0.037   54.590    0.000    2.035    1.524
    Q27Phys_i         2.040    0.037   54.558    0.000    2.040    1.523
    Q27Phys_j         1.663    0.039   43.137    0.000    1.663    1.204
    Q27Phys_n         2.108    0.036   59.180    0.000    2.108    1.652
    Q27Phys_a         1.557    0.037   41.598    0.000    1.557    1.161
    Q27Math_d         1.969    0.040   48.667    0.000    1.969    1.359
    Q27Math_g         1.978    0.041   48.060    0.000    1.978    1.342
    Q27Math_b         2.154    0.042   50.717    0.000    2.154    1.416
    Q27Math_c         1.991    0.040   49.455    0.000    1.991    1.381
    Q27Math_e         2.438    0.039   62.273    0.000    2.438    1.739
    Q27Math_f         2.272    0.039   58.020    0.000    2.272    1.620
    Q27Math_h         2.356    0.038   62.202    0.000    2.356    1.737
    Q27Math_i         2.366    0.038   63.059    0.000    2.366    1.760
    Q27Math_j         2.142    0.041   52.769    0.000    2.142    1.473
    Q27Math_n         2.349    0.037   64.278    0.000    2.349    1.795
    Q27Math_a         2.030    0.042   48.457    0.000    2.030    1.353
    Q29a              2.412    0.037   65.362    0.000    2.412    1.825
    Q29b              2.352    0.034   68.953    0.000    2.352    1.925
    Q29c              2.309    0.034   67.953    0.000    2.309    1.897
    Q29d              2.357    0.032   72.604    0.000    2.357    2.027
    Q29e              2.307    0.034   68.243    0.000    2.307    1.905
    eng               1.751    0.044   40.238    0.000    1.751    1.123
    Pinterest         0.000                               0.000    0.000
    Precognition      0.000                               0.000    0.000
    Pcompetence       0.000                               0.000    0.000
    physid            0.000                               0.000    0.000
    Minterest         0.000                               0.000    0.000
    Mrecognition      0.000                               0.000    0.000
    Mcompetence       0.000                               0.000    0.000
    mathid            0.000                               0.000    0.000
    AB                0.000                               0.000    0.000

Variances:
    Q27Phys_d         0.499    0.025                      0.499    0.252
    Q27Phys_g         0.332    0.019                      0.332    0.176
    Q27Phys_b         0.358    0.019                      0.358    0.217
    Q27Phys_c         0.339    0.019                      0.339    0.204
    Q27Phys_e         0.365    0.017                      0.365    0.195
```

```
    Q27Phys_f         0.421    0.019                               0.421    0.229
    Q27Phys_h         0.308    0.015                               0.308    0.173
    Q27Phys_i         0.265    0.014                               0.265    0.148
    Q27Phys_j         0.788    0.033                               0.788    0.414
    Q27Phys_n         0.754    0.031                               0.754    0.463
    Q27Phys_a         0.000                                        0.000    0.000
    Q27Math_d         0.466    0.024                               0.466    0.222
    Q27Math_g         0.371    0.022                               0.371    0.171
    Q27Math_b         0.386    0.022                               0.386    0.167
    Q27Math_c         0.397    0.021                               0.397    0.191
    Q27Math_e         0.341    0.016                               0.341    0.174
    Q27Math_f         0.431    0.020                               0.431    0.219
    Q27Math_h         0.289    0.014                               0.289    0.157
    Q27Math_i         0.284    0.014                               0.284    0.157
    Q27Math_j         0.684    0.029                               0.684    0.324
    Q27Math_n         0.695    0.029                               0.695    0.405
    Q27Math_a         0.000                                        0.000    0.000
    Q29a              0.534    0.025                               0.534    0.305
    Q29b              0.272    0.015                               0.272    0.182
    Q29c              0.229    0.014                               0.229    0.155
    Q29d              0.511    0.022                               0.511    0.378
    Q29e              0.514    0.023                               0.514    0.350
    eng               1.851    0.073                               1.851    0.762
    Pinterest         1.000                                        0.186    0.186
    Precognition      1.000                                        0.335    0.335
    Pcompetence       1.000                                        1.000    1.000
    physid            1.000                                        0.171    0.171
    Minterest         1.000                                        0.220    0.220
    Mrecognition      1.000                                        0.267    0.267
    Mcompetence       1.000                                        1.000    1.000
    mathid            1.000                                        0.152    0.152
    AB                1.000                                        1.000    1.000


Group 2 [1]:

                   Estimate  Std.err  Z-value  P(>|z|)   Std.lv  Std.all
Latent variables:
  Pinterest =~
    Q27Phys_d         0.526    0.014   37.408    0.000    1.219    0.883
    Q27Phys_g         0.539    0.014   37.950    0.000    1.249    0.920
  Precognition =~
    Q27Phys_b         0.658    0.014   48.142    0.000    1.137    0.911
    Q27Phys_c         0.665    0.014   47.976    0.000    1.150    0.899
  Pcompetence =~
    Q27Phys_e         1.229    0.020   61.842    0.000    1.229    0.908
    Q27Phys_f         1.189    0.020   59.769    0.000    1.189    0.892
    Q27Phys_h         1.215    0.020   62.249    0.000    1.215    0.905
    Q27Phys_i         1.236    0.019   63.955    0.000    1.236    0.920
    Q27Phys_j         1.057    0.021   49.557    0.000    1.057    0.800
    Q27Phys_n         0.935    0.021   43.468    0.000    0.935    0.700
  physid =~
    Q27Phys_a         0.501    0.011   47.685    0.000    1.211    1.000
  Minterest =~
    Q27Math_d         0.599    0.015   40.927    0.000    1.278    0.877
```

```
    Q27Math_g         0.629    0.015   41.566    0.000    1.343    0.923
  Mrecognition =~
    Q27Math_b         0.718    0.015   48.437    0.000    1.388    0.935
    Q27Math_c         0.670    0.014   47.809    0.000    1.297    0.915
  Mcompetence =~
    Q27Math_e         1.275    0.020   63.191    0.000    1.275    0.919
    Q27Math_f         1.240    0.021   60.458    0.000    1.240    0.897
    Q27Math_h         1.246    0.020   62.955    0.000    1.246    0.908
    Q27Math_i         1.234    0.019   63.457    0.000    1.234    0.916
    Q27Math_j         1.196    0.022   53.326    0.000    1.196    0.826
    Q27Math_n         0.875    0.027   32.054    0.000    0.875    0.681
  mathid =~
    Q27Math_a         0.572    0.011   49.867    0.000    1.468    1.000
  AB =~
    Q29a              1.102    0.021   53.607    0.000    1.102    0.830
    Q29b              1.105    0.018   61.316    0.000    1.105    0.902
    Q29c              1.119    0.017   64.116    0.000    1.119    0.933
    Q29d              0.917    0.019   49.522    0.000    0.917    0.790
    Q29e              0.976    0.019   51.413    0.000    0.976    0.812

Regressions:
  Pinterest ~
    Pcompetence       2.089    0.066   31.490    0.000    0.902    0.902
  Precognition ~
    Pcompetence       1.410    0.041   34.548    0.000    0.816    0.816
  physid ~
    Pinterest         0.398    0.033   12.174    0.000    0.381    0.381
    Precognition      0.986    0.040   24.937    0.000    0.705    0.705
    Pcompetence      -0.376    0.073   -5.154    0.000   -0.156   -0.156
  Minterest ~
    Mcompetence       1.884    0.057   33.263    0.000    0.883    0.883
  Mrecognition ~
    Mcompetence       1.656    0.046   35.807    0.000    0.856    0.856
  mathid ~
    Minterest         0.357    0.031   11.585    0.000    0.297    0.297
    Mrecognition      0.972    0.039   25.154    0.000    0.733    0.733
    Mcompetence      -0.222    0.068   -3.276    0.001   -0.086   -0.086
  eng ~
    mathid            0.060    0.012    4.877    0.000    0.154    0.127
    physid            0.081    0.014    5.982    0.000    0.196    0.161
    AB                0.288    0.032    9.062    0.000    0.288    0.236

Covariances:
  physid ~~
    mathid            0.179    0.024    7.406    0.000    0.179    0.179

Intercepts:
    Q27Phys_d         1.183    0.035   33.571    0.000    1.183    0.857
    Q27Phys_g         1.202    0.035   34.734    0.000    1.202    0.886
    Q27Phys_b         0.866    0.032   27.195    0.000    0.866    0.694
    Q27Phys_c         0.996    0.033   30.536    0.000    0.996    0.779
    Q27Phys_e         1.465    0.035   42.420    0.000    1.465    1.082
    Q27Phys_f         1.265    0.034   37.170    0.000    1.265    0.948
    Q27Phys_h         1.394    0.034   40.695    0.000    1.394    1.038
    Q27Phys_i         1.393    0.034   40.600    0.000    1.393    1.036
    Q27Phys_j         1.094    0.034   32.461    0.000    1.094    0.828
```

```
    Q27Phys_n         1.720    0.034   50.521    0.000    1.720    1.289
    Q27Phys_a         0.888    0.031   28.731    0.000    0.888    0.733
    Q27Math_d         1.676    0.037   45.096    0.000    1.676    1.151
    Q27Math_g         1.751    0.037   47.158    0.000    1.751    1.203
    Q27Math_b         1.700    0.038   44.870    0.000    1.700    1.145
    Q27Math_c         1.637    0.036   45.255    0.000    1.637    1.155
    Q27Math_e         2.122    0.035   59.931    0.000    2.122    1.529
    Q27Math_f         1.932    0.035   54.781    0.000    1.932    1.398
    Q27Math_h         2.069    0.035   59.069    0.000    2.069    1.507
    Q27Math_i         2.135    0.034   62.085    0.000    2.135    1.584
    Q27Math_j         1.921    0.037   52.039    0.000    1.921    1.328
    Q27Math_n         2.221    0.033   67.737    0.000    2.221    1.728
    Q27Math_a         1.644    0.037   43.902    0.000    1.644    1.120
    Q29a              2.378    0.034   70.206    0.000    2.378    1.791
    Q29b              2.275    0.031   72.812    0.000    2.275    1.858
    Q29c              2.191    0.031   71.595    0.000    2.191    1.827
    Q29d              2.449    0.030   82.639    0.000    2.449    2.109
    Q29e              2.102    0.031   68.519    0.000    2.102    1.748
    eng               0.805    0.031   25.859    0.000    0.805    0.660
    Pinterest         0.000                               0.000    0.000
    Precognition      0.000                               0.000    0.000
    Pcompetence       0.000                               0.000    0.000
    physid            0.000                               0.000    0.000
    Minterest         0.000                               0.000    0.000
    Mrecognition      0.000                               0.000    0.000
    Mcompetence       0.000                               0.000    0.000
    mathid            0.000                               0.000    0.000
    AB                0.000                               0.000    0.000

Variances:
    Q27Phys_d         0.421    0.019                      0.421    0.221
    Q27Phys_g         0.281    0.016                      0.281    0.153
    Q27Phys_b         0.265    0.014                      0.265    0.170
    Q27Phys_c         0.312    0.016                      0.312    0.191
    Q27Phys_e         0.320    0.014                      0.320    0.175
    Q27Phys_f         0.365    0.016                      0.365    0.205
    Q27Phys_h         0.327    0.014                      0.327    0.181
    Q27Phys_i         0.279    0.013                      0.279    0.154
    Q27Phys_j         0.629    0.024                      0.629    0.360
    Q27Phys_n         0.907    0.034                      0.907    0.510
    Q27Phys_a         0.000                               0.000    0.000
    Q27Math_d         0.489    0.023                      0.489    0.230
    Q27Math_g         0.314    0.019                      0.314    0.149
    Q27Math_b         0.277    0.016                      0.277    0.126
    Q27Math_c         0.327    0.016                      0.327    0.163
    Q27Math_e         0.300    0.014                      0.300    0.156
    Q27Math_f         0.373    0.016                      0.373    0.195
    Q27Math_h         0.332    0.015                      0.332    0.176
    Q27Math_i         0.293    0.013                      0.293    0.162
    Q27Math_j         0.664    0.026                      0.664    0.317
    Q27Math_n         0.886    0.033                      0.886    0.537
    Q27Math_a         0.000                               0.000    0.000
    Q29a              0.549    0.023                      0.549    0.311
    Q29b              0.279    0.014                      0.279    0.186
    Q29c              0.187    0.011                      0.187    0.130
    Q29d              0.508    0.020                      0.508    0.376
```

Q29e	0.493	0.020			0.493	0.341
eng	1.260	0.046			1.260	0.847
Pinterest	1.000				0.186	0.186
Precognition	1.000				0.335	0.335
Pcompetence	1.000				1.000	1.000
physid	1.000				0.171	0.171
Minterest	1.000				0.220	0.220
Mrecognition	1.000				0.267	0.267
Mcompetence	1.000				1.000	1.000
mathid	1.000				0.152	0.152
AB	1.000				1.000	1.000

R output for modification indices allowing loadings to be freely estimated. Significant modification indices are highlighted.

	lhs	op	rhs	group	mi	epc	sepc.lv	sepc.all	sepc.nox
1	Pinterest	=~	Q27Phys_d	1	0.646	0.005	0.012	0.008	0.008
2	Pinterest	=~	Q27Phys_g	1	0.067	-0.002	-0.004	-0.003	-0.003
30	Precognition	=~	Q27Phys_b	1	1.847	0.011	0.018	0.014	0.014
31	Precognition	=~	Q27Phys_c	1	0.229	-0.004	-0.007	-0.005	-0.005
59	Pcompetence	=~	Q27Phys_e	1	0.975	-0.011	-0.011	-0.008	-0.008
60	Pcompetence	=~	Q27Phys_f	1	1.547	0.014	0.014	0.011	0.011
61	Pcompetence	=~	Q27Phys_h	1	0.010	-0.001	-0.001	-0.001	-0.001
62	Pcompetence	=~	Q27Phys_i	1	0.068	-0.003	-0.003	-0.002	-0.002
63	Pcompetence	=~	Q27Phys_j	1	0.240	0.007	0.007	0.005	0.005
64	Pcompetence	=~	Q27Phys_n	1	1.024	0.016	0.016	0.012	0.012
92	physid	=~	Q27Phys_a	1	5.293	0.021	0.054	0.039	0.039
120	Minterest	=~	Q27Math_d	1	0.648	0.006	0.012	0.008	0.008
121	Minterest	=~	Q27Math_g	1	0.042	-0.001	-0.003	-0.002	-0.002
149	Mrecognition	=~	Q27Math_b	1	0.037	0.001	0.003	0.002	0.002
150	Mrecognition	=~	Q27Math_c	1	0.044	-0.001	-0.003	-0.002	-0.002
178	Mcompetence	=~	Q27Math_e	1	0.805	-0.009	-0.009	-0.007	-0.007
179	Mcompetence	=~	Q27Math_f	1	0.709	-0.009	-0.009	-0.007	-0.007
180	Mcompetence	=~	Q27Math_h	1	0.002	0.000	0.000	0.000	0.000
181	Mcompetence	=~	Q27Math_i	1	0.086	0.003	0.003	0.002	0.002
182	Mcompetence	=~	Q27Math_j	1	0.607	-0.011	-0.011	-0.007	-0.007
183	Mcompetence	=~	Q27Math_n	1	4.473	0.030	0.030	0.024	0.024
211	mathid	=~	Q27Math_a	1	3.856	0.018	0.043	0.030	0.030
239	AB	=~	Q29a	1	0.269	0.006	0.006	0.005	0.005
240	AB	=~	Q29b	1	0.078	0.003	0.003	0.002	0.002
241	AB	=~	Q29c	1	0.739	-0.008	-0.008	-0.007	-0.007
242	AB	=~	Q29d	1	0.997	-0.012	-0.012	-0.010	-0.010
243	AB	=~	Q29e	1	0.056	-0.003	-0.003	-0.002	-0.002
244	Pinterest	=~	Q27Phys_d	2	0.950	-0.006	-0.014	-0.010	-0.010
245	Pinterest	=~	Q27Phys_g	2	0.099	0.002	0.005	0.003	0.003
273	Precognition	=~	Q27Phys_b	2	2.717	-0.013	-0.021	-0.017	-0.017
274	Precognition	=~	Q27Phys_c	2	0.337	0.005	0.007	0.006	0.006
302	Pcompetence	=~	Q27Phys_e	2	1.434	0.014	0.014	0.010	0.010
303	Pcompetence	=~	Q27Phys_f	2	2.277	-0.017	-0.017	-0.013	-0.013
304	Pcompetence	=~	Q27Phys_h	2	0.015	0.001	0.001	0.001	0.001
305	Pcompetence	=~	Q27Phys_i	2	0.100	0.003	0.003	0.002	0.002
306	Pcompetence	=~	Q27Phys_j	2	0.353	-0.009	-0.009	-0.007	-0.007
307	Pcompetence	=~	Q27Phys_n	2	1.507	-0.019	-0.019	-0.014	-0.014
335	physid	=~	Q27Phys_a	2	7.785	-0.026	-0.058	-0.048	-0.048
363	Minterest	=~	Q27Math_d	2	0.953	-0.007	-0.014	-0.010	-0.010
364	Minterest	=~	Q27Math_g	2	0.061	0.002	0.004	0.003	0.003
392	Mrecognition	=~	Q27Math_b	2	0.055	-0.002	-0.003	-0.002	-0.002
393	Mrecognition	=~	Q27Math_c	2	0.065	0.002	0.003	0.002	0.002
421	Mcompetence	=~	Q27Math_e	2	1.184	0.011	0.011	0.008	0.008
422	Mcompetence	=~	Q27Math_f	2	1.044	0.011	0.011	0.008	0.008
423	Mcompetence	=~	Q27Math_h	2	0.002	0.000	0.000	0.000	0.000
424	Mcompetence	=~	Q27Math_i	2	0.126	-0.003	-0.003	-0.003	-0.003
425	Mcompetence	=~	Q27Math_j	2	0.893	0.013	0.013	0.009	0.009
426	Mcompetence	=~	Q27Math_n	2	6.581	-0.036	-0.036	-0.027	-0.027
454	mathid	=~	Q27Math_a	2	5.673	-0.021	-0.053	-0.036	-0.036
482	AB	=~	Q29a	2	0.395	-0.008	-0.008	-0.006	-0.006
483	AB	=~	Q29b	2	0.115	-0.003	-0.003	-0.003	-0.003
484	AB	=~	Q29c	2	1.087	0.010	0.010	0.008	0.008

485	AB =~	Q29d	2	1.467	0.014	0.014	0.012	0.012
486	AB =~	Q29e	2	0.082	0.003	0.003	0.003	0.003

R output for modification indices allowing loadings and regressions to be freely estimated. Significant modification indices are highlighted.

	lhs	op	rhs	group	mi	epc	sepc.lv	sepc.all	sepc.nox
7	Pinterest	~	Pcompetence	1	0.060	0.005	0.002	0.002	0.002
16	Precognition	~	Pcompetence	1	2.616	0.027	0.016	0.016	0.016
19	physid	~	Pinterest	1	0.325	0.007	0.007	0.007	0.007
20	physid	~	Precognition	1	0.235	-0.012	-0.008	-0.008	-0.008
25	physid	~	Pcompetence	1	0.075	0.007	0.003	0.003	0.003
35	Minterest	~	Mcompetence	1	0.171	0.007	0.003	0.003	0.003
44	Mrecognition	~	Mcompetence	1	1.264	-0.018	-0.010	-0.010	-0.010
49	mathid	~	Minterest	1	0.002	-0.001	0.000	0.000	0.000
50	mathid	~	Mrecognition	1	2.779	-0.036	-0.026	-0.026	-0.026
53	mathid	~	Mcompetence	1	0.267	-0.013	-0.005	-0.005	-0.005
57	eng	~	physid	1	7.320	0.022	0.053	0.035	0.035
60	eng	~	mathid	1	5.578	0.018	0.046	0.030	0.030
63	eng	~	AB	1	4.010	0.040	0.040	0.026	0.026
97	Pinterest	~	Pcompetence	2	0.088	-0.006	-0.002	-0.002	-0.002
106	Precognition	~	Pcompetence	2	3.849	-0.032	-0.019	-0.019	-0.019
109	physid	~	Pinterest	2	0.478	-0.009	-0.009	-0.009	-0.009
110	physid	~	Precognition	2	0.346	0.014	0.010	0.010	0.010
115	physid	~	Pcompetence	2	0.111	-0.008	-0.004	-0.004	-0.004
125	Minterest	~	Mcompetence	2	0.251	-0.009	-0.004	-0.004	-0.004
134	Mrecognition	~	Mcompetence	2	1.859	0.022	0.012	0.012	0.012
139	mathid	~	Minterest	2	0.002	0.001	0.001	0.001	0.001
140	mathid	~	Mrecognition	2	4.088	0.043	0.032	0.032	0.032
143	mathid	~	Mcompetence	2	0.393	0.016	0.006	0.006	0.006
147	eng	~	physid	2	10.769	-0.027	-0.065	-0.052	-0.052
150	eng	~	mathid	2	8.206	-0.022	-0.055	-0.044	-0.044
153	eng	~	AB	2	5.899	-0.048	-0.048	-0.039	-0.039

Appendix C SEM Correlation Matrix

	Q27Phys_a	Q27Phys_b	Q27Phys_c	Q27Phys_d	Q27Phys_e	Q27Phys_f	Q27Phys_g	Q27Phys_h
Q27Phys_a	1.000							
Q27Phys_b	0.836	1.000						
Q27Phys_c	0.796	0.805	1.000					
Q27Phys_d	0.738	0.694	0.710	1.000				
Q27Phys_e	0.664	0.628	0.668	0.721	1.000			
Q27Phys_f	0.695	0.648	0.669	0.706	0.823	1.000		
Q27Phys_g	0.742	0.683	0.702	0.792	0.727	0.749	1.000	
Q27Phys_h	0.655	0.617	0.660	0.647	0.799	0.775	0.745	1.000
Q27Phys_i	0.686	0.647	0.680	0.682	0.798	0.786	0.760	0.851
Q27Phys_j	0.632	0.627	0.670	0.602	0.650	0.657	0.675	0.718
Q27Phys_n	0.513	0.475	0.515	0.512	0.622	0.619	0.575	0.660
Q27Math_a	0.359	0.335	0.366	0.294	0.294	0.298	0.322	0.318
Q27Math_b	0.360	0.397	0.408	0.312	0.321	0.329	0.339	0.351
Q27Math_c	0.362	0.366	0.450	0.325	0.325	0.326	0.337	0.354
Q27Math_d	0.348	0.330	0.347	0.422	0.319	0.334	0.380	0.335
Q27Math_e	0.276	0.260	0.287	0.293	0.440	0.371	0.315	0.402
Q27Math_f	0.276	0.259	0.281	0.280	0.369	0.423	0.308	0.370
Q27Math_g	0.283	0.262	0.298	0.308	0.283	0.278	0.378	0.308
Q27Math_h	0.236	0.227	0.268	0.253	0.367	0.336	0.298	0.439
Q27Math_i	0.256	0.242	0.280	0.287	0.375	0.358	0.322	0.397
Q27Math_j	0.259	0.260	0.298	0.266	0.324	0.324	0.306	0.359
Q27Math_n	0.215	0.196	0.226	0.229	0.306	0.299	0.243	0.322
Q29a	0.313	0.303	0.308	0.389	0.326	0.339	0.350	0.311
Q29b	0.326	0.328	0.311	0.385	0.312	0.347	0.363	0.304
Q29c	0.344	0.339	0.339	0.399	0.324	0.362	0.377	0.323
Q29d	0.248	0.245	0.249	0.293	0.253	0.270	0.276	0.251
Q29e	0.324	0.331	0.324	0.368	0.300	0.330	0.343	0.293
eng	0.394	0.375	0.363	0.390	0.315	0.329	0.348	0.288

	Q27Phys_i	Q27Phys_j	Q27Phys_n	Q27Math_a	Q27Math_b	Q27Math_c	Q27Math_d	Q27Math_e
Q27Phys_i	1.000							
Q27Phys_j	0.741	1.000						
Q27Phys_n	0.662	0.558	1.000					
Q27Math_a	0.335	0.321	0.238	1.000				
Q27Math_b	0.375	0.370	0.262	0.852	1.000			
Q27Math_c	0.361	0.366	0.275	0.803	0.821	1.000		
Q27Math_d	0.343	0.315	0.257	0.732	0.693	0.703	1.000	
Q27Math_e	0.394	0.310	0.333	0.692	0.674	0.686	0.694	1.000
Q27Math_f	0.377	0.307	0.307	0.717	0.685	0.692	0.676	0.827
Q27Math_g	0.314	0.308	0.236	0.756	0.699	0.709	0.784	0.710
Q27Math_h	0.380	0.323	0.333	0.681	0.662	0.680	0.643	0.805
Q27Math_i	0.431	0.321	0.344	0.684	0.672	0.683	0.648	0.808
Q27Math_j	0.365	0.431	0.325	0.666	0.675	0.677	0.605	0.699
Q27Math_n	0.324	0.275	0.500	0.501	0.491	0.519	0.501	0.629
Q29a	0.325	0.281	0.297	0.226	0.238	0.251	0.286	0.267
Q29b	0.324	0.284	0.277	0.212	0.224	0.250	0.298	0.245
Q29c	0.346	0.324	0.295	0.212	0.228	0.248	0.286	0.231
Q29d	0.265	0.239	0.243	0.148	0.156	0.189	0.212	0.190
Q29e	0.318	0.308	0.276	0.198	0.213	0.231	0.259	0.201
eng	0.299	0.317	0.213	0.281	0.290	0.278	0.298	0.208

	Q27Math_f	Q27Math_g	Q27Math_h	Q27Math_i	Q27Math_j	Q27Math_n	Q29a	Q29b
Q27Math_f	1.000							
Q27Math_g	0.717	1.000						
Q27Math_h	0.775	0.715	1.000					
Q27Math_i	0.788	0.718	0.847	1.000				
Q27Math_j	0.689	0.674	0.732	0.758	1.000			
Q27Math_n	0.608	0.539	0.642	0.645	0.581	1.000		
Q29a	0.254	0.239	0.254	0.266	0.228	0.238	1.000	
Q29b	0.247	0.248	0.226	0.250	0.224	0.225	0.769	1.000
Q29c	0.236	0.236	0.220	0.244	0.229	0.218	0.741	0.826
Q29d	0.184	0.163	0.189	0.207	0.190	0.209	0.621	0.684
Q29e	0.216	0.212	0.203	0.220	0.223	0.209	0.629	0.691
eng	0.214	0.249	0.186	0.197	0.189	0.142	0.285	0.276

	Q29c	Q29d	Q29e	eng
Q29c	1.000			
Q29d	0.725	1.000		
Q29e	0.749	0.713	1.000	
eng	0.288	0.176	0.279	1.000

Appendix D Open-ended Survey Questions

What year are you in college?

What is your current major?

What was your intended major when you entered college?

Has your declared/intended major changed since you started college? If so, why?

Please describe the three most crucial influences (people, experiences, school-related subject, etc.) on your career choice in order of most to least important.

Please describe the characteristics (e.g. social, intellectual, technical, and other skills) needed to be an engineer.

Do you see yourself as an engineer (anchored scale from "No, not at all" to "Yes, very much")

Describe three was in which you see yourself as an engineer?

What do you want to do with a career in engineering?

Describe a scenario/experience in which you felt recognized as an engineer. (If you haven't had a scenario/experience where you have been recognized as an engineer, state so.)

Describe three ways in which science and engineering can impact the world.

Describe three ways in which science and engineering can impact your life personally.

Do you see yourself as a math person? (anchored scale from "No, not at all" to "Yes, very much")

List three ways in which you see yourself as a math person.

Do you see yourself as a physics person? (anchored scale from "No, not at all" to "Yes, very much")

List three ways in which you see yourself as a physics person.

Appendix E Case Study Interview Protocol

All inteviews followed a semi-structured interview protocol which allowed for follow-up questions and probing for deeper understanding.

Sara Interview Spring 2013

Class

What did you think about class today?

What about class do you enjoy?

Think about your favorite day in this class. Tell me about what happened during that day.

Think about one of your least favorite class days. Tell me about that.

What topics from the class interest you most? Why?

Do you talk about this class outside of class time?

Do you help other students in this class?

Have you ever looked up additional information outside of class?

How does this teacher compare to your other teachers?

Career Plans

What are your current plans for your career? How did you decide on that?

What other careers have you thought about? (looking for possible non-engineers)

Do you have a specific discipline in mind? (if indicated that they are interested in engineering)

Who encourages you toward your career goals?

Did any topics you discussed in class affect your career plans?

Identity

What does it mean to be a science person?

Could anyone be a science person?

Are you a science person?

What does it mean to be a math person?

Reword if necessary...what are the characteristics of a math person

Could anyone be a math person?

Are you a math person?

What does it mean to be a physics person?

Could anyone be a physics person?

Are you a physics person?

Do physics people have other interests?

Do you have other interests?

Do your friends like physics? Think physics is cool? Think less of you for taking physics? Care about their grades?

Do most students in your school like physics? Think physics is cool? Think less of you for taking physics? Care about their grades?

What is engineering?

What do engineers do?

What could you do with a career in engineering?

Who can do engineering?

<u>Agency</u>

What can engineering and science do for our world?

Do you see science as relevant to your life?

Do think about science for fun?

Is it important to know chemistry/physics?

PROBE for more info

Sara Interview Fall 2013

What school are you attending?

What is your major?

Why did you choose that school/major?

Perceptions of engineering what you thought? Different?

How was your experience with the clean water program this summer?

What did you do on that trip?

Was the trip different than before?

Take previous survey and look at attitudes (identities/agency beliefs)...how do you feel about that now?

Probe for information on school structure, major structure, and other emergent ideas.

Sara Interview Spring 2014

How did you calculus class go last semester?

How do you feel about being a math person?

How is swimming going?

Are you taking physics this semester?

What other classes are you taking this semester?

How are they going?

Do you feel like an engineer?

Have you been recognized as an engineer?

Do you feel like you fit into your community? Your engineering community?

What do you plan on doing with your career in engineering?

What are your plans for next year?

Do you plan to stay at your school for the upcoming year?

What are your plans for the summer? (internship, clean water program, etc.?)

What would have been some of the barriers to you pursuing engineering? (How could your story have been different?)

Has talking about your decision process and career path with me changed your view or decision of engineering?

Michael Interview Spring 2013

How do you discuss sustainability topics (e.g. disease, life cycle analysis) throughout the course?

Why do you discuss these topics in these ways?

How did you decide which topics to include?

Can you summarize your teaching philosophy?

Can you tell me more about [specific teaching strategies used during the week of observations]?

Can you tell me more about [a previously mentioned class project]?

Do you discuss engineering and science career opportunities? How?

Do you encourage students toward specific career paths?

Michael Interview Spring 2014

Tell me about Sara.

How long have you known Sara?

In what context have you known her?

Was Sara typical of your students or was she a unique case?

In what ways?

Was Sara typical of your female students or was she a unique case?

In what ways?

What was her involvement in the clean water program?

How did she get interested in engineering?

How did she make her college decision?

Please describe how Sara developed and grew over the time you knew her.

Where do think she will end up?

Appendix F Sara Survey Responses Spring 2013

Information Concerning Participation in a Research Study
(High School Science Students)

CLEMSON
ENGINEERING AND SCIENCE EDUCATION

Engineering Recruitment and Sustainability

Researchers at Clemson University are interested in in your experiences learning science. By filling out this survey, you will help us find ways to improve science education for future students. Please note:

- You and your parent must have signed consent forms to participate.
- The survey will take approximately 10 minutes to complete.
- Participation is voluntary. You may withdraw at any time.
- Participation will NOT impact your grade in this course in any way.
- If you have any questions or concerns, please contact Leidy Klotz; phone – (864) 656-3326; email – leidyk@clemson.edu.
- Participants may contact the Clemson University Office of Research Compliance at 864-656-6460 if they have any questions regarding their rights as research participants.

Please make your best estimate for each item
and answer as many questions as possible.

Thank you for your time!

SUSTAINABILITY AND YOU:

1. To what extent do you disagree or agree with the following:

Strongly disagree	0	1	2	3	4	Strongly agree
Human creativity will ensure that we do not make the earth unlivable	O	O	O	O	O	
I feel a responsibility to deal with environmental problems	O	O	O	O	O	
Environmental problems make the future look hopeless	O	O	O	O	O	
Nothing I can do will make things better in other places on the planet	O	O	O	O	O	
Climate change is caused by humans	O	O	O	O	O	
I think of myself as part of nature, not separate from it	O	O	O	O	O	
We should be taking stronger actions to address climate change	O	O	O	O	O	

2. How likely are you to do the following:

Not at all likely	0	1	2	3	4	Extremely likely
Put on more clothes rather than turn up the heat when I'm cold	O	O	O	O	O	
Use less water when taking a shower or bath	O	O	O	O	O	
Perform community service	O	O	O	O	O	
Educate others about the importance of these or similar actions	O	O	O	O	O	

ABOUT SCIENCE-RELATED INTERESTS/ATTITUDES/EXPERIENCES:

3. Please rate the current likelihood of your choosing a career in the following:

Not at all likely	0	1	2	3	4	Extremely likely
Mathematics	O	O	O	O	O	
Science/Math teacher	O	O	O	O	O	
Environmental science	O	O	O	O	O	
Biology	O	O	O	O	O	
Physics	O	O	O	O	O	
Chemistry	O	O	O	O	O	
Engineering	O	O	O	O	O	

4. Please rate your general interest in the following areas.

Not at all interested	0	1	2	3	4	Very interested
Understanding natural phenomena	O	O	O	O	O	
Understanding science in everyday life	O	O	O	O	O	
Explaining things with facts	O	O	O	O	O	
Telling others about science concepts	O	O	O	O	O	
Making scientific observations	O	O	O	O	O	

5. How confident are you in your ability to do the following:

Not confident at all	0	1	2	3	4	Very confident
Design an experiment to answer a scientific question	O	O	O	O	O	
Conduct an experiment on your own	O	O	O	O	O	
Interpret experimental results	O	O	O	O	O	
Write a lab report/scientific paper	O	O	O	O	O	
Apply science knowledge to an assignment or test	O	O	O	O	O	
Explain a science topic to someone else	O	O	O	O	O	
Get good grades in science	O	O	O	O	O	

6. **To what extent do you disagree or agree with the following:**

	Strongly disagree	0	1	2	3	4	Strongly agree
I see myself as a *science* person		O	O	O	O	O	
My parents/relatives/friends see me as a *science* person		O	O	O	O	O	
My *science* teacher sees me as a *science* person		O	O	O	O	O	
I see myself as a *math* person		O	O	O	O	O	
My parents/relatives/friends see me as a *math* person		O	O	O	O	O	
My *math* teacher sees me as a *math* person		O	O	O	O	O	
I see myself as a *physics* person		O	O	O	O	O	
My parents/relatives/friends see me as a *physics* person		O	O	O	O	O	
My *physics* teacher sees me as a *physics* person		O	O	O	O	O	

7. **To what extent do you disagree or agree with the following statements:**

	Physics					Math				
	Strongly disagree				Strongly agree	Strongly disagree				Strongly agree
	0	1	2	3	4	0	1	2	3	4
I am interested in learning more about this subject	O	O	O	O	O	O	O	O	O	O
I am confident that I can understand this subject in class	O	O	O	O	O	O	O	O	O	O
I am confident that I can understand this subject outside of class	O	O	O	O	O	O	O	O	O	O
I enjoy learning this subject	O	O	O	O	O	O	O	O	O	O
I can do well on exams in this subject	O	O	O	O	O	O	O	O	O	O
I understand concepts I have studied in this subject	O	O	O	O	O	O	O	O	O	O
Others ask me for help in this subject	O	O	O	O	O	O	O	O	O	O
I can overcome setbacks in this subject	O	O	O	O	O	O	O	O	O	O

never took physics

8. **To what extent do you disagree or agree with the following:**

	Strongly disagree	0	1	2	3	4	Strongly agree
Learning science will improve my career prospects		O	O	O	O	O	
Science is helpful in my everyday life		O	O	O	O	O	
Science has helped me see opportunities for positive change		O	O	O	O	O	
Science has taught me how to take care of my health		O	O	O	O	O	
Learning science has made me more critical in general		O	O	O	O	O	
Science and technology make our lives healthier, easier and more comfortable		O	O	O	O	O	
A country needs science and technology to become developed		O	O	O	O	O	
Science and technology will provide greater opportunities for future generations		O	O	O	O	O	
The benefits of new technologies greatly outweigh the risks		O	O	O	O	O	
I hope to gain general knowledge across multiple fields		O	O	O	O	O	
I identify relationships between topics from different courses		O	O	O	O	O	
I analyze projects broadly to find a solution that will have the greatest impact		O	O	O	O	O	

ABOUT YOUR HIGH SCHOOL EXPERIENCES:

9. How would you rate your interactions with your …?

	Extremely Negative					*Extremely positive*
Integrated Chemistry-Physics teachers	1	2	3	4	5	6
Chemistry teachers	1	2	3	4	5	6
Physics teachers	1	2	3	4	5	6

10. For the most advanced math course you took what was your final grade?

A+ A A- B+ B B- C+ C C- D F

11. In your previous science course, what was your final grade?

A+ A A- B+ B B- C+ C C- D F

ABOUT YOUR MIDDLE SCHOOL SCIENCE EXPERIENCES:

12. What was your average grade in middle school science?

A+ A A- B+ B B- C+ C C- D F

13. What was your average grade in middle school math?

A+ A A- B+ B B- C+ C C- D F

14. In middle school, how confident were you about your abilities in

Not confident at all						*Extremely confident*
Science	1	2	3	4	5	6
Mathematics	1	2	3	4	5	6

15. In middle school, how interested were you in

Not interested at all						*Extremely interested*
Science	1	2	3	4	5	6
Mathematics	1	2	3	4	5	6

ABOUT YOURSELF AND YOUR FAMILY:

16. What was the highest level of education for your parents/guardians?

	Less than high school diploma	High school Diploma/GED	Some college or associate/trade degree	Bachelor's degree	Master's degree or higher	Don't know
Male parent/guardian	O	O	O	O	O	O
Female parent/guardian	O	O	O	O	O	O

17. Are you male or female?
Male Female

18. What year are you?
Freshman Sophomore Junior Senior

19. What is your race? ***(For multi-racial, mark all that apply)***
Black White Asian or Pacific Islander American Indian or Alaskan Native
Other:________________

20. Are you of Hispanic origin?
Yes No

You have reached the end of the survey. Thank you very much for your time!

Appendix G *A Priori* Codebook for CEA

Career Choice

Definition: This code is designed to show what students' desired or undesired careers are and should be able to answer the question, "What are students' (un)desired future careers?" This code includes intermediate careers that students name prior to a terminal career.

Examples: I'm hoping to branch maybe off of geological engineering and kind of go into environmental, but I mean I'm not fully positive that that's what I want to do, but right now that's what my plan is.

Influence on Career

Definition: Captures the external influences of others on students' career choice. This code answers the question, "What/who influences students' chosen career?"

Examples: Going to [country] definitely made me like start to and also my class in high school with [Michael] that made me like just interested into it, and working like at the internship further continued it, and then actually just being in college and experiencing it makes me want to keep going.

Perception of Career

Definition: Characteristics students believe they need to be an engineer. This code answers the question, "What do students think they need to be an engineer?"

Examples: I think that in order to be an engineer, you must have skills such as being creative, intellectual, technical, good at math, etc. You need to be able to think outside the box and work well in groups, as well as by yourself.

Interest (area)

Definition: A person's desire or curiosity to think and learn about an area (e.g. mathematics, physics, engineering, STEM, etc.). The code answers the question, "Is this student interested/uninterested in [area]?"

Example: I like chemistry as a whole so like there's not like a particular, because like each new thing I just like learning more about it. I like being in AP Chem now because we like go more into depth of where like chemistry was more just like on the surface.

Performance/Competence (area)

Definition: People's beliefs about their ability to understand (competence) or excel (performance) in an area (e.g. mathematics, physics, engineering, STEM, etc.). This code should be able to answer the question, "How well does a student feel that s/he can understand and do the tasks required?"

Example: I'm in pre calculus but like I mean I still get it (competence), like I get good grades in that (performance), too.

***Note:** students speaking of others coming to them for help is coded as Performance/-Competence - (area). This concept loaded onto Performance/Competence rather than Recognition in quantitative work [122].

Recognition (area)

Definition: How people perceive how others view them in relation to an area (e.g. mathematics, physics, engineering, STEM, etc.). This code should be able to answer the question, "Does the student feel that others see them as the type of person who does [area]?"

Examples: They [friends] all know that I want to do the chemical engineering and they all know that I, my friends tease me about it, I go yeah, you're a chemistry nerd. I'm like whatever. But so I mean, my friends realize that I like it.

***Note:** students speaking of others coming to them for help is coded as Performance/-Competence - (area). This concept loaded onto Performance/Competence rather than Recognition in quantitative work [122].

Identity (area)

Definition: How individuals see themselves based on their perceptions and navigation of everyday experiences in a given context . This code answers the question, "What kind of person does the student see/not see themselves as?"

Example: I still think of myself as a like a math-based person it's just been a lot harder.

Agency Beliefs

Definition: students' perception of their ability to change their world through everyday actions and their broader goals. Students agency beliefs involve how students see and think about STEM as a way to better themselves and the world . This code should be able to answer the question, "Does a student value science/engineering for action/change in the world in direct relation to his/her life?"

Example: I just wanted to go there to help people out. So, I mean it [bringing water to country] taught me just like once again to like be thankful for what I have, and just um that you should always help people, and, and then they liked helped me out with they changed me and made me a better person, and like yeah. It's a really neat thing.

Appendix H Emergent Codebook for Qualitative Data

<u>Mastery Orientation</u>

Definition: This code is designed to show students' intrinsic motivation. These students believe that they have some control over factors related to learning. Specifically, that they can learn, that hard work and efforts pays off, and that they have or can acquire strategies that will help them learn. This code should be able to answer the question, "Does this student believe that their success or failure depends on the amount of effort they invest in the project?" This code includes students beliefs that they can learn more and love of learning for knowledge rather than performance.

Examples: I mean, Im not the kind of student that just takes something and then like forgets about it. Like I actually want to learn everything because I do love learning.

I just learn by teaching myself more so I just, like I can see everything better, I mean, yeah, I can do the labs and figure it out and stuff but I mean like in the learning aspect I can just learn better on paper and stuff I guess.

<u>Grit</u>

Definition: This code is designed to show the tendency to sustain interest in and effort toward very long-term goals and should be able to answer the question, "What are students' level of determination or grit?"

Examples: I mean it's [engineering] one of my goals in life. It's something that I think I would enjoy to do, and I could just see myself doing it and so, like I guess, just because like I know that I can do it and like I'm not just gonna give up on it.

I like having the challenge. Like it is a harder field to go into and it keeps me working to be better and study more and stay on top of things and I don't know. I just, I like that part of it.

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