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An Investigation of Engineering Majors: Graduates' Enrollment Timelines and First-Year Students' Perceptions and Exploration

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AN INVESTIGATION OF ENGINEERING MAJORS: GRADUATES' ENROLLMENT TIMELINES AND FIRST-YEAR STUDENTS' PERCEPTIONS AND EXPLORATION

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by
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Abstract

The selection of a specific engineering major can substantially impact a student's undergraduate experience and can also impact future career opportunities. This work is divided into complementary studies of Enrollment, Perception, and Exploration. Together, the three studies seek to answer six research questions related to (i) when and where students enroll in their graduation majors in different matriculation models, (ii) how students perceive both engineering in general and the engineering majors, and (iii) the impacts of a major exploration course on confidence in major choice, major changes, and fit and satisfaction in engineering in general and in the engineering majors.

Primarily using the Attraction-Selection-Attrition Framework and the Student Integration Model, the Study of Enrollment investigates time to enrollment in graduation major and persistence using institutional records from multiple institutions. The results of this study indicate different patterns in enrollment in graduation major based on the institutions' matriculation model. Generally, students at direct matriculation institutions enroll in their graduation major more quickly, but those students have more major changes than students at institutions with first-year engineering programs.

Using a framework of Social Cognitive Career Theory and Expectancy-Value Theory, the Study of Perception uses free-response survey questions from a major exploration course to investigate changes in students' perceptions of engineering in general and in the engineering majors. The results of this study show that students' perceptions of engineering in general and their intended engineering majors are expanded during an optional major exploration course. Responses often become more specific at the end of the course compared to the beginning.

Framed with the Attraction-Selection-Attrition Framework and the Student Integration Model, the Study of Exploration uses propensity score matching to create two matched groups to investigate the effects of a major exploration course on first-year engineering students' confidence in major choice, major changes, and fit and satisfaction in engineering. The results of this study show significant differences in the frequency of major changes among students who enrolled in the major exploration course compared with those that do not. Other metrics, while not significant, have differences that are favorable for the major exploration course that highlight its value for helping students make a more informed major choice.

The results of this work provide evidence that students are willing to change their engineering majors after matriculation. Students likely make changes to improve academic and social fit and integration and because of changes in perceptions of the engineering majors during their first year. Some changes in perception are likely the result of dedicated major exploration courses which also has a positive (but not statistically significant) impact on confidence in major selection as well as fit and satisfaction in engineering majors.

Dedication

To Mom, Dad, Brooke, and Baxter: thank you all for your continuous support and encouragement since well before I ever began my graduate school journey!

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Table of Contents

List of Tables

Page

List of Figures

Page

1 Introduction

1.1 Motivation

An engineering workforce is essential for society to meet our current and future challenges. By understanding how students select and persist in their engineering majors, we can improve in-major retention and graduation rates so that students find their engineering discipline quickly without having multiple major changes during their undergraduate studies. These improvements will help mitigate any actual or perceived shortfall of engineers on the labor market and minimize spending tuition dollars on classes that would become unnecessary after a student changes major.

The literature about how and why students choose to study engineering in general is robust; however, our understanding of the individual engineering majors is in progress. This work contributes to the literature by providing a deeper understanding of students' actions and perceptions during the first year of engineering by disaggregating by students' intended majors. Additionally, with comparisons between students who do and do not enroll in a major exploration course, this study advances our knowledge about the benefits of such a course. Previous research has investigated the benefits of similar courses by comparing across cohorts, but this study uses a novel course design as well as a matched comparison group from the same cohort who do not enroll in the elective course to better understand the impacts of the course.

1.2 Positionality Statement

As a first-year undergraduate student, I had no idea what engineering major I wanted to pursue. Like many of my friends, I selected to major in engineering because I was good at math and science (or at least I was told I was). In my senior year of high school, I was registered for “Engineering Calculus” through a dual-enrollment program, that was the equivalent of Calculus I and II at most institutions.

I remember during my first year being asked frequently what I was going to major in or what my major was, which was officially a non-degree granting general engineering major for the first semester. I was given the opportunity to select a degree-granting major at the end of my first semester and selected Chemical Engineering because I had developed an interest in my General Chemistry courses and had attended office hours to have discussions about the course and my major with my instructor. While I was happy with my decision, I was encouraged to continue to explore other options, including Computer Science, which was included in the College of Engineering. So, during my second semester, I enrolled in sophomore seminar courses for both Chemical Engineering and Computer Science before deciding to fully commit to Chemical Engineering at the start of my second year.

I never really gave my major selection another thought except when I was occasionally asked why I majored in Chemical Engineering and would normally respond with my interest in Chemistry but also an “I’m not really sure.” Then, while I was in graduate school for chemical engineering, I attended two engineering education research seminars and developed an interest in engineering education research. In some of my first discussions about engineering education research, I shared how I was curious how I selected my major and how other first-year engineering students make the selection. At the time, this project was going to be part of dissertation in chemical engineering. However, as I continued to work on the project, my interest continued to grow to the point that I switched institutions in order to enroll in the program that allowed me to write this dissertation.

During this dissertation process, I have also been teaching in a General Engineering program first as a graduate student and, at the time of graduation, as a full-time lecturer. This experience has helped frame this work. During this work, I was careful to maintain my position as a researcher and read student responses (Chapter 5) for their explanatory value and not as an instructor grading papers. Data was also anonymized (Chapters 5 and 6) to minimize the chances or re-identifying any students, whether my own or not. I am also aware of my experience as a first-year student but given that I do not remember why I pursued my major – other than my interest in Chemistry – removing myself from students' responses was not overly challenging; nonetheless, I have been aware of it.

I originally planned to complete an entirely quantitatively focused dissertation to attempt to answer my research questions centered around first-year engineering students' major selection. However, during the proposal process, I decided to include a qualitative component in order to begin to understand what first-year students perceive about the majors, which are likely similar to my former perceptions when I was a first-year engineering student. I hope that this work will be a positive contribution to the literature in understanding how first-year engineering students select and persist in an engineering major.

1.3 Structure

After this Introduction, a Literature Review is presented followed by the Theories, Models, and Metaphors used throughout this work. The Attraction-Selection-Attrition Framework, Student Integration Model, and the engineering metaphors are used to frame the Study of Enrollment and Study of Exploration. Social Cognitive Career Theory is the guiding theory for the Study of Perception with the task values from Eccles' Expectancy Value Theory supporting the framework.

Chapter 4, the Study of Enrollment, investigates students' timelines to their graduation majors in engineering and highlights students who switch majors in two different matriculation models – direct matriculation to a degree-granting major and first-year engineering programs. This study uses data from 11 different institutions. The results from this study provide context for the two subsequent studies by determining when students enroll in their graduation majors. Additionally, this study provides population statistics for comparison to the single institution that is the subject of subsequent studies.

Chapter 5, the Study of Perception, uses data from a major exploration course at a single institution to study students' perception of engineering and their top-choice engineering major during their first semester. The institution studied in this chapter is one of the 11 institutions used in the previous chapter. The results from this chapter offer explanations of why students who changed majors early in their academic careers, as seen in Chapter 4, make the changes. Additionally, the data collected in Chapter 5 is from the same course that is the focus of Chapter 6. This allows for results from these two chapters to reviewed together to better understand the impacts of the course on both perceptions and quantitative measures of confidence, fit, and satisfaction.

Chapter 6, the Study of Exploration, uses data from the same major exploration course at the same institution as Chapter 5 to investigate the impacts the course has on students' major changes, confidence in major choice, fit and satisfaction in engineering in general, and fit and satisfaction in their intended engineering major. The results from this chapter can relate to the results from Chapter 5 to offer explanations of why some students have changes in perception of engineering or their intended engineering major. Finally, this work ends with a Conclusions chapter.

This work was conducted with approval from the Clemson University Institutional Review Board.

2 Literature Review

This literature review is organized into four sections, some of which tie closely with specific studies presented in this work. The first section provides an overview of the research into how students select and persist in engineering in general, without a focus on individual majors. The second section includes the work that has investigated students' perceptions of the engineering disciplines; this section is of particular importance to the Study of Perception. The third section is about the differences in matriculation models in engineering which is important for the Study of Enrollment; the third section also discusses the differences in first-year engineering courses which is important for both Study of Perception and the Study of Exploration. The literature review ends with a summary of research results published about the factors that students consider when making a major selection decision.

2.1 Selection of and Persistence in Engineering in General

Typically, before students decide to pursue a specific engineering major, students first must decide that they want to major in engineering in general. The factors that attract students to the field of engineering have been explored with mostly consistent results. Among the most prevalent factors for students are their abilities in math and science [1]–[4]. However, some ambivalent students choose to major in engineering because they are aware of the difficulty of transferring into engineering after beginning their undergraduate studies [5]–[7].

The impacts of an engineering degree are also important considerations for many students when choosing to major in engineering. Engineering students often discuss their future ability to have impacts on society and the ability to address the problems facing the world upon graduation, especially among students majoring in civil and environmental engineering [3], [8]. Students also consider the availability of career options because some students are more focused on "making a career choice than an educational choice" [9]; this has also been reported in Talking About Leaving Revisited [10]. Salary is also an important consideration for students [2], [11] and one of the reasons parents believe engineering is a good career choice for their children [1].

As expected, not all students that begin in engineering remain and graduate with an engineering degree. However, engineering has one of the highest rates of persistence between 57% [7] and 65% [10]. Despite the higher rate of persistence, recruitment is a considerable issue for engineering. Of all engineering students in their eighth semester, 90% began in engineering; this proportion is considerably higher than any other group of majors [7]. These statistics are also concerning because even though persistence in engineering is high, there can be high fluctuation in the number of students graduating with an engineering degree; for example, more students graduated with engineering degrees in 1985 than in 2010 [12].

Seymour and Hewitt have reported that many students who are capable of earning STEM degrees leave their degree programs [13]; this trend continues with more than 10% of students with GPAs of at least 3.5 switching from STEM majors [10]. The Persistence in

Engineering (PIE) survey has been used to identify some of the differences between students who do and do not persist in engineering degrees – sources of motivation, confidence in math and science skills, and financial concerns [4]. In that study, more non-persisting students were motivated by their family, while students who persisted were motivated by a high school mentor. Confidence in math and science skills were also a differentiating factor; students who persist are more confident in those skills than students who do not persist. While there are some differences between these two groups of students, many of the factors in the survey instrument were not significantly different for students who did and did not persist in engineering [4]. This conclusion is consistent with Seymour and Hewitt's conclusion that the differences cannot be identified by "high school preparation, performance scores or effort expended" [13].

2.2 Engineering Disciplines & Perceptions

Another of Seymour and Hewitt's conclusions is that interest in the discipline and the careers that follow are "conducive to persistence" [13]. The factors that influence major selection are important for engineering educators to know so that the factors can be used to foster interest [3]. The work to identify these factors includes understanding the perceptions that students have of the engineering disciplines. Research has shown that first-year engineering students consistently identify many important topics that are familiar to all engineering disciplines, such as maintenance, research, and processes [14]. Additionally, students ascribed mechanical engineering as having the most "options;" this may be due to the marketing of the major, its general perception as a "broad discipline," or the wide variety of work that is performed by mechanical engineers. This study found that while some perceptions were broadly held, the disciplines were perceived differently based on the students' majors and the institution they attended [14].

Main *et al*. [15] showed significant differences in the impacts of cooperative education programs on the timeline to and the likelihood of graduation when disaggregating results by the discipline, which serves as a strong argument for reporting, and therefore studying, engineering education by major as well. Additionally, the disciplines have been shown to have their own cultures [16], [17]. These cultural differences are seen in social behavior as well as methods of teaching and learning; some disciplinary cultures are also seen as more welcoming of women [16]. The unique content in each of the engineering majors is also evidenced by the multiple versions of the Fundamentals of Engineering (FE) exam [18].

2.3 Matriculation Models & First-Year Courses

Matriculation models vary across institutions. However, two matriculation models are more common – direct matriculation to engineering majors with common coursework required for all majors (DMa) and first-year engineering programs (FYEPs) where students are housed in a non-degree granting program before matriculating to their specific engineering major [19].

There are advantages to both models. A study by Orr *et al.* [6] found that 89% of students who graduated in engineering after completing an FYEP graduated in their first engineering major. The authors also found that students who matriculate directly to an engineering major and went on to graduate also have a high retention rate in their first major at 78%. Direct matriculation models also help students avoid feeling disconnected from their future majors, which is sometimes problematic for FYEPs. However, students in FYEPs have slightly higher retention rates to the third semester compared to direct matriculation institutions [20].

A study by Brawner *et al.* [21] found that even though a matriculation model can have effects on students, few students were aware of the model used by institutions at the time of application. The same article also reported that students who enrolled in first-year engineering courses that included information about disciplines offered at their institutions were able to either confirm their discipline selection or use the information to make a discipline selection. A similar study also reported that required introduction to engineering courses could help students make discipline selection decisions as well as increase retention [22]. First-year engineering courses have also been described as having a "polarizing effect" on students' certainty in pursuing an engineering degree [23].

While first-year engineering courses have been found to have impacts on students, not all first-year engineering programs are the same, even among institutions with the same matriculation model. Reid and Reeping [24] developed a classification scheme to categorize the different types of first-year engineering courses based on course content. The scheme has eight unique categories for classification including academic advising, math skills, design, and the engineering profession. It is more difficult to categorize courses over time because, as the authors note, these courses are often “designed by instructors to meet their preferred objectives” [24] which can lead to changes in course content over time. However, courses that focus on the Engineering Profession and Academic Advising are likely more beneficial to students deciding on or confirming their engineering major.

2.4 Factors Students Consider During Major Selection

A study by Meyers *et al.* [25] investigated how outcome expectations and self-efficacy are considered by first-year students' during major selection. These factors are part of Social Cognitive Career Theory [26], [27] and represent the anticipated results from completing a task and the confidence in one's ability to complete tasks, respectively. Performance outcomes, a source of self-efficacy, were the most significant factor for students in each of the five engineering departments studied. Students intending to major in Civil and Environmental Engineering mentioned outcome expectations more frequently than other majors; for example, "I wanted it to have some sort of impact on people." The authors note that this major's emphasis on outcome expectations could be due to the perception of societal impact after graduation [25].

Another study found that a single-item measure of confidence in major choice was a significant predictor for students staying in their intended engineering major at admission to their declared major one year later, after completing an FYEP [28]. While this item was found to be predictive of major changes within engineering, it is not predictive of remaining or leaving engineering in general. These results were consistent with a previous study that found that students who graduated in the same engineering major as they entered had the highest levels of confidence in their intended engineering major and in engineering as a career choice [29]. Additionally, among first-year female engineering students, confidence in engineering in general and their choice of engineering major increases over their first semester [30].

3 Theories, Models, and Metaphors

Overall, this work seeks to better understand the process surrounding first-year engineering students' major selection through three complementary studies. Because this work investigates different aspects of the major selection process – namely, the times when students enroll, students' perceptions of the majors in which they are enrolling, and the impact of a major exploration course – no single framework was appropriate to contextualize the entirety of the major selection process. Instead, theories, models, and metaphors were independently selected for each study to highlight the relevant constructs of the study to offer an explanation of quantitative results and to inform the interpretation of qualitative results.

The Study of Enrollment in Chapter 4 uses the Attraction-Selection-Attrition Framework (ASA), the Student Integration Model, and the engineering metaphors to frame when and where students enroll in their graduation majors. ASA will serve as a framework for this study because of its assumptions that students who do not fit in an environment are more likely to leave and those that do fit are most likely to be retained. The Student Integration Model is included because it frames persistence, or fit from ASA, as the successful integration both academically and socially and attrition as unsuccessful integration in one or both. This provides additional levels of possible explanation of findings related to major switching, or a lack thereof, that are not available in ASA alone. The engineering ecosystem metaphor is included because both ASA and the Student Integration Model would consider each of the engineering majors separately, but the ecosystem recognizes the interactions between them.

The Study of Perception in Chapter 5 uses Social Cognitive Career Theory (SCCT) and Expectancy Value Theory (EVT) to frame first-year students' perceptions of engineering in general and of their intended engineering majors. SCCT was selected because the survey questions analyzed in this study focus on outcome expectations, a construct of the theory. Some survey responses also mention values students hold which is not central to SCCT. So, EVT and its multiple task values was selected as a supplementary framework to help frame the additional details in those responses.

Like the Study of Enrollment, the Study of Exploration in Chapter 6 uses the Attraction-Selection-Attrition Framework and the Student Integration Model to frame the impacts of a major exploration course on student's confidence in major choice, major changes, and fit and satisfaction in engineering in general and their intended engineering major. ASA was selected as the framework for this study because one of the constructs being investigated are students' fits in both engineering and their intended engineering majors. As before, the Student Integration Model is also used because it considers persistence to the result of both academic and social integration at an institution, or in this case a degree program, and adds additional perspective when considered with ASA.

This chapter presents an overview of each theory, model, and metaphor that will be used in the subsequent studies. Within each of the next three chapters, a discussion of the theoretical framework will also be included.

3.1 Attraction-Selection-Attrition Framework

The Attraction-Selection-Attrition Framework (ASA) [31], from industrial & organizational psychology, uses its three namesake constructs to explain person-environment fit. As a result of the ASA cycle, organizations become homogenous and develop a culture, which is also influenced by the organizations' goals. ASA assumes that students are attracted to majors in which they are interested, and that the environment is a function of person and behavior. The outcome of these assumptions though is that majors are more likely to become more homogenous over time and develop a culture because of the students attracted and then selected or admitted. Work by Godfrey [16], [17] on the cultures of the engineering disciplines shows there is evidence that these homogenized cultures already exist in the engineering majors which speaks to the relevance of this framework.

ASA does not posit that individuals who do not find fit *should* leave an environment or an engineering major, only that individuals who do not find fit are *most likely* to leave, a process of attrition. Therefore, students who are qualified and able to complete an engineering major may leave or be pushed out because of a lack of fit in the culture, which has been largely shaped by the White male majority, when they could be successful in the major if they were retained. So, majors where students enroll later, presumably after leaving another major, could be indicative of more welcoming and inclusive cultures.

Because this work will utilize institutional data, students who have and have not switched majors will be identified. This framework will provide a possible explanation for why students chose to persist or switch from their engineering majors.

3.2 Student Integration Model

The Student Integration Model [32] describes persistence at or dropout from an institution as longitudinal processes with an emphasis on academic and social integration and their impacts on goal commitment and institutional commitment. Tinto argues that the more an individual student is integrated into the academic and social systems at their institution, the more likely that student is to persist and graduate from the institution. In the model, academic integration is a combination of grades and intellectual development while attending the institution. Social integration is seen as interactions between the student and other people, both students and faculty, who have varying personal characteristics.

Should a student only be integrated into one of the two systems, dropout could occur. Tinto argues that lack of integration into one system results in different kinds of dropout [32]. For example, if a student is only integrated into the academic system, but has not integrated into the institution's social system, the student may choose to voluntarily dropout or withdraw. However, if a student is integrated socially, but is not integrated into the academic system, the student could be dismissed from the institution due to insufficient grades, an involuntarily dropout. Because graduation is connected to goal commitment and academic integration, it has been suggested that academic integration is "somewhat more important" than social integration [32].

In Chapter 4, the sample is limited only to students who graduate with an engineering degree. Therefore, students who are either dismissed from the institution or voluntarily withdraw from the institution due to a lack of academic and/or social integration are not included. However, applying Tinto's model to a degree program, engineering students could withdraw from one engineering major due to a lack of academic or social integration within that program but could still integrate into a different engineering major. Because Tinto makes the case that withdrawal "appears to relate to the lack of congruency between the individual and both the intellectual climate of the institution and the social system," [32] and Godfrey has identified different subcultures by engineering discipline, leaving a discipline equates to leaving the corresponding academic and social systems.

Work by Cabrera *et al*. [33] has shown that Tinto's Student Integration Model [32] has similarities with Bean's Model of Student Departure [34], [35]. In their work, Cabrera *et al*. [33] showed that the courses factor from Bean's model is synonymous with the academic integration factor from Tinto's model. This is useful because the academic integration factor has been shown to be indicative of persistence. The courses factor helps expand the factor because it is defined as "the degree to which a student views the content of the curriculum as desirable" [35].

3.3 Metaphors for Persistence and Attrition in Engineering

Three common metaphors that have been used to describe persistence and attrition in engineering are the pipeline, pathway, and ecosystem [36], [37]. Generally speaking, the pipeline metaphor is most restrictive because it assumes all students begin at the same point and are either retained to graduation or are lost along the way due to a "leak" in the pipe. One critique of this metaphor is that while many students persist in one major from matriculation to graduation, the pipeline metaphor is not inclusive of students with major changes. It has been argued that this traditional metaphor has been favored because it has "worked for the dominant group" [38].

The second metaphor, an engineering pathway, allows for more options from enrollment to graduation including major changes and stop-outs. This metaphor is generally received more positively than pipelines because students play an active role in their degree path instead of being subjected to the system as in the pipeline metaphor [36].

The ecosystem metaphor, which is the third and final metaphor as well as the underlying metaphor for this work, complicates the pathways metaphor by looking at environments, such as departments, within the institution instead of viewing each student's pathway individually. Like the pathways metaphor, the ecosystem metaphor is accepted and has been explicitly applied in a recent study [39].

The ecosystem metaphor is most appropriate for the Study of Enrollment because the focus is when students enroll in their graduation major and how many students are retained by their first major. The ecosystem metaphor is most congruent because these questions are about the academic majors and not individual students. Additionally, because the focus is on students who ultimately graduate in engineering, it is expected that students will not follow a linear path to graduation but may have multiple engineering majors during their academic careers, which is aligned most with the ecosystem metaphor.

3.4 Social Cognitive Career Theory

Social Cognitive Career Theory (SCCT) [26], [27] is primarily interested in the time frame surrounding the preparation for career entry and executing a plan to enter a career. Therefore, this theory seeks to explain interests, choices, and performance during late adolescence and early adulthood, when most people are preparing to enter a career for the first time after completing their education. Even though SCCT is named a career development theory, the authors note that it also explains academic development to the extent that it represents preparation for a career. This is often the case in engineering, as many engineering careers require an engineering degree. The theory seeks to explain the interdependence of people and their environment. In addition to self-efficacy and outcome expectations, the theory also uses goals as a significant factor with complementary models of interest, choice, and performance [26], [27].

Self-efficacy is the confidence people have about their perceived ability to complete a domain-specific task and answers the question, "Am I capable of completing this task?" While self-efficacy can be correlated with ability, it is not the same as ability [26]. It is possible that a person has a lot of confidence in their ability to complete a task (and thus has high self-efficacy for the task) but does very poor when actually completing the task (and thus has lower ability for the task). Successful task completion is one source of self-efficacy and often the most influential source, but there are four in total, as proposed by Bandura. In a 1977 paper [40], he proposed the four sources of self-efficacy as: (i) performance accomplishments, (ii) vicarious experience, (iii) verbal persuasion, and (iv) emotional arousal. Vicarious experiences include hands-on activities and verbal persuasion could include feedback from an instructor or peers. Emotional arousal is the emotions surrounding tasks including the emotions people have as they approach different tasks.

Outcome expectations are the perceived positive and negative consequences of completing a task and answers the question, “What will happen if I complete this task?” Positive outcomes could include money, approval, and self-satisfaction. Negative outcomes could include fines, poor grades, and non-support from family and friends. As these examples illustrate, consequences can come in many forms including physical, social, and self-evaluative [26].

SCCT proposes that people form lasting interests in tasks in which they have both high self-efficacy in their ability to complete and expect to receive positive outcomes expectations for their completion. Consequently, goals are influenced directly by interests, self-efficacy, and outcome expectations. Interests then indirectly inform the actions that a person tasks through goal selection. Ultimately, the outcomes of an action or task create a feedback loop that inform both self-efficacy and outcome expectations, which then informs interests [26], [27].

This feedback loop is not necessarily immediate. Because the feedback does not immediately inform interests, a time delay can occur. The time between the performance outcome and any change in interests also depends on which of the sources of self-efficacy and outcome expectations are informed and how salient that source is to the person's interests.

The choice model of SCCT, which will be the center of the framework in the Study of Perception, is shown in Figure 3.1. Self-efficacy and outcome expectations drive interests, which in turn inform choice goals. The choice goal then leads to choice actions, which will eventually lead to feedback as a result of some performance. For example, a student may decide to major in chemical engineering, a choice goal. Then, the student would begin to take action in order to achieve the goal, like talking to an advisor and officially declaring the major. Finally, the student will receive feedback on their performance, for example, an acceptance or rejection notice from the chemical engineering major or receiving a test grade.

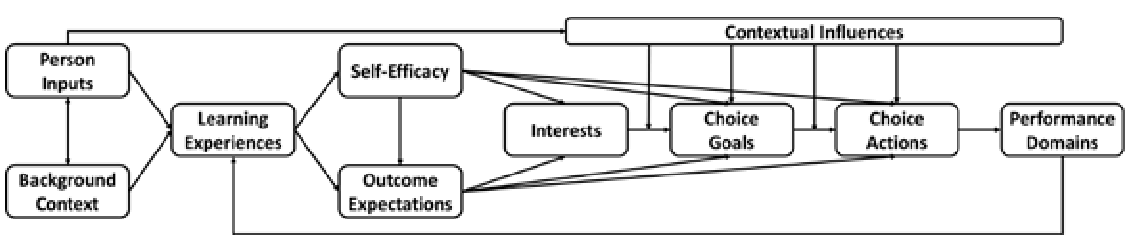

Figure 3.1 – The Choice Model of Social Cognitive Career Theory [26]

These choices are not static and do not occur in a vacuum. For example, a performance outcome could be a poor grade on a first-year engineering or chemistry exam, which ultimately causes the student to reconsider their major and make a choice to change their goals and subsequent actions; for example, declaring a major other than chemical engineering [26].

The choice model highlights the importance of goals and contextual influences on choices. Goals are even more important when they are specific, attainable, realistically achievable based on a person's own control, and set not too far into the future. In this model, contextual influences are the mechanisms for including the effects of gender, race, and ethnicity. Contextual influences also include potential barriers to a choice [26]. For example, some engineering majors have minimum first-year GPA requirements [41]. Because interests inform choice goals, this model assumes that people make career and academic decisions based on their interests. According to SCCT's choice model, the choices made and the outcomes attained provide a feedback loop to inform interest development and choices indirectly through learning experiences, self-efficacy, and outcome expectations.

3.5 Eccles' Expectancy-Value Theory

Additionally, Eccles' Expectancy-Value Theory (EVT) [42], [43] will be used to frame the Study of Perception. While this theory has many constructs that influence achievement-related choices, the two namesake constructs are the only two proposed to have direct effects on choices and thus will be the focus here.

The expectancy construct is focused on a person's perceived chance of success at completing a given task [42]. The task value construct is multifaceted and includes four additional constructs [43]. The first of these task values is the *interest value* which is a person's enjoyment in completing the task or the expected enjoyment in a future task. The *attainment value* is the amount of personal importance a task has or how consistent a task is with one's sense of self, similar to identity. The *utility value* is the future usefulness of completing a task. The final task value is *relative cost* which describes the amount of effort or time a task requires, including the loss of other tasks or activities that could have been completed, and potential impact if attempting the task is unsuccessful [42], [43]. Oppositive of the other three task values, a lower relative cost correlates with a higher perceived task value. Evidence supports the usefulness of this theory and especially the task value constructs in predicting achievement-related choices [44].

3.6 Conclusions

Used in combination, these theories will provide appropriate frameworks for the three complementary studies that follow. The Study of Enrollment will use ASA as a framework because of its assumptions that students who do not fit in an environment are more likely to leave. This will be combined with the Student Integration Model because it includes academic and social integration as important for persistence. Because the study looks at engineering majors as systems, the engineering ecosystem metaphor is also included. The Study of Perception focuses on students' outcome expectations in engineering and the engineering majors, so SCCT was selected as the framework because outcome expectations are a central part of the theory. EVT will supplement the framework because some students also mention the task values important to that theory. Lastly, ASA was selected as the framework for the Study of Exploration, because survey items asked about students' fit in both engineering and their intended engineering majors. Because academic and social integration are important for persisting in a degree program, like at an institution, the Student Integration Model is also used.

The theories can also be combined into one overarching framework as shown in Figure 3.2. Using Social Cognitive Career Theory (SCCT) [26], [27] as the baseline, the task values of Expectancy-Value Theory [42], [43] help to expand different aspects of SCCT. The utility value can be associated with outcomes expectations because both are forward-looking. The attainment value can be seen as informed by interest, self-efficacy, and contextual influences because of its focus on self. The interest task value is closely related with the native interest construct of SCCT, and the cost task value is likely to influence choice goals, similar to self-efficacy, outcome expectations, and interests.

The academic and social integration factors from the Student Integration Model [32] can be viewed as part of the SCCT performance domains because integration is considered important for persistence while the performance domains are feedback on a choice action that can lead to persistence. Especially for academic integration, the SCCT performance domains may influence the integration factors. Lastly, the core constructs of the Attraction-Selection-Attrition Framework [31] can also help expand theoretical understanding of students' major selection process. The attraction phase is like selecting a choice goal or a major that is intended to become a student's actual major. The selection phase is like actually declaring that major and taking a choice action to make the major official. The attrition phase is a possible outcome of the performance domains as well as academic and social integration if a student is not satisfied with their original choice and needs to select a new major. These three constructs are grouped together because any one or any combination could cause a student to leave a major either by choice or by policy requirement. This change of major then serves as a learning experience to inform a new major selection.

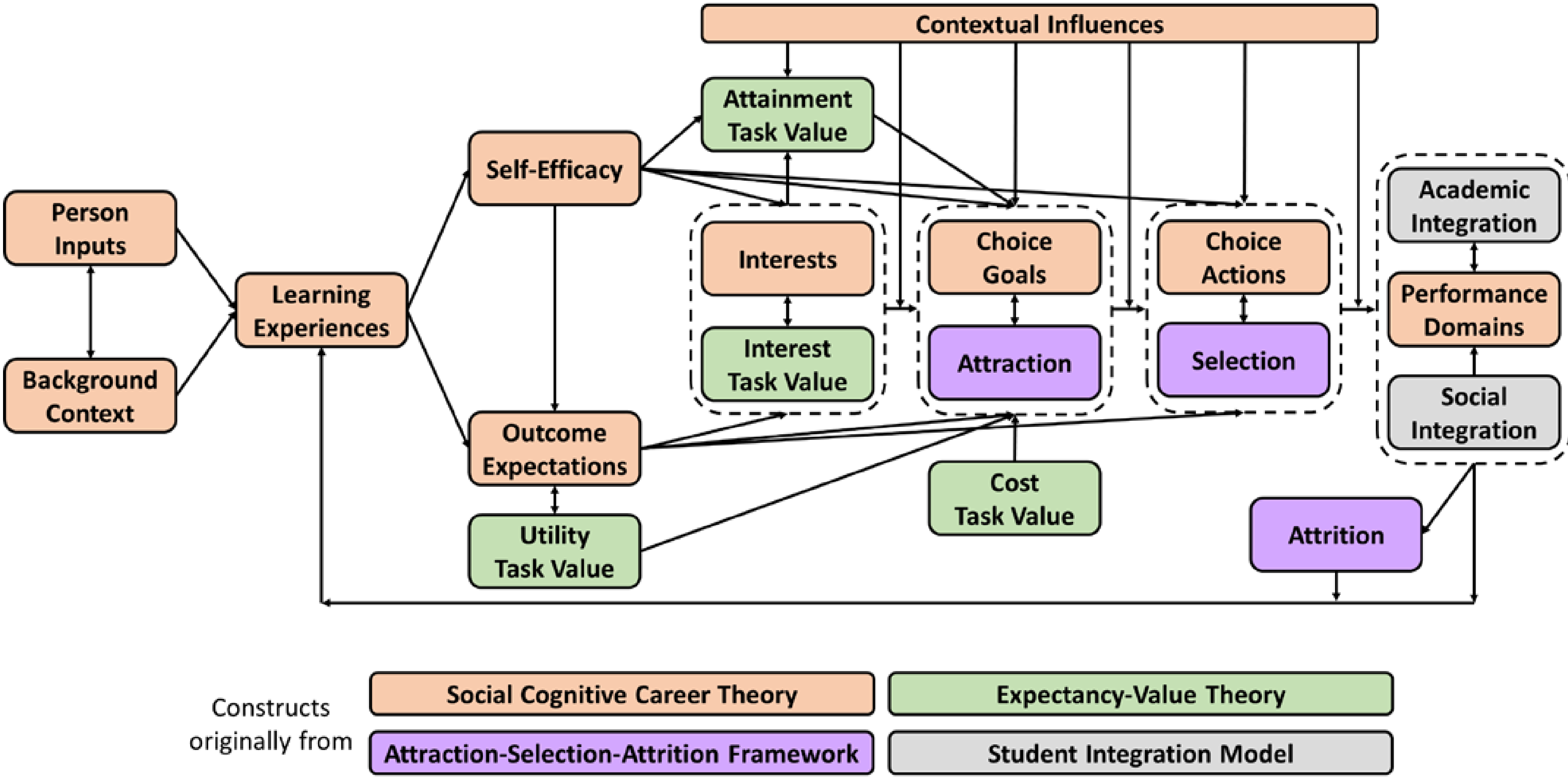

Figure 3.2 – Expansion of Social Cognitive Career Theory with the other Theories and Models Used in This Work

4 Study of Enrollment[1] [2]

While some engineering careers can begin with an engineering degree from any discipline, other jobs require a potential candidate to have studied in a particular field of engineering. Additionally, a student's college major can have a significant impact on their college experience. These two factors combined make choosing a major one of the most critical decisions first-year undergraduate students have to make. Many universities offer first-year engineering programs (FYEPs) that allow students to pre-select into engineering while delaying commitment to a specific engineering major until the conclusion of the first-year program. Even institutions that do not offer first-year programs often include a common first-year sequence that allows students to switch their engineering major without necessitating a delay to graduation.

Matriculation patterns in engineering have been studied at individual institutions [45], [46], and across multiple institutions [21], [47]. Some studies have focused on specific disciplines [48]–[50]. This study will investigate when engineering graduates enroll in their graduation major, the proportion of graduates who persist in their first engineering major, and how each of those vary by discipline-specific major and matriculation model.

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[1] This material is based upon work supported by the National Science Foundation (NSF) under Grant No. 1545667. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the NSF.

[2] Portions of this chapter were originally published in the 2021 Proceedings of the American Society for Engineering Education Annual Conference & Exposition [91].

4.1 Theoretical Framework

This study is framed using a combination of Schneider's Attraction-Selection-Attrition (ASA) Framework [31], Tinto's Student Integration Model [32], and the engineering metaphors that have been used to describe engineering persistence, switching, and dropout [36]. While the data used in this study are institutional records and students' motivations and reasons for changing majors will not be possible to report, these frameworks provide reference for reasons that students are likely considering during their decision-making process.

ASA will serve as a framework for this study because of its assumptions that students who do not fit in an environment, in this case, a specific engineering major, are more likely to leave the major and those that do fit are most likely to be retained by the major. In this context, fit is the congruence of expectations and reality of a major. The Student Integration Model describes persistence, which is related to fit, as the results of both academic and social integration and their impacts on goal commitment and institutional commitment. Correspondingly, switching majors points to a lack of integration in the first major and a desire to integrate into a new one. Finally, the engineering ecosystem metaphor fits with the current study because the focus is when students enroll in their graduation major and how many students are retained by their first major. The ecosystem metaphor is most congruent because these questions are about the academic majors and not individual students.

The data used in this study are institutional records which allow for the observation of major changes during students' academic careers, where conclusions about a student's fit in a major, or lack thereof, is one of several possibilities. Therefore, conclusions from this study will be limited to retention and persistence of the engineering majors. Findings from this multiple-institution study will provide context to explore more recent major changing behavior and perceptions of the engineering majors to explore the connections between perceptions and major changing behavior.

4.2 Research Questions

The research questions in this chapter focus on when and where engineering students enroll in their graduation majors.

RQ1. When did engineering graduates enroll in the major they graduated in? How does this vary by discipline-specific major and/or matriculation model?

RQ2. What proportion of engineering graduates persisted in their first engineering major? How does this vary by discipline-specific major and/or matriculation model?

4.3 Data and Methodology

4.3.1 Data Source

This study utilized an existing national dataset, the Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD) [51]. The version of MIDFIELD used in this analysis was "fix9" of the database originally compiled on March 16, 2020.

This dataset provides longitudinal data for over 1.6 million students who began school during or after the Fall 1987 term. Of those students, over 134,000 students were First-Time-in-College (FTIC), matriculated in engineering, and had six years of data available in MIDFIELD. Of the over 790,000 degrees in MIDFIELD, more than 126,000 degrees are awarded in engineering as identified by CIP code.

The dataset is composed of data for all students who attended a collection of 17 schools, including primarily undergraduate institutions, historically Black universities, and R1 universities [52]. With this diversity of institution types, the MIDFIELD sample is generally representative of the United States engineering student population for race/ethnicity and sex [53].

MIDFIELD [51] is organized into four complementary tables – students, courses, terms, and degrees – that function as four complementary data frames in R [54]. The students table includes one entry for each student and details each student's high school records, standardized test scores, matriculation term, matriculation major, institution attended, transfer status, race, sex, and other demographic information. The courses table includes one entry for every course attempted by every student detailing each course taken, the term the course was taken, the grade awarded, and other course details. The terms table includes one entry for each term attended by each student and details the student's academic standing for the term, the student's major for the term, and the student's term and cumulative GPAs. The degrees table includes one entry for each degree awarded to a student, detailing the student's graduation major and graduation term.

4.3.2 Duplicate Student Records

Some individual student records were duplicated in the dataset. These students were removed from the dataset using the unique() function in the R base [54]. However, some students' duplicated degrees are listed as having different terms awarded, but are the same degree awarded to the same students, often by as little as one year apart. These errors were identified, isolated, and reported to the data manager for further exploration in the raw data files from the institutions. The MIDFIELD data manager corrected these errors before analysis continued.

4.3.3 Assigning Matriculation Models

In addition to the student data, MIDFIELD also includes policy summaries for each of the member institutions that describe admission requirements, matriculation practices, and degree progression [55]. These policy summaries combined with the Chen *et al.* taxonomy of matriculation models in engineering [19] informed the classification scheme used in this study.

The four different matriculation models used to describe the MIDFIELD institutions are:

1. FYE – First-Year Engineering Program; a formal program where all students take the same first-year classes with a formal designation as an FYEP student,
2. DtD – Direct to Department; students declare an engineering major when entering the university,

3. Pre – Pre-engineering / pre-major; students are enrolled in pre-engineering or a major-specific pre-major (e.g., pre-EE); students must meet requirements to move to the degree-granting major, and
4. DtU – Direct to University; students do not have a major until certain requirements are met or a certain amount of time passes.

The matriculation model for each institution was appended to the degrees table by institution. For the institution that has varying matriculation models during the study period, the matriculation model was appended based on each student's entry term as recorded in the students table.

After the matriculation models were appended to each degree record, the seven institutions originally classified as FYE were separated to ensure that all of those students matriculated to an FYEP as expected. Approximately 84% of students expected to be enrolled in an FYEP major at matriculation were enrolled in one. Three institutions had low or no (≤2%) FYEP enrollment despite being classified as FYE institutions. These discrepancies were investigated, and two institutions were reclassified as DtD and the other was removed. The institutions that were reclassified had descriptions of FYEPs in their course catalogs; however, in MIDFIELD, students from those institutions matriculated to engineering majors. Therefore, these institutions did not meet the FYE study criteria which requires a formal designation as an FYEP student in addition to the common coursework. A third institution was removed because it admitted students into a General Studies program in the first year, not a dedicated FYEP.

Another institution allowed for a combination of two matriculation models – FYE and DtD – and was excluded from analysis due to the inability to classify students appropriately.

Due to a small number of students from a small number of institutions using the Pre and DtU matriculation models, students who matriculated under either of these matriculation models were excluded from analysis due to our inability to draw conclusions based on the sample available. The final sample includes students from 11 institutions; three institutions are classified as FYE and eight institutions are classified as DtD.

4.3.4 Inclusion Criteria

Because there are over 1.6 million student records in MIDFIELD from 17 institutions from students who ever attended those institutions since 1987, the sample of interest was identified from within the database. The identification and subsequent quantitative analysis were completed in the R programming environment [54].

Using the degrees table, I filtered to include only degrees awarded in engineering, including the designation of the specific engineering major awarded. The degree was considered to be in engineering if the National Center for Education Statistics' Classification of Instructional Programs (CIP) [56] code began with 14 (e.g., 140701) indicating classification as an engineering program. Then, using the students table, I created a list of students who were First-Time-in-College (FTIC) students and matriculated in engineering. These indicators are necessary because transfer students have very high retention rates in their matriculation majors and do not have similar experiences as first-year students. Additionally, similar to transfer students, students who switch into engineering would likely have considerably different experiences from those students who matriculate into engineering. I then created a subset of the list of FTIC students who matriculate into engineering by removing students with less than six years of data available in MIDFIELD; i.e., six years have passed since the student enrolled and the six years of data are available in MIDFIELD.

I created a subset of the engineering degrees earned by the FTIC students who matriculated in engineering and have at least six years of data available in MIDFIELD. I then copied each student's matriculation term, matriculation major, and traditional demographic data to a newly created data table. The final inclusion criterion is students' full-time status in their first non-summer term. Because students who attend part-time will have different timelines to their enrollment in their graduation major and to graduation, students who do not attend full-time in their first semester are excluded. Full-time status in the first term is considered a proxy for intention to enroll full time for the duration of the degree program.

One MIDFIELD institution offers one engineering degree whose CIP code begins with 14 but is not offered in the institution's College of Engineering and is therefore removed from analysis. Students who completed this degree program as a second major to any other engineering program at the institution are retained. Additionally, students who complete this degree program at other MIDFIELD institutions, where it is included in the College of Engineering, are retained.

4.3.5 Enrollment in Graduation Major

I created individual subsets of the terms table that included all the terms attended in which at least one course was attempted for credit or the student was on co-op for each student in the pre-sample until their graduation term. Each term record includes the students' major for the term, as well as a code for the semester and year of the term. With students' individual terms data, I worked backward through the data and identified the first term that students enrolled in their graduation major and then did not leave the major until graduation. Working backward is important, so that students whose path is, for example, FYEP → Mechanical → Civil → Mechanical → Graduation, are counted at the second instance of Mechanical because those students did not initially persist in the major.

During this process, I also recorded students' majors immediately before they enrolled in their graduation major (if the student had one), students' majors immediately after completing an FYEP (if the institution offered an FYEP) or otherwise leaving a general engineering designation at institutions without an FYEP, and the students' major during their third term (for general comparisons between FYE and DtD institutions).

Because I compiled students' matriculation terms from the students table and determined the term that students enrolled in their graduation major using the terms table, I calculated the time difference between matriculation and enrollment in graduation major by counting the number of terms between matriculation term and term enrolled in graduation major, for each student. Results will be reported using the number of fall and spring (15-week) semesters with the following equivalencies:

- fall, winter, and spring (10-week) quarters are considered ⅔ of a semester,
- full summer (12-week) semesters are considered ⅘ of a semester, and
- partial summer (6-week) semesters are considered ⅖ of a semester.

4.3.6 Consistency Markers

As part of data validation, I checked to make sure that the major recorded in the graduation term in the terms table matched the degree awarded in the degrees table for that student. I also checked to make sure that the term the degree was awarded matched the last term in the term table for the student, after removing any terms after the degree was awarded. I created "graduation major consistency" and "graduation term consistency" markers to track students who did and did not have consistent graduation majors and terms. If a student did not have a consistent graduation major due to earning multiple degrees, I checked to see if the second degree matched the last major in the terms table if both degrees were awarded at the same time. If the second degree awarded matched the major in the terms table for the graduation term, the degrees were reordered in the pre-sample data because when a student earned two degrees simultaneously the labels for "degree 1" and "degree 2" were applied arbitrarily. The "graduation major consistency" marker was also updated to "T" for true in these instances.

Two additional markers were created and used to indicate if a student's first entry in the term table had an identical term and major compared to the information provided in the students table, which includes matriculation information. On each metric, students with consistent data were labeled as “T” and those without consistent data were labelled as “F” for false.

With all four consistency markers – matriculation term, matriculation major, graduation term, and graduation major – labeled for each student, a final consistency marker was created to identify if a student had consistent data for all four markers. If all four consistency markers were “T” then this final consistency marker, labeled “all metrics consist,” was labeled as “T”; however, if even one of the original four consistency markers was “F,” then the “all metrics consistent” marker was also labeled as “F.”

The final sample was then identified as the subset of the pre-sample that had a value of “T” for “all metrics consistent.”

4.3.7 Sample Demographics

The final sample includes 48,664 full-time, first-time-in-college engineering graduates who met the inclusion criteria and passed quality checks described above. The composition of the sample by race/ethnicity and sex is provided in Table 4.1. This sample contains more White engineering graduates than the graduating engineering population in the United States, presented in Table 4.2 [57], likely due to the exclusion of certain institutions due to matriculation model and the age of the dataset. The median degree term for the sample is Spring 2001.

Table 4.1 – Sample Composition by Race/Ethnicity and Sex as Reported in Institutional Data

	White	Asian	Black	Inter-national	Hispanic / Latinx	Native American	Other / Unknown
Male	63.4%	4.8%	3.3%	5.0%	2.0%	0.2%	1.5%
Female	14.4%	1.3%	2.2%	1.0%	0.6%	0.1%	0.4%

Table 4.2 – Engineering Graduates by Race/Ethnicity and Sex as Reported by ASEE in 2017-2018 [57]

	White	Asian	Black	Inter-national	Hispanic / Latinx	Native American	Other / Unknown
Male	43.8%	9.6%	2.8%	8.2%	7.9%	0.2%	5.4%
Female	11.2%	3.6%	1.0%	2.3%	2.3%	0.1%	1.6%

While most of the institutions included in this study use the DtD matriculation model, the composition of students by matriculation model is closer to evenly split. This is because the three institutions using the FYE matriculation model are large, public institutions with well-established engineering programs, including their FYEPs. The composition of students by matriculation model and graduation major is shown in Table 4.3 for majors that graduate at least five percent of the sample population and are offered by at least one institution in each matriculation model. Engineering majors that enroll less than five percent of all students are collapsed into the "Other Engr" category.

Table 4.3 – Sample Composition by Matriculation Model & Graduation Major

Grad Major	Abbr.	DtD Institutions	FYE Institutions	TOTAL
Mechanical	ME	7,004	4,402	11,406
Electrical	EE	4,116	3,416	7,532
Civil	CIV	3,672	3,694	7,366
Chemical	CHE	2,425	2,517	4,942
Industrial	IE	2,381	2,510	4,891
Aerospace	AERO	3,252	1,406	4,658
Computer	CPE	1,568	1,918	3,486
Other Engr	otherEngr	1,923	2,460	4,383
TOTAL		26,341	22,323	48,664

Because students in this study are engineering graduates, the enrollment by major was compared to the number of degrees awarded in the 2017-2018 academic year as published by the American Society for Engineering Education [57]. Mechanical Engineering is underrepresented (23% vs 29%) in this study compared to national data and Aerospace Engineering is overrepresented (10% vs 4%). Aerospace Engineering being overrepresented is not surprising because two of the DtD institutions specialize in that major. All other major studied differ by less than 4% of the national sample.

4.4 Analysis

4.4.1 Overview

To answer the research questions, average times to enrollment in graduation major were compared across different groups. To compare these times, Welch's t-test was used. The results of the t-test allow for a determination of whether the two averages are statistically different or not. Additionally, the proportion of students enrolled in their graduation major by certain time points were compared. To compare these proportions, Chi-Square Tests of Independence were used. The results of the chi-square test allowed for a determination of whether the two proportions were statistically different or not. For both t-tests and chi-square tests, effect sizes (Cohen's d and Cramer's V, respectively) were calculated for any statistically significant difference in order to comment on the practical importance of the difference.

4.4.2 Chi-Square Tests of Independence and Cramer's V

Chi-Square Tests of Independence were used to determine if two variables in a cross-tabulation of data were independent of one another. The cross tabulation had R rows and C columns of data with a sum of observations for each row and column. To complete the test, the actual values for each combination of variables, N_{RC}, were compared to the expected value for that combination of variables, E_{RC}. The expected value for the RCth cell of the table, E_{RC}, was the product of the Rth row total, $N_{R.}$, and the Cth column total, $N_{.C}$, divided by the total number of observations, N [58]:

$$E_{RC} = \frac{N_{R.}\, N_{.C}}{N} \tag{4.1}$$

The test statistic, χ^2, was then calculated as the sum of the square differences of the actual and expected values for each cell divided by the expected value for the cell [58]:

$$\chi^2 = \sum_{RC} \frac{(N_{RC} - E_{RC})^2}{E_{RC}} \tag{4.2}$$

The number of degrees of freedom, df, for the test was the product of one less than the number of rows and one less than the number of columns [58]:

$$\text{df} = (\text{R} - 1)(\text{C} - 1) \tag{4.3}$$

Using a null hypothesis that the variables were independent of each other and the alternative hypothesis that the variables were dependent, the null hypothesis was rejected if twice the probability that the critical value was greater than the test statistic, commonly called the "p-value", was less than the allowable Type I error, α.

With large samples, like those in this study, rejecting the null hypothesis of chi-square tests is not uncommon [59]. Therefore, Cramer's V was calculated to determine the effect size. The calculation used the effectsize package [60] in R [54]. Cramer's V was calculated as the square root of the quotient of the test statistic from the Chi-Square Test of Independence, χ^2, and the product of the total number of observations, N, and the minimum of the number of rows or columns, M, minus one:

$$\text{V} = \sqrt{\frac{\chi^2}{\text{N}\,(\text{M} - 1)}} \tag{4.4}$$

Cramer's V can range from 0 to 1 meaning no association and perfect association, respectively. Between the extremes, values of 0.1 suggest an effect that is not very meaningful, values of 0.3 suggest a medium effect, and values of 0.5 suggest a large effect [61].

4.4.3 Welch's t-tests and Cohen's d

To determine if there was a significant difference between two population means, t-tests are commonly used. The more common version of the t-test, commonly called Student's t-test, assumes that the two samples have equal variances and nearly equal sample sizes. However, these two assumptions were difficult to meet in this study due to the uneven sample sizes. To overcome the limitations of the Student's t-test, also called the Equal Variance t-test, a second test that allows for unequal variances and sample sizes, the Unequal Variance t-test or Welch's t-test, was developed by Welch [62], [63].

In order to calculate the test statistic, t, for Welch's t-test, the sample means, y_i, sample variances, s_i, and the sample sizes, n_i, are required. The statistic was then calculated as [62]:

$$t = \frac{y_1 - y_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \tag{4.5}$$

And the degrees of freedom were calculated as [62]:

$$df = \frac{(n_1 - 1) * (n_2 - 1)}{\left(1 - \frac{\frac{s_1^2}{n_1}}{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}\right)^2 * (n_1 - 1) + \left(\frac{\frac{s_1^2}{n_1}}{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}\right)^2 * (n_2 - 1)} \tag{4.6}$$

Using a null hypothesis that the means were equal to each other and the alternative hypothesis that the variables were not equal to each other, the null hypothesis was rejected if twice the probability that the critical value was greater than the test statistic, commonly called the "p-value", was less than the allowable Type I error, α.

After a determination of statistical significance, Cohen's d was calculated as a measure of practical importance that is not influenced by sample size. There are multiple versions of Cohen's d based on the t-test used. I used what Cohen [64] describes as Case 2 with unequal variances, which complements the use of Welch's t-test. The calculation used the effectsize package [60] in R [54] with pooled_sd = *FALSE*. Cohen's d was calculated as the difference in the sample means divided by the average variance [64]:

$$d = \frac{A_1 - A_2}{\sqrt{\frac{\bar{A}_1^2 + \bar{A}_2^2}{2}}} \tag{4.7}$$

Cohen's d has a minimum value of 0 meaning there is no practical difference but does not have a maximum value. However, there are generally accepted values for interpreting Cohen's d; values of 0.2 suggest a small effect, values of 0.5 suggest a medium effect, and values of 0.8 suggest a large effect [64].

4.5 RQ1 – Time to Enrollment in Graduation Major

4.5.1 Paths to Graduation Majors

Implicit in an investigation into the time it takes for engineering students to enroll in what will become their graduation majors comes an assumption that students do not always begin their undergraduate careers enrolled in that major. At DtD institutions, most students begin in a degree-granting engineering major, though some choose a non-degree granting, undesignated, or undecided option. At FYE institutions, all students begin in an FYEP from which students then move to a degree-granting program. This requirement for students at FYE institutions essentially guarantees that the earliest a student at an FYE institution could be enrolled in their graduation major is one year after matriculation to the institution.

To confirm and visualize that not all students who will graduate immediately matriculate to their graduation major, I created two Sankey diagrams, one for each type of institution – DtD in Figure 4.1 and FYE in Figure 4.2. In the left column of each diagram are students' first non-FYEP majors. For students at DtD institutions, this is normally the students' matriculation majors and at the FYE institutions, this is students' majors immediately after completing the required FYEP. The right column in each diagram is students' graduation majors. Engineering majors that enroll less than five percent of all students are collapsed into the *otherEngr* category. Students who enroll in a non-engineering major after completing an FYEP are categorized as *nonEngr*. The width of the ribbon between each matriculation and graduation major indicates the relative number of students who follow that path.

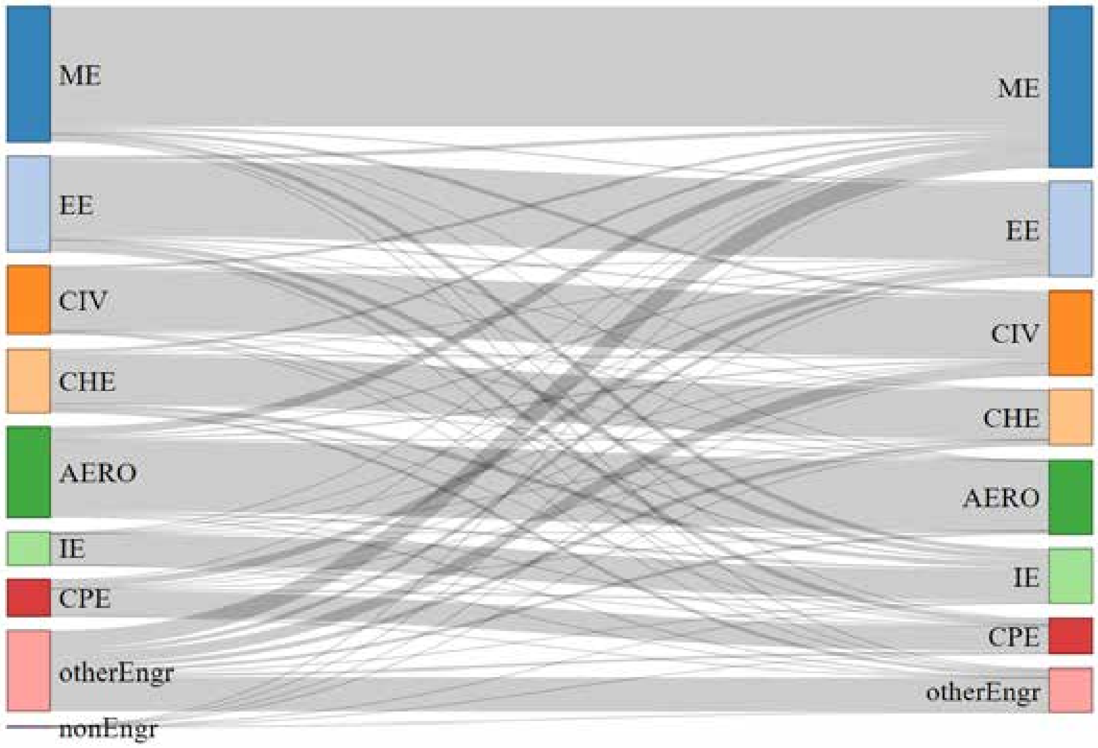

Figure 4.1 – Sankey Diagram for DtD Institutions

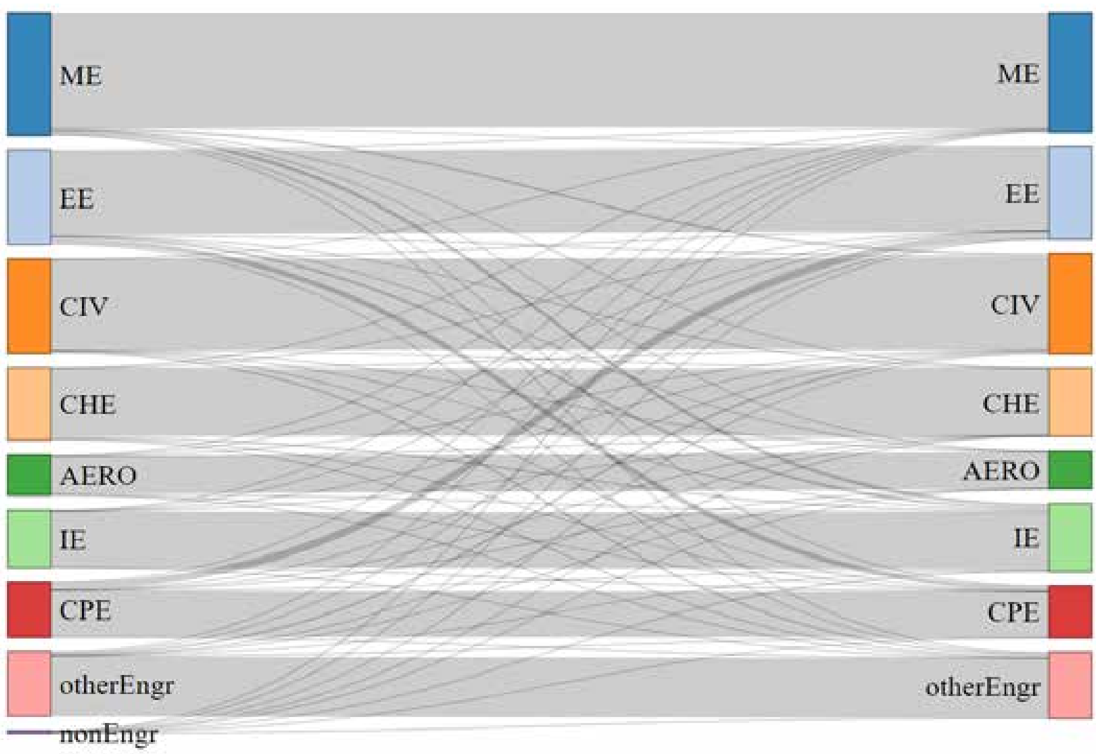

Figure 4.2 – Sankey Diagram for FYE Institutions

At both types of institutions, most students never switch majors and graduate in their matriculation major or their first major after completing an FYEP. However, by visual comparison alone, there are more major changes at DtD institutions compared to FYE institutions. At DtD institutions, the most common changes are from matriculation in lower enrolled engineering majors in the *otherEngr* designation to graduation in Mechanical Engineering and Civil Engineering. The two most common changes at FYE institutions are from a first degree-granting major of Computer Engineering to graduation in Electrical Engineering and vice versa.

The visual differences between the institution types could partly be due to the fact that some major changes in the first year at FYE institutions are changes to intended engineering major that are not officially documented and therefore cannot be visualized in the Sankey diagram. Additionally, because engineering majors with lower enrollments were collapsed into the *otherEngr* designation, some students may switch between majors in this category, but these changes are not visualized on either Sankey diagram for simplicity and readability.

Given the potential time advantage students at DtD institutions have to enroll in their graduation majors at matriculation, but the increased frequency of students switching away from their matriculation majors at DtD institutions, the remainder of Section 4.5 will be an exploration of the time it takes students to enroll in their graduation majors at each institution type.

4.5.2 By Matriculation Model

Figure 4.3 shows the cumulative percent of students who will graduate enrolled in their graduation major by semester for both matriculation models. The figure shows that nearly 65% of eventual graduates at DtD institutions enroll in their graduation major at matriculation. By nature of a required FYEP, very few students at FYE institutions enroll in their graduation major at matriculation. However, there is a dramatic increase in the number of students enrolling in their graduation major after 2 semesters at FYE institutions, when most students become eligible to declare a degree-granting major.

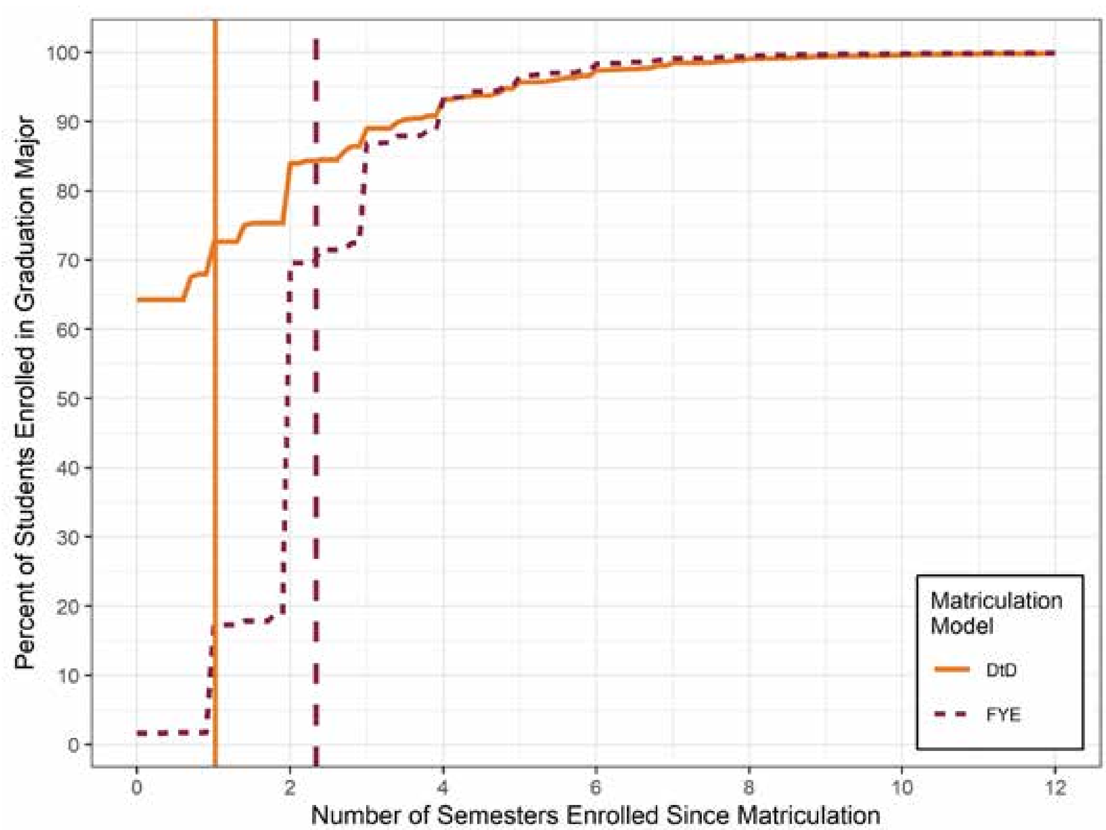

Figure 4.3 – Cumulative Percentage of Students Enrolled in Their Graduation Major by Matriculation Model

By semester 4, over 90% of future graduates in each matriculation model have enrolled in their graduation major and the cumulative percentage enrolled increases consistently toward 100% for both matriculation models. The average time that students at DtD institutions enroll in their graduation majors is 1.02 semesters after matriculation, indicated by the solid vertical line in Figure 4.3; the median time to enrollment is 0 semesters. For students at FYE institutions, the average time to enrollment in graduation major is 2.34 terms after matriculation, indicated by the dashed vertical line, and the median time to enrollment is 2 terms.

Comparing these averages using Welch's t-test, the results are significantly different ($t = 92.02$, $df = 46745$, p-value ≈ 0) with an effect size, calculated using Cohen's d, of 0.825. Unsurprisingly, this result is both statistically different and meaningfully different given the structures of the two matriculation models. Students who are permitted to enroll in a degree-granting major at matriculation enroll in their graduation major sooner, on average, than students required to complete an FYEP.

While most future graduates in each matriculation model enroll in their graduation major at their first opportunity, the difference of the averages of 1.32 semesters is less than the "on-time" difference of two semesters. One of the arguments in favor of a direct matriculation model is that it allows students to assimilate into their major and its culture more quickly than an FYEP allows [6]. The results presented here do not refute this suggestion but help contextualize this perceived advantage of the DtD matriculation model because students in the DtD model only enroll in their graduation major an average of 1.32 terms earlier than students who complete an FYEP, not two semesters (or one year) that might otherwise be expected.

Because the matriculation models are structurally different, in order to better compare the time it takes students to enroll in their graduation major after their first opportunity to do so, I determined the time that students who will graduate at FYE institutions are enrolled in the required FYEP. After identifying the time a student was enrolled in the FYEP, that time was subtracted from the time to enrollment in graduation major since matriculation. The average number of terms enrolled in an FYEP is 2.12 semesters and the median length of enrollment is 2 semesters. Using this adjusted term of enrollment in graduation major, Welch's t-test was repeated.

Compared to the average time to enrollment in graduation major of 2.34 terms after matriculation for students at FYE institutions, the average time to enrollment in graduation major is only 0.23 terms after completing the required FYEP. The median time to enrollment in graduation major after completing the required FYEP is 0 terms, which means that most students at FYE institutions enroll in their graduation major immediately after completing the FYEP. Comparing the averages of time to enrollment in graduation major after the first opportunity to do so using Welch's t-test, the results are significantly different ($t = -60.93$, $df = 38437$, $p\text{-value} < 0.001$) with an effect size, calculated using Cohen's d, of 0.539.

This result indicates that students at FYE institutions enroll in their graduation major more quickly after their first opportunity (the completion of the FYEP) compared to when students at DtD institutions enroll in their graduation major after their first opportunity (matriculation to the institution). This result points to the idea that students use the first year to confirm whether or not to continue in engineering or a particular major [21], [23].

As a final comparison between matriculation models, I determined the number of students enrolled in their graduation major by their third term after matriculation. This determination provides an opportunity to compare the two models at the same time using a time when every "on-time" student has had the opportunity to enroll in a degree-granting major; additionally, because the median time of enrollment in an FYEP is 2 semesters at an FYE institutions, most students at FYE institutions have enrolled in a degree granting major by semester 3. The number of students enrolled in their graduation major by their third semester since matriculation is shown in Table 4.4.

Table 4.4 – Students Enrolled in Graduation Major by Semester 3 by Matriculation Model

	Total Number of Students	**Enrolled in Graduation Major in Semester 3**	
		Number of Students	**Percentage of Students**
DtD	26,341	22,327	84.8%
FYE	22,323	15,689	70.3%
All	48,664	38,016	78.1%

To determine if the percentage of students enrolled in their graduation major by term 3 for each of the matriculation models varied by matriculation model, I completed a Chi-Square Test of Independence. The test resulted in a significant difference ($\chi^2 = 1481$, df = 1, p-value < 0.001). To estimate the effect size, I calculated Cramer's V which has a value of 0.175, which indicates a small effect in favor of the DtD matriculation model with respect to the proportion of students enrolled in their graduation major by term 3. This result helps qualify the previous findings that while students at FYE institutions matriculate to their graduation major very quickly after completing the FYEP, not all students have completed that requirement "on-time" by their third term.

4.5.3 By Engineering Major

Disaggregating by graduation major, the average time that future graduates enroll in their graduation majors varies from 0.73 to 2.44 semesters after matriculation depending on the engineering major; the median times to enrollment vary from 0 to 2 semesters. The average and median time to enrollment in each of the majors that graduate at least five percent of the sample are shown in Table 4.5.

Table 4.5 – Average and Median Times to Enrollment in Graduation Major by Graduation Major

	IE	**CPE**	**CIV**	**EE**	**ME**	**CHE**	**AERO**
Average	2.44	1.98	1.86	1.61	1.39	1.29	0.73
Median	2.00	2.00	2.00	1.40	1.00	1.00	0.00

Notably, Industrial Engineering has the longest average time to enrollment in the major. This result is consistent with other results in the literature that have noted that Industrial Engineering is the only major that accepts at least three percent of students who switch their engineering major after matriculating to a degree-granting major [47] and is the most successful major in graduating students who switch from their first engineering major [37]. The literature has also noted that Industrial Engineering's gains have come from almost all race and gender combinations [65].

While Industrial Engineering has a longer average time to enrollment in the major, this could partly be due to where the major is offered. Looking at Table 4.3, approximately 51% of Industrial Engineering graduates attend FYE institutions. By contrast, only 39% of Mechanical Engineering graduates attend FYE institutions. With a larger proportion of Industrial Engineering graduates attending FYE institutions, the average and median times to enrollment in the major could be skewed higher. Similarly, about 70% of Aerospace Engineering graduates attend DtD institutions, one of which specializes in Aerospace Engineering, which is very likely causing the major's average time to enrollment to be the lowest of those studied.

Therefore, to accurately investigate the individual engineering majors, the data must be disaggregated by both the matriculation model and the engineering major, not only the engineering major. This disaggregation will be the focus of Section 4.5.4.

4.5.4 By Matriculation Model and Engineering Major

Disaggregating the time to enrollment in graduation major by both graduation major and matriculation model, the average time to enrollment varies from a minimum of 0.20 semesters for Aerospace Engineering majors at DtD institutions to a maximum of 2.79 semesters for Industrial Engineering majors at FYE institutions. The mean and median times for each major that graduates at least five percent of the sample for each matriculation model are shown in Figure 4.4 by decreasing average time at FYE institutions. Vertical lines indicate the mean time to enrollment in graduation major for each matriculation model, as previously reported.

Figure 4.4 – Mean and Median Times to Enrollment in Graduation Major by Graduation Major and Matriculation Model

Similar to the results before disaggregation, Industrial Engineering still has the highest average time to enrollment among the majors with average times of 2.06 semesters and 2.79 semesters at DtD and FYE institutions, respectively. This result agrees with the literature in multiple facets. First, Industrial Engineering is among the lowest initially enrolled majors for both DtD and FYE institutions [20]. Similarly, Industrial Engineering has been found to have a net gain of students by attracting more students after initial enrollment than it loses to other majors [49]. And finally, Industrial Engineering has been found not only to attract more students than it loses but is the only major found to attract at least three percent of students from all other engineering disciplines [47]. These findings from the literature point to the fact that Industrial Engineering would have a later mean time to enrollment compared to other fields, which is confirmed by this chart. In the ASA framework, these findings are also attributable to a welcoming culture that attracts students who have left other majors.

Comparing across the models for each major, most of the majors follow the same pattern from the higher average times to enrollment to lower average time. However, Computer Engineering is an exception with an unusually high average time to enrollment at DtD institutions compared to FYE institutions. While most students who graduate in Computer Engineering at DtD institutions matriculate into the major upon entering the institutions, 219 students (14%) switch into Computer Engineering from Electrical Engineering which causes an increased average time to enrollment.

To further explore the time differences between the majors at DtD institutions, I created Figure 4.5 to show the cumulative percentages of students enrolled in their graduation major by semester over six years for each graduation major. The figure makes very clear that the majority of students who graduate in Industrial Engineering at DtD institutions enroll in the major after matriculation, which is not the case for any other major. Additionally, Computer Engineering is the last major to enroll over 98% of its graduates.

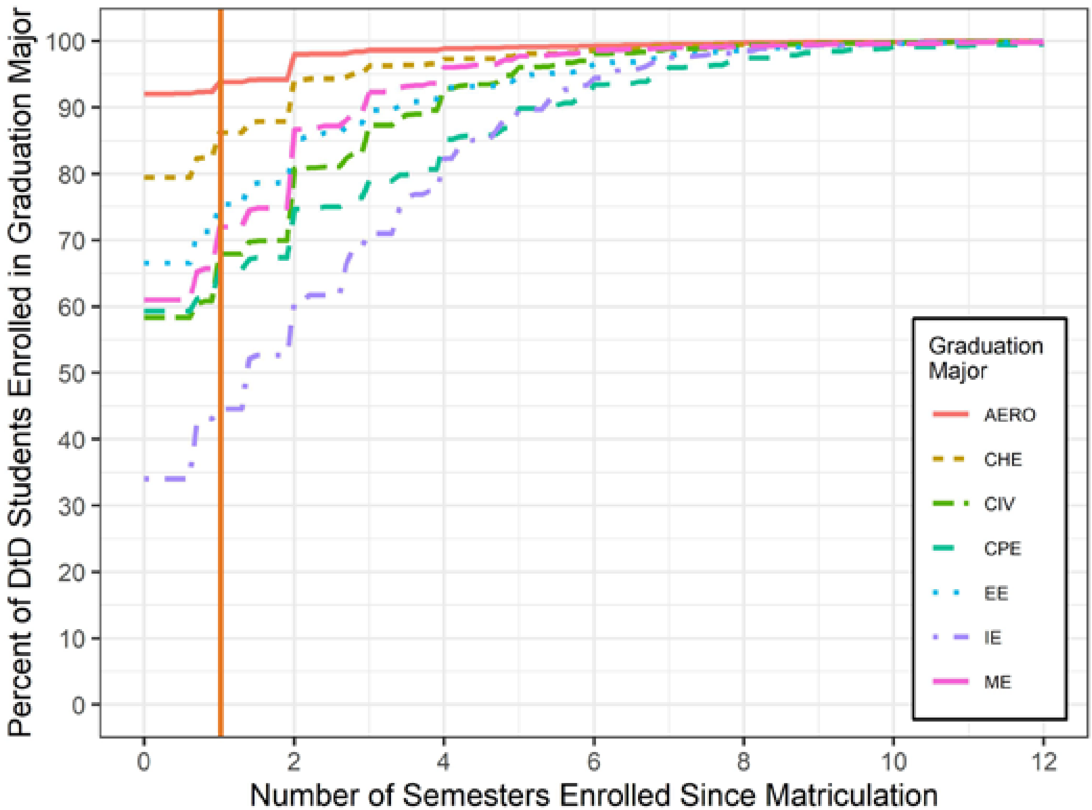

Figure 4.5 – Cumulative Percentage of Students Enrolled in Their Graduation Major by Graduation Major at DtD Institutions

Similarly, I created Figure 4.6 to further explore time differences to enrollment in graduation major by graduation major at FYE institutions. Similar to DtD institutions, students at FYE institutions who graduate in Industrial Engineering enroll in their major later than all other majors; however, the difference between the majors at FYE institutions is not as pronounced when compared to the timeline at DtD institutions. Additionally, the delayed enrollment in Computer Engineering observed at DtD institutions is less apparent at the FYE institutions. In addition to the significantly shorter time to enrollment for students at FYE institutions after completing an FYEP, these comparisons also highlight the "polarizing effect" of an FYEP where students become more sure whether or not a particular major is a good fit for them.

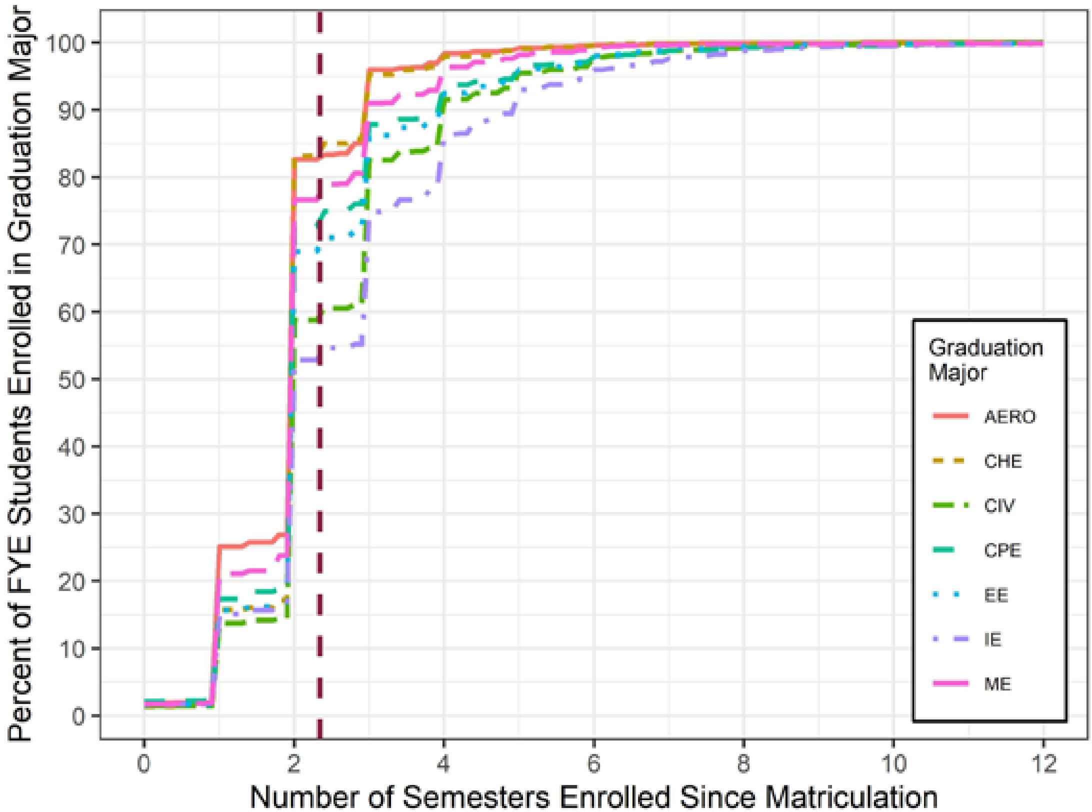

Figure 4.6 – Cumulative Percentage of Students Enrolled in Their Graduation Major by Graduation Major at FYE Institutions

4.5.5 Conclusions

It is not uncommon for engineering students to switch their engineering majors after matriculation to their institutions, as visualized in the Sankey diagrams in Figure 4.1 and Figure 4.2. Institutions where students matriculate directly to an engineering major see more major changes than institutions with an FYEP. However, at FYE institutions, students change their intended engineering majors during the first year though it is not officially documented [28].

On average, students who graduate from DtD institutions enroll in their graduation majors 1.02 semesters after matriculation, with a median time to enrollment of 0 semesters. And students who graduate from FYE institutions have an average time to enrollment in graduation major of 2.34 semesters after matriculation with a median time of enrollment of 2 semesters. However, when considering that students at FYE institutions spend an average of 2.12 semesters enrolled in the FYEP, students at FYE institutions enroll in their graduation more quickly after they first opportunity than students at DtD institutions. This points to the “polarizing effect” [23] of FYEPs because they are known to help students confirm whether or not to continue in a particular major.

Grouping students by graduation major instead of matriculation model, students who graduate in Industrial Engineering enroll in their major later, on average, than all other majors and students who graduate in Aerospace Engineering enroll in their major the fastest, on average, of the majors who graduate at least five percent of the sample. Under the assumption from the Attraction-Selection-Attrition framework that majors where students enroll later, presumably after leaving another major, could be indicative of more welcoming and inclusive cultures, it is probable that Industrial Engineering is home to such a culture. This possibility can be confirmed using results published in the literature [65], [66].

Similar conclusions about Industrial Engineering can be found in the disaggregation by both matriculation model and engineering major. For both matriculation models, students who graduate in Industrial Engineering enroll in their major later than the other majors studied, on average. Understanding when students are enrolling in their graduation major in each of these matriculation models will also allow engineering programs to encourage students to explore majors sooner, especially those majors with later times to enrollment to help students make an informed major decision earlier in their engineering careers.

4.6 RQ2 – Persistence in First Engineering Majors of Engineering Graduates

4.6.1 First Engineering Major by Matriculation Model

To understand persistence of engineering graduates in their first engineering majors, we must first determine which majors students matriculate in. At FYE institutions, all students matriculate in an FYEP from which they must then enroll in a degree-granting major. Because all students must leave the FYEP, students first major after completing the FYEP is used in this analysis. At DtD institutions, most all students (88.0%) matriculate directly to a degree granting program; however, some matriculate to some type of general engineering major normally reserved for students who plan to pursue engineering but are still unsure of which discipline to select. For the 3,167 students in this situation, their first major after leaving the general engineering designation is used as their first engineering major in this analysis.

To determine if students who complete an FYEP choose different first majors than students who matriculate directly to a degree-granting engineering major, I used a Chi-

Square Test of Independence. To perform the test, students were disaggregated by their matriculation model and first non-FYEP major. Only majors with greater than or equal to five percent of total enrollment and that are available at both FYE and DtD institutions are included in the analysis to make sure the test conditions are met. The composition of students by matriculation major and first non-FYEP major are shown in Table 4.6 sorted by decreasing total enrollment. While these results focus on graduation they are also similar to those reported in 2013 about eighth-semester persistence in engineering [22].

Table 4.6 – Sample Composition by Matriculation Model and First non-FYEP Major

	ME	**EE**	**CIV**	**CHE**	**IE**	**AERO**	**CPE**
FYE	20.2%	15.7%	15.6%	11.9%	9.6%	6.8%	9.1%
DtD	22.3%	15.7%	11.3%	10.6%	5.5%	14.9%	6.1%
Diff	-2.1%	0.0%	4.3%	1.3%	4.1%	-8.1%	3.0%

The test resulted in a significant difference (χ^2 = 1328, df = 6, p-value < 0.001), possibly due to the large sample size and/or the inclusion of Aerospace Engineering. To accommodate for the large sample, I calculated Cramer's V which has a value of 0.177 and indicates low association between the variables which leads to the conclusion that the differences in enrollment between the matriculation models are not very meaningful. To accommodate for the inclusion of Aerospace Engineering which is the primary engineering degree at two of the DtD institutions, I reran the Chi-Square Test of Independence using only the "Big 5" engineering disciplines – ME, EE, CIV, CHE, and IE. This test also resulted in a significant difference (χ^2 = 379, df = 4, p-value < 0.001). I re-calculated Cramer's V which has a value of 0.106 and indicates low association between the variables which leads to the conclusion that the differences in enrollment between the matriculation models are not very meaningful.

These results are also visualized in the mosaic plots in Figure 4.7. The leftmost plot shows the expected distribution of students into the majors if matriculation model had no influence as evidenced by equal proportions of students in each major for each matriculation model. The middle plot shows the actual distribution of students into seven engineering disciplines. To accommodate for the inclusion of Aerospace Engineering which is the primary engineering degree at two of the DtD institutions, the rightmost plot shows the actual distribution of students in the "Big 5" engineering disciplines. Boxes shaded blue with solid borders on the mosaic plots indicate enrollment that is greater than expected in the major and boxes shaded red with dashed borders indicate enrollment that is less than expected.

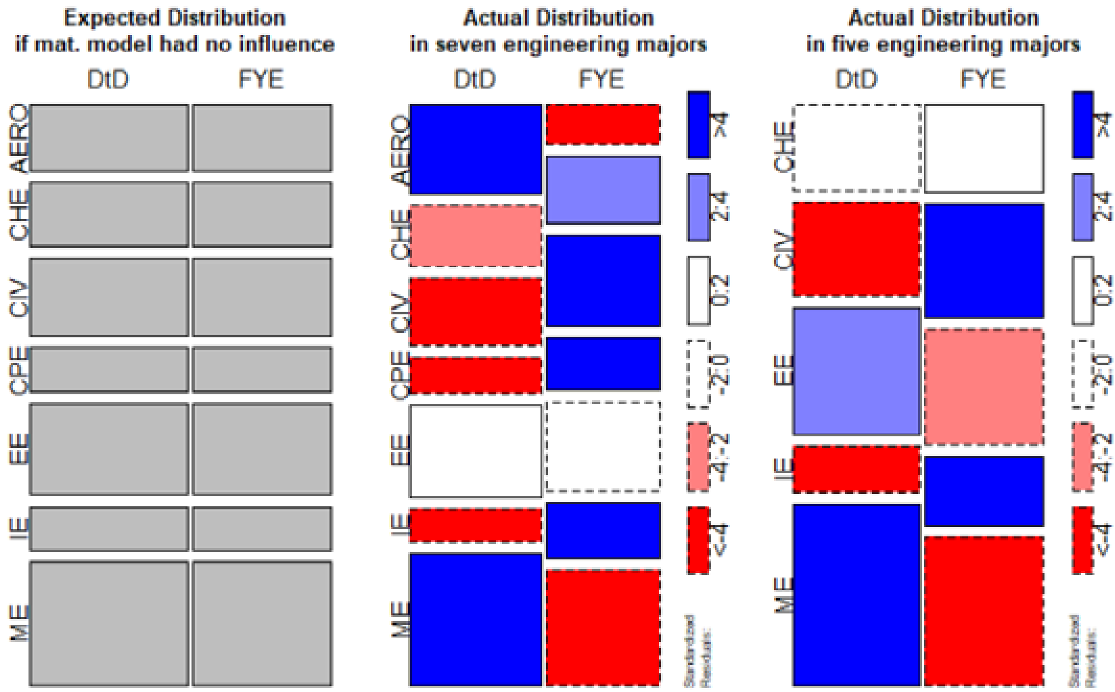

Figure 4.7 – Mosaic Plot of Expected and Actual Enrollment of Engineering Graduates in Common Engineering Majors by Matriculation Model

While there are statistically significant differences between the expected and actual enrollments, the differences are not very meaningful according to the Cramer's V calculations. A significant result with a not very meaningful effect is to be expected because the goal of FYEPs is not to encourage students to select any particular engineering major over another, but to allow students the option to make a more informed major selection. In Figure 4.7, the plot shows that students in FYEPs select CIV and IE, which are generally lesser-known fields, at slightly higher rates than EE and ME, which are generally better-known fields.

An institution simply having an FYEP does not inherently help students with major selection, the content focus of the FYEP and its constituent coursework is important. So, whether or not a student's major selection after completing an FYEP is actually more informed would be partially determined by their coursework. First-year engineering courses that include information about disciplines offered at their institutions allow students to either confirm their discipline selection or use the information to make a discipline selection. However, as illustrated by Ken Reid's classification of first-year engineering courses, the types of FYEP courses vary dramatically with some focused on math skills and design rather than advising [24].

Because students who complete an FYEP delay their official commitment to an engineering discipline, there is reason to believe that these students will be more persistent in their first degree-granting major after completing the FYEP because changes to their intending engineering major may occur during the first year, but are not officially documented. There is evidence to suggest that students in FYEPs do change their intended engineering majors during the first year, even among students who are confident in their initial decision at matriculation to the university [28].

4.6.2 By Matriculation Model

Using students' first non-FYEP major, students were categorized into one of three groups based on their major changing behavior or lack thereof. The first group is composed of students who persisted in their first engineering major and graduated in the same major. The second group are students who switched out of their first engineering major but later returned to graduate in their first engineering major. The final group are students who switched out of their first engineering major and graduated in a major other than their first engineering major. The distribution of students in these groups by matriculation model is shown in Table 4.7.

Table 4.7 – Rates of Persistence in First non-FYEP Engineering Major by Matriculation Model

	Persist & Graduate in First Engr Major	**Switch, Graduate in First Engr Major**	**Switch, Graduate in Another Engr Major**
DtD	74.4%	1.1%	24.5%
FYE	90.4%	1.2%	8.4%

This data makes clear that more students persist in their first engineering major at FYE institutions compared to DtD institutions. This difference can also be seen in the Sankey diagrams in Figure 4.1 and Figure 4.2 because students who persist in their first engineering major and graduate in it are shown as ribbons that go straight across each chart. Using a Chi-Square Test of Independence, the difference between the proportions of students in each persistence group by matriculation model are statistically significantly different ($\chi^2 = 2210$, df = 2, p-value < 0.001), but only has a small effect size with a Cramer's V of 0.213. Because students at FYE institutions select their first engineering major an average of 2.34 semesters after matriculation, it makes sense that those students have a higher rate of persistence in their major. This result serves as evidence that FYEPs allow students the opportunity to learn about the different engineering majors available at their institutions and then can make more informed major choices that reduce the need to switch majors later in their academic careers.

Because students at FYE institutions choose their first engineering major later than students at DtD institutions, it is worthwhile to compare the rates of persistence of the matriculation models at a similar timepoint. To do this, I determined whether or not students persist in the major they are enrolled in at their third semester, when all "on-time" students have enrolled in an engineering major. The results are shown in Table 4.8.

Table 4.8 – Rates of Persistence in Third Semester Major by Matriculation Model

	Persist & Graduate in 3rd Semester Major	Switch, Graduate in 3rd Semester Major	Switch, Graduate in Another Engr Major
DtD	84.0%	0.8%	15.2%
FYE	69.5%	0.7%	29.7%

Comparing the matriculation models at semester 3, when all "on-time" students have had the opportunity to declare a degree-granting major, DtD institutions have a higher rate of persistence in semester 3 majors compared to FYE institutions. In DtD programs, the persistence rates in the third semester major are higher than in the first (degree-granting) engineering major (Table 4.6), whereas the opposite is true in FYE programs. Few students in DtD programs are ever enrolled in a general engineering designation and of those who are, few remain in a general engineering designation by their third semester, therefore nearly all students who persist and graduate in their first degree-granting engineering major also persist and graduate in their third semester major. In total, the proportion of students who persist and graduate in their third semester major is 9.6% higher (84.0% vs 74.4%) than the rate of persistence in the first engineering major among students at DtD institutions. The third semester major persistence rate at FYE institutions is lower because not all students have matriculated to a degree-granting major by semester 3. Because students must eventually switch out of the FYEP, many students are classified as switchers only because they have not completed the FYEP yet.

Because not all FYEP students have declared a degree-granting major by semester 3, it is also worthwhile to compare between FYE institutions using persistence in the first non-FYEP major and DtD institutions at semester 3. This comparison allows for a more representative understanding of the FYE institutions and allows for students at DtD institutions to switch their majors early, as is possible for students at FYE institutions when switching an intended engineering major that is not officially declared. Comparing these two metrics, students at FYE institutions have a higher rate of persistence in their first non-FYEP majors (90.4%) than do students at DtD institutions in their third semester majors (84.0%), but the difference is smaller than when comparing the same metric for both matriculation models.

Because students at FYE institutions enroll in their graduation majors later than students at DtD institutions but have higher rates of persistence, it raises a question of which matriculation model has faster times to graduation. Students at DtD institutions graduate in 9.42 semesters on average; the median time is 9.33 semesters. Students at FYE institutions graduate in 8.32 semesters on average; the median time is 8.0 semesters. Using Welch's t-test, these averages are significantly different ($t = 63$, $df = 44168$, $p < 0.001$) with an effect size 0.581, which is just above the medium threshold of 0.50.

Combining the results of time to enrollment in graduation major, persistence in first engineering majors, and time to graduation, students at DtD institutions enroll in their graduation majors more quickly on average, but students at FYE institutions persist at a higher rate in their first engineering majors and graduate more quickly than students at

DtD institutions. These results speak favorably of FYEPs and the FYE matriculation model and point to advantages for students because FYEPs provide students a formal designation as first-year engineering students with time to explore different engineering majors before committing to a degree-granting engineering major. Because students have this time to explore their interests and can make a more informed major selection, the fact that FYE institutions have a higher rate of persistence in first engineering majors than DtD institutions makes sense. In terms of the ASA framework, as students select their engineering majors, they had time to learn about the differences in the engineering majors and have been attracted to the major which they believe will be best suited for them; this process ultimately leads to greater persistence and graduation and thus a lower rate of attrition.

These results do come with the limitation that the students included in this study are only those who eventually graduate in engineering. Students who left engineering and/or their institution were not included because this study began with engineering graduates and traced their paths backwards to matriculation. Future work should also investigate the paths of students who leave engineering and graduate in other majors. Students who leave the institution should also be studied, but those methods will necessarily be different from those used here.

4.6.3 By Engineering Major

Complementary to an investigation of persistence by matriculation model, I also determined the rates of persistence by first degree-granting engineering majors. Using the same three groups described in Section 4.6.2, the rates of persistence and switching for each of the engineering majors that graduate at least five percent of students in the sample are shown in Figure 4.8. The figure is sorted by decreasing rates of persistence and includes vertical lines to indicate the average rates of persistence and switching.

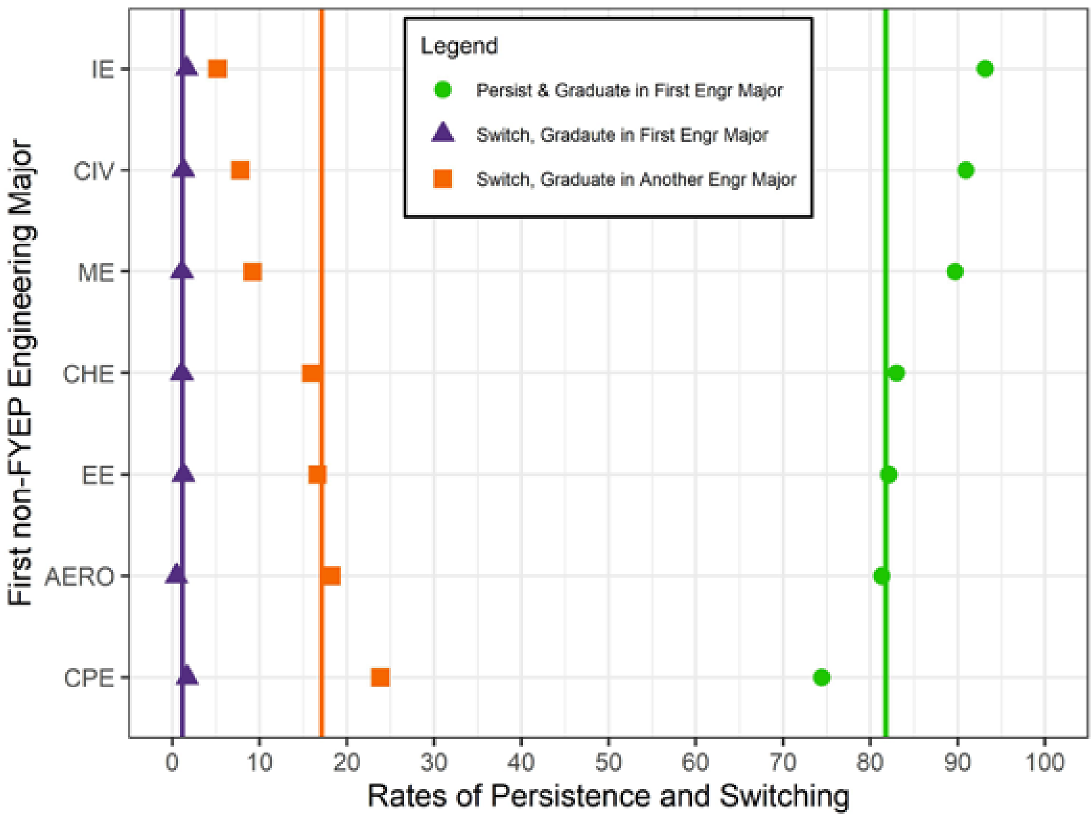

Figure 4.8 – Rates of Persistence and Switching by First non-FYEP Engineering Major

Industrial, Civil, and Mechanical Engineering have the highest rates of persistence of the majors that graduate at least five percent of the sample. It is somewhat surprising that Industrial Engineering has the highest rate of persistence since this major is also the one with the longest time to enrollment among graduates. However, given that this persistence metric is calculated using students' first non-FYEP major, this indicates that students who begin in Industrial Engineering are very unlikely to leave. This speaks to the fact that Industrial Engineering has a welcoming culture that has been documented in the literature [65], [66] because more students who begin in Industrial Engineering remain in Industrial Engineering and many students who switch from another engineering major switch to Industrial Engineering. It is also somewhat surprising that Mechanical Engineering has a higher than average rate of persistence because many students describe the major as being one of many "options" [14]. This perception may cause some students to select Mechanical Engineering as a "default" major, especially at DtD institutions, and then switch away after learning of other majors; however, the results in Figure 4.8 do not support that viewpoint.

A small number of students do not persist in their first non-FYEP engineering major but later return to it and graduate in that major. This occurs with a very low frequency, as shown in Figure 4.8, but it still of interest. The number of students who leave and then return to each of the engineering majors that gradate at least five percent of the sample are shown on the diagonal in Table 4.9. The majors that student enroll in while away from their graduation major are also included; however, students enroll in more than only the seven engineering majors shown, so not all student paths are shown. The diagonal entries represent to the total number of students returning to the major.

Table 4.9 – Number of Students who Switch from and Return to Their First Engineering Major by Major

		Ever Enrolled in						
		ME	**EE**	**CIV**	**CPE**	**CHE**	**IE**	**AERO**
First Engr Major and Grad Major	**ME**	114	6	6	3	2	6	6
	EE	3	98	0	53	1	1	1
	CIV	4	38	82	2	0	1	0
	CPE	2	40	0	62	0	2	1
	CHE	0	1	2	0	59	0	0
	IE	10	3	4	1	3	59	3
	AERO	1	1	0	0	0	0	26

Of the 62 students who left but later returned to Computer Engineering, 40 students (65%) were majoring in Electrical Engineering at one point; the next most popular majors were Mechanical Engineering and Industrial Engineering, with only 2 students (3%) each. A similar pattern also occurs for students who switch from but then return to graduate in Electrical Engineering; 54% "visited" Computer Engineering. For the 59 Industrial Engineering graduates who switch and return, the two most common majors enrolled in before returning to Industrial Engineering are Mechanical Engineering (10 students; 17%) and Civil Engineering (4 students; 7%). Given the small number of students who exhibit this behavior, it is difficult to draw conclusions from this data other than students in Computer Engineering and Electrical Engineering switch between those majors at higher rates than other pairs of majors.

4.6.4 By Matriculation Model and Engineering Major

In order to better understand the rates of persistence in graduates' first engineering majors, it is necessary to disaggregate the sample by matriculation model and first engineering major simultaneously. Figure 4.9 reports the rate of persistence in students' first engineering majors by both matriculation model and first engineering major sorted by decreasing rates of persistence at FYE institutions. The vertical lines note the average rate of persistence for each of the matriculation models.

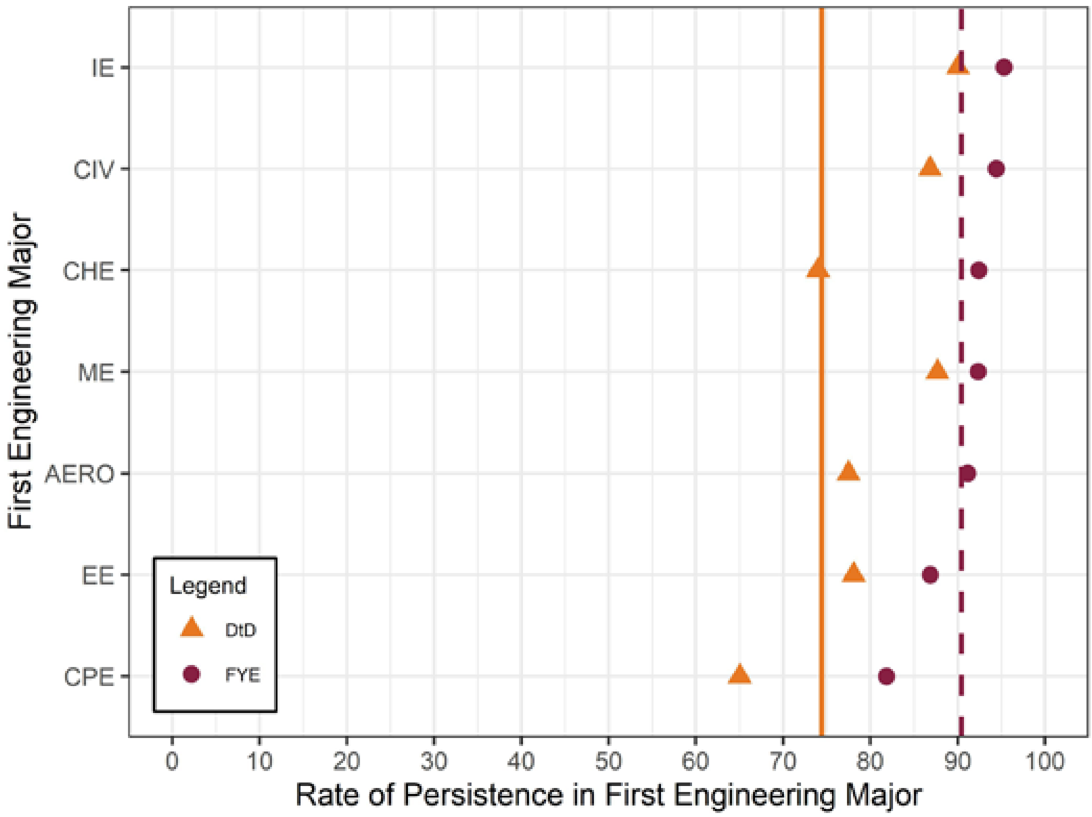

Figure 4.9 – Rates of Persistence in First Engineering Major by Major and Matriculation Model

Consistent with the results by matriculation model only in Section 4.6.2, each major has a higher rate of persistence at FYE institutions compared to DtD institutions. However, the difference between the two matriculation models varies from a minimum difference of 4.7% for Mechanical Engineering to a maximum difference of 18.4% for Chemical Engineering.

While Figure 4.9 shows the retention of students in each of the majors shown, by taking the difference from 100%, the rate of switching can also be observed. Using the frameworks for this study, students who leave a major likely did not find fit in the major (ASA) or did not socially or academically integrate into the major (Student Integration Model). With this understanding, those majors with lower rates of persistence may need to evaluate the culture within their fields to make sure it is welcoming. Additionally, some attrition could be the result of student misconceptions about the major in which they enrolled. By understanding students' perceptions of the majors, misconceptions could be addressed before enrollment to allow for a more informed major decision; this will be part of the focus of Chapter 5. Because all the students studied in this chapter graduate in an engineering major, those who graduate in their first choice were attracted to and selected by the major in addition to integrating both academically and socially. On the other hand, students who switched majors before graduating did not integrate into their first major but did find another major better aligned with their interests and were attracted there.

4.6.5 Conclusions

These findings indicate that students who graduate in engineering do not sort themselves into majors at meaningfully different rates based on their matriculation model. This result is encouraging because the focus of an FYEP is not to encourage students to select any certain major or set of majors, but to allow students to make the best decision. In fact, many students are not aware of the matriculation model their institution uses when they select it [21].

As expected, not all students persist in their first engineering major. These major changes are encouraged as long as students are switching to majors more in line with their interests, where they will more easily integrate socially and academically, or find better fit. Computer Engineering has the lowest rate of persistence overall and for both matriculation models separately. Other work has identified unique, albeit discouraging, characteristics of Computer Engineering as well [67]. However, most students who leave Computer Engineering switch to Electrical Engineering which is often offered within the same department at many universities which ideally minimizes any delays to graduation. Regardless, the majors with the lowest rates of persistence could benefit from an internal evaluation to make sure their programs are inclusive and welcoming to all students. These majors could also work to retain students in the major most at risk of leaving (with the understanding that for some students, leaving is best for them) by providing additional resources for integration, such as student chapters of professional organizations. Finally, these programs could work to make sure that students' perceptions of the major align with the perceptions of current students and faculty so that students better understand the major before enrolling. This may also include addressing misconceptions.

4.7 Conclusions

Most engineering graduates enroll in the major that will become their graduation major at their first opportunity to do so, either at matriculation for DtD institutions or after completing an FYEP at FYE institutions. However, more students switch from their first engineering major at DtD institutions, reducing a perceived advantage that students at those institutions enroll a year sooner than their FYE counterparts. In the results described, students at DtD institutions only enroll 1.32 semesters sooner. Of the students who switch their majors, most switch to Industrial Engineering. Because IE welcomes so many switchers, it has the largest time to enrollment for both matriculation models. Additionally, because so many students switch to IE from other engineering majors, it speaks positively of the culture of Industrial Engineering, which has been reported in the literature.

Interestingly, Industrial Engineering also has the highest rate of persistence among students who start in the major for both matriculation models. Computer Engineering has the lowest rate of persistence among students who start in that major, though many students do switch to Electrical Engineering, which is often offered in the same department. Majors that have higher times to enrollment should evaluate to understand why students are attracted to their major later than average. Majors that have lower rates of initial persistence should evaluate to understand why students leave after enrolling. These factors could include the culture of the major, the level of integration in both social and academic areas, and misperceptions about the major. Improving or correcting these areas combined with additional advertisement, especially for later enrolled majors, could be beneficial for both recruitment and retention of engineering students.

4.8 Future Work

While the institutions used in this study share common matriculation practices, all institutions of the same type are not necessarily identical to each other. For example, some institutions offer majors not available elsewhere and some may have enrollment criteria for specific engineering majors that exceed the requirements for engineering in general. Future work should include institutional characteristics including potential barriers to enrollment in certain majors, like GPA, as well as enrollment maximums.

While this data is provided by many of the highest enrolled engineering schools in the United States, these results are partially limited because MIDFIELD contains recent historical data, but data from some institutions is older than others. Because this data is partially historical, some of the most recent trends in enrollment timelines may not be visible in this work due to the data timeframe. Future work would ideally include more recent data from even more institutions. Work to expand MIDFIELD is currently ongoing and will be beneficial for this future work [68].

Future work should also investigate the paths of students who leave engineering and graduate in other majors. While this work focused on students who graduated in engineering, some students switch out of engineering to other fields and graduate. Additionally, some students who graduated in an engineering major may have switched within or from engineering if they had access to necessary support and resources. Students who leave the institution should also be studied, but those methods will necessarily be different from those used here.

5 Study of Perception

Portions of this chapter were originally published in the 2021 Proceedings of the First-Year Engineering Experience Conference [69].

Before making important decisions, it is important to gather as much information as possible to help make informed choices. However, many first-year undergraduate students are required to make a decision about which major to pursue with little exposure to the options available to them. This is especially true in engineering where many students are confident in their desire to pursue engineering and/or a particular engineering major, but do not necessarily understand what their major will entail or the other options that are available to them. To help address this concern, some institutions have implemented first-year engineering programs (FYEPs) which allow students to explore the different engineering majors available at their institution and not have to make a formal commitment to an engineering major until the end of the program. The literature includes reports that these programs help students decide if engineering is the best major for them [21], [23], allow for students to graduate more quickly [6], and improve retention [22] when compared to institutions without an FYEP. Additionally, the findings reported in Chapter 3 expand upon this literature by including disaggregation by engineering major.

To understand the previous quantitative differences, work has started to explore the impact of major exploration initiatives at different universities. To start, the literature has identified that upper-level high school students, even in communities with significant engineering exposure, have very limited understanding of what engineering is [70]. Literature focused on first-year engineering students' perceptions has reported the most common attributes ascribed to many of the engineering majors [14]. The current work expands the literature by exploring changes in first-year engineering students' perceptions while completing an optional engineering major exploration course.

5.1 Theoretical Framework

This study is framed using Social Cognitive Career Theory (SCCT) [26], [27] and Eccles' Expectancy-Value Theory (EVT) [42], [43]. The responses analyzed are responses to questions asked that focus on outcome expectations – "What do engineers do for a living?" which is the focus of RQ3 and "Describe what you believe engineers in your top-choice major do at work." which is the focus of RQ4. Because the focus of these questions is on outcome expectations, SCCT was selected as the primary framework. Some students also mention their self-efficacy, another SCCT construct, for certain tasks related to their outcome expectations.

Other students expanded on their responses and included statements related to interests and values. While interest is incorporated into SCCT, values are not a core construct of the theory. Therefore, EVT was selected as a supplementary framework to help frame the additional details some students provided about their values for certain tasks. EVT was selected because in addition to its explanatory value, the expectancy construct in EVT is similar to the idea of SCCT's self-efficacy construct which is a person's confidence in being able to complete a certain task [26]. The expectancy construct also has a connection to SCCT's outcome expectations construct because both require the person to look into the future and consider possible outcomes [71, p. 364].

5.2 Research Questions

The research questions in this chapter focus on students' perceptions of engineering and their intended engineering major before and after completing a major exploration course.

RQ3. How do first-year engineering students perceive engineering in general prior to and after completing a major exploration course?

RQ4. How do first-year engineering students perceive the engineering majors they are most interested in pursuing prior to and after completing a major exploration course?

5.3 Data and Methodology

5.3.1 Data Source

This study uses data from course surveys that ask first-year engineering students about their perceptions of engineering and the engineering major they are most interested in pursuing. The data was collected at one public research university in the southeastern United States. The institution has a required FYEP.

The course survey, which is included as Appendix A – Major Exploration Course Survey (Relevant Questions), was distributed at the beginning and end of the half-semester, one credit, pass / no pass major exploration course, and was required at both time points to earn a passing grade in the course. The survey asks students about knowing an engineer personally, their top choice of major, their confidence in that choice of major, and two free-response questions. The first free response question asks students, "What do engineers do for a living?" and the second asks students to, "Describe what you believe engineers in your top-choice major do at work." These questions are similar to those asked by Kajfez *et al.* [14] who asked "students to describe what an engineer in a specific discipline would do in the workplace." The survey has asked both free-response questions, and collected most of the other information, since the Fall 2016 semester for approximately 400 students each fall term and 35 students each spring term.

5.3.2 Course Description

The course being studied here is an optional component of a first-year engineering program. During the study period, Fall 2016 – Fall 2019, inclusive, there were no significant changes to the course format. During each of the 50-minute course periods, the instructor invited an engineer from industry or a member of the university's engineering faculty to present on their work experiences. For example, one speaker who graduated from the university with a degree in Industrial Engineering discussed her experiences working at many different companies, including Amazon and Walmart. Another speaker, with degrees from the university in Mechanical Engineering, shared his experiences working for a local company testing power tools and discussed previous work he had completed in China. As a final example, an Electrical Engineering graduate shared her personal experience as a co-op and then continued development of leadership skills at General Electric. Most speakers also provided advice for the first-year students in their coursework and for when they enter the job market.

During the course, students are reminded that they may change their intended engineering major at their discretion. (Because students are in a first-year program, their official major is a non-degree granting first-year engineering program designation.) The course does not necessarily encourage students to switch their major, but only reminds them of their ability to do so. Additionally, none of the engineering majors are given preference in any attempt to encourage students to enroll in any particular majors.

5.3.3 Inclusion Criteria

In order to be included in the sample, students had to complete both the beginning- and end-of-course surveys and do so during the same semester. Since the Fall 2016 semester and for every fall and spring semester until Fall 2019, inclusive, a total of 1756 students completed the beginning-of-course survey and 1719 students completed the end-of-course surveys. Of these students, 1705 students completed the survey at both time points. Finally, of these students, 1697 students completed the surveys during the same semester.

Using institutional records, 1761 students earned a final grade in the course during the same time period which means that over 96% of students who completed the course also completed both the beginning- and end-of-course surveys.

5.3.4 Sample Demographics

The composition of the sample by race/ethnicity and sex as recorded in institutional records is provided in Table 5.1. Because this survey was part of a course assignment, these are the data about the actual survey respondents not generalized institutional records.

Table 5.1 – Sample Composition by Race/Ethnicity and Sex as Reported in Institutional Data

	White	**Black**	**Asian**	**American Indian or Alaska Native**	**Native Hawaiian or Other Pacific Islander**	**Other / Unknown**
Male	60.7%	6.5%	3.6%	0.8%	0.1%	0.1%
Female	23.5%	2.2%	1.4%	0.1%	0.1%	0.9%

5.4 Analysis

Coding of the data followed the process outlined by Saldaña [72]. For both survey items, students' beginning-of-course responses were coded first using holistic coding so that the codes most closely matched the students' original words. For the survey item about engineering in general, exactly 200 codes were developed during this coding pass. For the survey item about the individual engineering majors, students were divided into majors by their top major choice. For all 10 majors combined, 465 codes were developed during this coding pass. However, some of the codes are duplicative across the majors.

The codes from the first pass were then used to develop categories with a single definition. Each category contained multiple codes. For the survey item about engineering in general, 14 categories were identified. For the survey item about the individual engineering majors, a total of 173 categories were identified for all 10 majors, ranging from 11 to 27 categories per major. Like the codes, some of the categories are duplicative across the majors.

During the second coding pass, the categories developed from the first pass were applied to the data. For the survey item about engineering in general, five of the 14 categories were broken down into subcategories. The codes were applied in a binary fashion such that a response either had a category present or not. If two different instances of the same category were included in a response, it was only categorized once.

After completing this cycle with the beginning-of-course data, the categories and subcategories used during the second coding pass were used as *a priori* codes with the end-of-course data. Emergent coding was also used with the end-of-course data so that any differences between the beginning- and end-of-course data were captured.

Given the large quantity of data, frequency counts were determined to see which categories were mentioned by students the most often. Changes in the frequency counts were also compared to help identify interesting patterns in the data which are discussed later in this chapter.

5.5 RQ3 – Perceptions of Engineering in General

5.5.1 Overview of Categories

Students' responses to the item "What do engineers do for a living?" generated 14 unique categories. Every response fell into at least one category and some students mentioned ideas that belonged to multiple categories and were coded as such. The list of the categories including their frequency in responses collected before and after the major exploration course, a definition, and example quote are provided in Table 5.2.

Table 5.2 – Categories Used to Describe What Engineers Do for a Living

Category	Pre	Post	Definition	Example Quote
	N = 1697			
Problem Solving	48%	53%	Engineers work to solve many different types of problems. Engineers solve problems by developing solutions.	Engineers focus on problems and a way to solve them.
Creating and Designing	36%	34%	Engineers build novel products, processes, and/or technology.	Engineers design and create things.
Making Improvements	32%	34%	Engineers make changes and upgrades to existing products and/or processes. These upgrades often increase the efficiency of the process.	I believe engineers do all different kinds of things in the workplace. But I believe that engineers are at work to always be improving.
Innovating	7%	9%	Engineers innovate. These innovations often involve a product, processes, and/or ideas.	Innovate and design machines, processes, and materials that increases the standard of living. …
Societal Impact and Quality of Life	32%	39%	Engineers make the world a better place and/or make life easier for people.	Engineers do all types of different things trying to make the world better and easier to live in.
Applying Knowledge and Skills	17%	18%	Engineers use math and science. This may include a list of specific fields; for example, calculus or chemistry.	Engineers fix real world problems through application of math and sciences.

Variety of Work	7%	11%	Engineers can work in various fields and have multiple options to choose for work. This may include that engineers work on-site in the field as well as in office locations. This may also include statements that engineers work on "large and small" problems.	Engineers do many different things. Some engineers work to make processes move faster, some work to make aircrafts and cars, and other work to make different types of materials.
Depends on Engineering Major or Degree	6%	5%	Engineers do work that is largely determined by the discipline of engineering they studied.	Engineers solve problems in their field using their knowledge taught in class.
Maintenance	3%	3%	Engineers are responsible for the upkeep of products and/or processes to make sure they continue to function.	Build and maintain everything.
Teamwork and Leadership	5%	4%	Engineers work with other people. Engineers can also be responsible for managing the team.	Work, usually in teams, to improve or create something that will improve the well being of others.
Creative and Critical Thinking	6%	5%	Engineers brainstorm to think of new and unique ways to approach problems; they think "outside the box."	Engineers use creative thinking to solve the world's issues.
Planning and Testing	3%	3%	Engineers design and execute plans to accomplish their work. They also test the results of their work.	They can literally do so many different things mostly to do with designing products and running tests on them as well making the products better.

Quality, Safety, and Cost Considerations	5%	8%	Engineers complete their work under constraints, often including time and cost, while making sure it meets expected standards.	Work with other engineers and other members of a team to confront an issue that exists in the world. They then work to make the best possible solution with given criteria in mind such as cost, environmental impact, community impact, etc.
Unsure	1%	0%	Students are unsure of what engineers do for a living.	Honestly, I have no idea.

In the following subsections, these categories will be discussed. This discussion will include additional example quotes from student responses to highlight the variety of responses within a category. Any changes observed from the whole of the data will also be discussed.

Additionally, the five of the first six categories – *Problem Solving*, *Creating and Designing*, *Making Improvements*, *Societal Impact and Quality of Life*, and *Applying Knowledge and Skills* – also have subcategories to further specify how students discussed these ideas with respect to what engineers do for a living. The subcategories will be discussed in their respective subsection, including changes in the frequency of each of the subcategories.

5.5.2 Problem Solving

When asked what engineers do for a living, the most common idea among the responses of the sample of first-year engineering students both before and after completing a major exploration course was that engineers solve problems. In addition to indicating that engineers solve problems, many students indicated what types of problems engineers solve. Some students also mentioned that engineers build solutions to solve problems. These additional details in student responses were used to develop seven sub-categories for the *Problem Solving* category. The frequency and definition for each *Problem Solving* subcategory is provided in Table 5.3 with an example quote.

Table 5.3 – Definitions of the *Problem Solving* Subcategories

Subcategory	**Pre**	**Post**	**Definition**	**Example Quote**
	N = 1697			
Generic Problems	26%	36%	Engineers solve problems.	Engineers solve problems that need to be fixed.
Real-World Problems	10%	12%	Engineers solve real world or societal problems.	Engineers work with math and other scientific ideas to solve problems in the real world.
Everyday Problems	2%	2%	Engineers solve everyday or practical problems.	Engineers apply science to solve problems in our everyday lives.
Complex Problems	2%	2%	Engineers solve difficult, challenging, or complex problems.	Solve complex problems and use creative ideas to fix issues in the world.
Technical Problems	1%	1%	Engineers solve technical, scientific, or physical problems.	Engineers use science and math to solve technical problems.

Problems Others Cannot Solve	1%	1%	Engineers solve problems that others cannot solve.	Solve problems that no one else can.
Build Solutions	11%	10%	Engineers build or design solutions to problems.	Engineers come up with designs to fix a problem.

The first six subcategories, *Generic Problems* to *Problems Others Cannot Solve*, offered indications of the types of problems that first-year engineering students believe that engineers solve. Students' responses could be categorized as more than one subcategory. Responses that did not specify the types of problems engineers solve were categorized as *Generic Problems*; some of these responses also mentioned offering a solution and would also be coded as *Build Solutions*. Additionally, some students would explain how engineers solve problems, which are the subject of other categories including *Applying Knowledge and Skills*, but did not elaborate about the type of problems being solved: "Engineers solve problems using math and science."

For students who did elaborate on the types of problems that engineers solve, the most popular descriptors were that engineers solve real-world problems or problems that exist in society: "Engineers solve problems that exist in all aspects of society." Many students with responses categorized as *Real-World Problems* also mentioned that the engineers' work makes the world a better place; these additional details are captured in another category, *Societal Impact and Quality of Life*, which will be discussed later.

Three other subcategories were developed that describe the types of problems that engineers solve. Some students responded that engineers solved challenging or *Complex Problems*; for example, engineers "[s]olve complex problems using their knowledge of how things work." Other students described the problems as *Everyday Problems* or *Technical Problems*. Both of these categories include multiple other similar ideas about the types of problems engineers solve for a living. Respectively, "[t]hey solve everyday problems and try to improve on ideas and products that could function better" and "I believe engineers solve scientific problems to make the world better." Some students combined the descriptive subcategories in their responses. These combinations of multiple, different descriptions were not very common, but when combined, students would most likely comment that "[engineers] solve complex problems in real-world situations…" combining the subcategories of *Real-World Problems* and *Complex Problems*.

One final descriptor that students used to describe the types of problems that engineers solve is that engineers "[s]olve problems that no one else can." While it is possible to interpret these types of problems as challenging or complex problems because students mentioned that these problems could not be solved by people in other professions, a separate subcategory was created, *Problems Others Cannot Solve*. This idea that "…engineers go out into the world and solve issues that other people can't" also speaks to the fact that students believe that engineers are able to make unique contributions to problem solving. To that end, many students mention that engineers are involved in *Teamwork and Leadership*, which is another category that will be discussed.

The final subcategory that students mentioned in their responses when discussing *Problem Solving* is that engineers *Build Solutions* to problems. When students wrote about building or designing solutions, many also described the types of problems being solved; for example, "[e]ngineers develop solutions to problems presented to them using their expertise and creativity." Many other students also commented that engineers design and improve different products and processes for a living; these responses are categorized into the *Creating and Designing* and *Making Improvements* categories, respectively, and will be discussed in the next two subsections.

Comparing the frequency of the categories between the survey responses at the beginning and end of the course, the two largest changes are increased frequencies in *Generic Problems* and *Real-World Problems*. Part of the increase in *Generic Problems* could be due to a decrease in specific descriptors being used; however, the number of other *Problem Solving* descriptors only decreased by seven instances, which does not account for the observed increase. Given that a large portion of the course is dedicated to presentations from program alumni who are working in industry, the increase in the frequency of the *Real-World Problems* subcategory makes sense because students learn about the problems that practicing engineers are solving in their careers. Additionally, it would follow that students are more willing to describe the problems as *Real-World Problems* compared to the problems presented in their other engineering classes, even if those problems are based on industry experiences. The increase in *Generic Problems* could be because students are solving problems in their other engineering courses.

Students mentioning that engineers spend their time solving problems at work is related to the idea of outcome expectations in SCCT. The students who mention some aspect of *Problem Solving* are connecting the idea of earning an engineering degree and becoming an engineer with the expectation to solve problems. This connection to outcome expectations is especially true for students who specifically mention solving *Real World Problems* because the ability to solve these types of problems will have further reaching impacts; for example, “Engineers solve different problems in today's society to make life more efficient and beneficial.”

Other responses are also connected with the interest construct of SCCT. Some students would mention that engineers are able to work on problems that they find interesting; for example, “A whole cornucopia of things, many of which I am interested. Ultimately, solving problems to help people and companies become better.”

5.5.3 Creating and Designing

In addition to ideas related to *Problem Solving*, many students commented that engineers create different kinds of things for a living. Because students used the word “create” and other similar words – design, build, make, and invent – to describe engineers’ work, the responses were coded based on the word(s) chosen. Additionally, most students who identified one of these verbs also described what things engineers work with. Many students used generic “things” to describe what engineers work with, but other students provided more details, specifying that engineers work with products, processes, machines, technology, and/or designs. These different items, the nouns, are the subject of most of the verbs. The overall prevalence and definition of each verb and noun are included in Table 5.4 as well as one final subcategory, *Research*. An example quote is also provided. The prevalence of each verb-noun combination is shown in Table 5.5.

Table 5.4 – Definitions of the *Creating and Designing* Subcategories

Subcategory	Pre	Post	Definition	Example Quote (emphasis added)
	N = 1697			
VERBS				
Design	19%	17%	Engineers design or develop <a noun>.	Engineers **design and develop** processes and ideas to simplify and optimize everyday lives.
Create	13%	11%	Engineers create <a noun>.	Engineers use science and math to solve problems and **create** products.
Build	7%	8%	Engineers build, construct, or manufacture <a noun>.	They **build** things that help improve everyday life
Make	2%	1%	Engineers make <a noun>.	Improve processes, **make** new machinery, provide necessary resources to society
Invent	2%	3%	Engineers invent <a noun>.	I believe they solve problems in the workplace, create solutions, and they **invent** new technology.
NOUNS				
Things	15%	13%	Engineers <verb> things, inventions, or stuff.	They build **things** that help improve everyday life
Products	9%	8%	Engineers <verb> products.	Engineers use science and math to solve problems and create **products**.

	Processes	8%	9%	Engineers <verb> processes, systems, or ways.	Engineers design and develop **processes** and ideas to simplify and optimize everyday lives.
	Technology	4%	4%	Engineers <verb> technology.	I believe they solve problems in the workplace, create solutions, and they invent new **technology**.
	Machines	2%	2%	Engineers <verb> machines, equipment, or instruments.	Improve processes, make new **machinery**, provide necessary resources to society
	Designs	1%	1%	Engineers <verb> designs.	Create new products or **designs** to improve or solve a problem
	Research	1%	1%	Engineers do research.	Engineers solve the world's problems, **do research**, and create improved technology.

Table 5.5 – Frequency of Verb-Noun Combinations in the *Creating and Designing* Category

%	**Things**	**Products**	**Processes**	**Tech.**	**Machines**	**Designs**	***null***
Design	7-6	6-5	5-5	2-2	2-1	0-0	2-3
Create	5-4	3-2	3-3	2-2	1-0	0-0	1-1
Build	3-4	2-2	1-1	1-1	1-1	0-0	0-1
Make	2-1	0-0	0-0	0-0	0-0	0-0	0-0
Invent	1-1	1-0	1-0	0-1	0-0	0-0	0-1

Notes: Frequency before and after the course are shown before and after the hyphen (-), respectively.

Even though Table 5.5 only shows the combinations of one verb with one noun, some students chose to list more than one verb and/or more than one noun in their responses. For example, the response, “Build and design various products, problem solving,” uses two different verbs and so is counted as both *Build Products* and *Design Products*.

Similarly, "Engineers, independently or as a team, work to create technology and processes…" was categorized as *Create Technology* and *Create Processes*. For this reason, the row and column totals in Table 5.5 do not sum to the reported frequencies in Table 5.4. An additional category of *null* is also present in Table 5.5 to count the number of students who mentioned a verb but did not offer a noun to accompany it; for example, "Calculate, management, design, plan ahead..." was only coded as *Design* and thus is counted in the respective *null* subcategory in Table 5.5. The *Designs* noun was used so infrequently with each verb that the percentage of students using the combination rounded to zero percent in every case.

Unlike *Problem Solving*, fewer students mentioned an aspect of *Creating and Designing* at the end of the course compared to the beginning of the course. Moreover, this trend holds for most of the subcategories and verb-noun combinations as well, though exceptions are present. One exception is the verb *Build,* which was used more frequently at the end of the course than the beginning, including when paired with the nouns *Things*, *Products*, and *Processes*. As an example, when asked before the class what engineers do for a living, one student responded, "They work on improving and innovating the world around us" which was coded as *Societal Impact and Quality of Life*, but did not specify how engineers have this impact. At the end of the course, when asked the same question, this student wrote that engineers "[m]ake lives easier through constructing things to better man kind [sic]." This response is also categorized as *Societal Impact and Quality of Life* but additionally categorized as *Creating and Designing* using the subcategory of *Build*

Things because of the addition of "constructing things" as a way engineers improve the quality of life.

While many students' responses are short, other students provide additional information and context that allow for a fuller picture to develop about their understanding of why engineers create and design things for a living. At the end of the course, one student wrote that, "Engineers do a variety of things depending on what type of engineer they are. Throughout the course I've learned that some engineers work on grand scale things such as that falcons [sic] stadium or they work on more day to day [sic] things that are smaller such as construction of pipelines and roadways." While this response has elements of many different categories, the student cited rather specific elements of construction categorized as *Build Things* – constructing pipelines and working on the Falcon's stadium. In context of the entire response, these were likely two different jobs mentioned by speakers that impacted the student's outcome expectations. By completing an engineering degree and pursuing an engineering career, the student would be able to work on both small or "day to day things" as well as large projects like the stadium.

5.5.4 Making Improvements

Complementary to students identifying that engineers create and design things and processes for a living, students also frequently mentioned that engineers make improvements to existing things and processes. As shown in Table 5.6, students often would provide only a generic indicator of what engineers spend their time improving, "Engineers solve problems or improve things." However, some students would provide additional specificity and indicate that engineers improve, products, products, technology, and machines, among other things.

Table 5.6 – Definitions of the *Making Improvements* Subcategories

Subcategory	**Pre**	**Post**	**Definition**	**Example Quote** (emphasis added)
	N = 1697			
Make Things Better	10%	12%	Engineers make things [generic] better.	Create or **improve on** things that benefit society.
Improve Efficiency	16%	16%	Engineers improve efficiency.	Attempt to make everything **more efficient**.
Improve Processes	8%	10%	Engineers improve processes or operations.	Engineers use their intellect to **improve processes**.
Improve Products	4%	4%	Engineers improve products or otherwise make them better.	Problem solve and use applied science/math to invent and **improve products**.
Improve Technology	3%	3%	Engineers improve technology.	Discover new and better ways to **improve technologies**
Improve Machines	2%	1%	Engineers improve machines or equipment.	**Improve the reliability and productiveness of machines** in the work environment as well as create a safer place for everyone.
Improve Designs	1%	1%	Engineers improve or simplify designs.	**Improve designs** and quality of life for everyone
Improve Solutions	0%	0%	Engineers improve solutions to problems.	Work to form solutions to problems or **create improvements to existing solutions**.

As with other categories, students' responses in this category could be the subject of many subcategories. As an example, one student wrote at the end of the course that "[u]sing a combination of logic, calculus, science, [and] reasoning, engineers create and improve systems, structures, designs, and machines to make to [sic] world run smoother and more efficiently while minimizing cost and maximizing output." In addition to the other categories represented in this response, within the *Making Improvements* category, this response was coded as *Improve Products*, *Improve Processes*, *Improve Efficiency*, *Improve Designs*, and *Improve Machines*. Note, however, that each student is counted only once in each category or subcategory even if they mention an idea multiple times.

Compared to before taking the course, 24 more students (1.4%) mentioned some aspect of *Making Improvements* in their response after completing the course. One example of a student who incorporated the category into the end-of-course response wrote that "[e]ngineers solve problems in creative ways" at the beginning of the course. This response was coded as *Problem Solving* and *Creative and Critical Thinking*. At the end of the course, the same student wrote that engineers "[s]olve problems to make systems in the world easier, more efficient, or safer." This response still invokes the *Problem Solving* category, but also mentions that the problems being solved *Improve Processes* and *Improve Efficiency* by making systems easier, more efficient, and safer.

5.5.5 Innovating

Similar to both of the previous two categories, *Creating and Designing* and *Making Improvements*, some students mentioned that engineers spend their time *Innovating* for a living. This idea was separated into its own category because of its dual definitions and interpretations. Some students provided enough detail to determine if innovation meant creating new products or improving an existing product, but other students did not. As an example, one student wrote that, “Engineers create and innovate methods of completing tasks.” Because the student mentioned that engineers “create…methods” it is easier to interpret “innovate methods” as improvement. However, for a student who wrote that, “[e]ngineers come up with innovative ways to make the world a better place” it is more difficult to determine if “innovate” is synonymous with “new” or “improved.” For this reason, this category was created separately from the *Creating and Designing* and *Making Improvements* categories. Some students also discussed *Innovating* as a noun instead of a verb. At the end of the course, one student wrote that engineers “[c]reate efficient and elegant solutions and innovations.”

5.5.6 Societal Impact and Quality of Life

As has been evidenced in other responses so far, another common theme in student responses is *Societal Impact and Quality of Life*. Even before the course, many students comment that they believe that engineers’ work has positive impacts on society at large and on the quality of life. These two potential impacts are also the subcategories for this category and are presented in Table 5.7 with their frequencies before and after the course, a definition, and an example quote.

Table 5.7 – Definitions of the *Societal Impact and Quality of Life* Subcategories

Subcategory	**Pre**	**Post**	**Definition**	**Example Quote**
	N = 1697			
Societal Impact	20%	28%	Engineers' work has positive impacts on society as a whole and the communities they serve.	Engineers attempt to find better solutions and build things to make the world a better place for everyone.
Quality of Life	15%	16%	Engineers' work improves the quality of life.	Engineers work to actively improve the quality of living for the population by improving aspects of our daily lives.

Students also often mention both of these subcategories in their response both before and after the course; for example, “They create and innovate. Make life easier and make the world a better place.” While similar, these two subcategories are distinct by the “size” of the impact. The societal impact is broader reaching and impacts all people at the same time. Comparatively, the quality-of-life component also impacts all people but does so at an individual level.

This category, and specifically the *Societal Impact* subcategory, experienced the largest increase in the number of responses at the end of the course compared to the beginning of the course. As an example, at the beginning of the course, one student wrote that, “Engineers make things. They solve problems and come up with revolutionary ideas and ways of doing things.” Then, at the end of the course, the same student wrote that, “Engineers create solutions for problems. They make innovating technology and processes that can make the world a better place.” This student’s response maintained some similar elements, including *Problem Solving*, but did add to the end-of-course response that the improvements that engineers make have a *Societal Impact*.

Similar to *Problem Solving*, ideas related to *Societal Impact and Quality of Life* in their responses are mostly closely related to the outcome expectations construct in SCCT. Because outcome expectations are the answer to the question, "What will happen if I complete this task?" the answer, in terms of being an engineer, are often the positive impacts on the communities and lives of individual people. According to SCCT, outcome expectations, with self-efficacy, inform interests which inform choice goals. Students in Civil Engineering and Environmental Engineering have reported that their ability to have an impact on society and to help the environment, respectively, were important factors for their choice of their engineering major [8].

5.5.7 Applying Knowledge and Skills

The literature reports that many students cite their abilities in math and science [1]–[4] as a reason they selected to study engineering. It is unsurprising then that many students mention math and science as part of what engineers do for a living. In addition to applying concepts related to math and science for a living, students also commented that engineers use computer programs. Finally, some students offered a more generic explanation of the knowledge engineers apply. These four subcategories along with their frequencies, definition, and an example quote are shown in Table 5.8.

Table 5.8 – Definitions of the *Applying Knowledge and Skills* Subcategories

Subcategory	**Pre**	**Post**	**Definition**	**Example Quote** (emphasis added)
	N = 1697			
General	3%	5%	Engineers apply what they know.	I believe that engineers **apply their knowledge** to develop more efficient problem solving techniques for various situations.
Math	12%	12%	Engineers use math. This may include specific examples like calculus.	Engineers tackle various problems around the workplace and solve them **using mathematics** and critical thinking
Science	12%	12%	Engineers use science. This may include specific examples like chemistry or physics.	Engineers **apply science** to solve problems in our everyday lives.
Computer Programs	1%	0%	Engineers use computer programs. This may include specific examples like AutoCAD or SolidWorks.	[D]esign and modify things sometimes **using programs such as AutoCAD and Solidworks**

As with other categories, responses in the *Applying Knowledge and Skills* categories were not limited to a single subcategory. Both before and after the course, more than half of students who mentioned an idea related to the category mentioned both *Math* and *Science* in their response; for example, “Engineers apply mathematics and science to real life situations in order to further the advancement of technology, environment sustainability, medicine, etc.”

Because the literature already reports that students consider their abilities in math and science important to their decision to be engineers, its presence in their responses is not very surprising. One student even wrote that being able to use “numbers and science” was of interest: “Engineers are the people that do interesting work with numbers and science, which is what interests me.” This aligns with the interest construct in SCCT, which is the product of both outcome expectations and self-efficacy. Therefore, it is likely that if this student was asked, “Are you capable of doing math and science?” the student would respond positively. Similarly, this is related to the interest task value of EVT because the student expresses interest in engineering because of engineers’ use of math and science.

5.5.8 Variety of Work

Students also mentioned that engineers perform a *Variety of Work*. One student even implied that there is no limit to the types of jobs that an engineer can have – “Its [sic] almost impossible to say in one line but there are almost infinite possibilities for engineers.” Other students provided examples to illustrate the variety of different work engineers can do for a living. At the end of the course, one student wrote that, “Engineers do many different things. Some engineers work to make processes move faster, some work to make aircrafts and cars, and other work to make different types of materials.” In addition to mentioning the *Variety of Work* in engineering, when providing examples, the student also mentioned that engineers spend their time *Creating and Designing* different aircraft, cars, and materials as well as *Making Improvements* to processes.

Because students in this study are enrolled in an engineering major exploration course in a first-year engineering program, students have expressed an interest in engineering by enrolling, but do not necessarily know what engineering is. This is partially evidenced by the fact that the number of responses in this category is greater at the end of the course compared to the beginning of the course. As an example, at the beginning of the course, one student wrote that “Engineers design, modify, or create something to be more efficient.” This response was categorized as *Creating and Designing* and *Making Improvements*. At the end of the course, the same student wrote that “[Engineers] can do a number of things, however, they mainly work to improve a design of a product.” This response was coded *Making Improvements* and *Variety of Work*.

Because students in the course already have some interest level in engineering in general, broadening their understanding of what engineering in general encompasses, namely a *Variety of Work*, should be beneficial for students to experience a positive feedback loop to connect their outcome expectations, an SCCT construct, with more specific interests. Ultimately, the feedback loop and refined interests should ideally lead to a goal of deciding on a specific engineering major, which is the focus of the next research question.

5.5.9 Depends on Engineering Major or Degree

With very little change from the beginning to the end of the course, some students mentioned that an engineer's work depends on the engineering major or degree earned by the person. For example, at the end of the course, a student wrote that “Engineers solve problems around communities and figure out ways to optimize efficiency on various systems and machines in their field of study.” This implies that some students consider that their decision about an academic major will not only influence their academic careers, but also impact the jobs and work they perform after graduating. Like the *Variety of Work* category, students likely use the information gained from both the major exploration course and their other experiences to begin to refine their interests in anticipation of the upcoming decision on which engineering major to choose.

About a quarter of students who mention that engineers' work *Depends on Engineering Major or Degree* combined this category with *Variety of Work*. As an example, one student wrote that, "Engineers do a wide range of tasks depending on the type of engineering and the position held but the things engineers do at work generally involve design, problem solving and streamlining processes to achieve the highest efficiency." This response indicates that engineers do a *Variety of Work* but qualifies the statement by saying that the variety is bound by the field of engineering in which the student earned a degree. With an understanding that engineers perform a *Variety of Work* even if it *Depends on Engineering Major or Degree*, students in the course realize that there are differences to the degree options before them.

5.5.10 Maintenance

Similar to, but distinct from, the category of *Making Improvements*, students also mentioned that some engineers perform *Maintenance* for a living. As presented in Table 5.2, the definition of the *Maintenance* category is that "Engineers are responsible for the upkeep of products and/or processes to make sure they continue to function." This is distinct from *Making Improvements* because maintenance requires upkeep and keeping the equipment or process in its current state of function. It is possible, however, that some maintenance work might also include the installation of parts that result in an improvement. *Maintenance* is also distinct because it includes repair work due to broken or otherwise disabled equipment or processes.

An example of this contrast is seen in this end-of-course response: "They [engineers] do different things, they fix things and make things better." This student first mentions the *Variety of Work* that engineers accomplish, then includes *Maintenance* when discussing that engineers "fix things," followed by *Making Improvements* when mentioning that engineers "make things better."

While there is only a nominal increase in the frequency of this category after the course compared to before, *Maintenance* is an example of an opportunity for students to expand their understanding of the field of engineering. In this regard, students have a greater context of what engineering entails, which allows students to reaffirm their decision to major in engineering and provides additional considerations for when students make their next decision – which engineering major to pursue.

5.5.11 Teamwork and Leadership

Students mentioned that engineers work with other people when they are completing their jobs. Some students specified that collaborators could be other engineers or could be people with backgrounds and skills in other areas of expertise. For example, one student who mentioned other engineers wrote, "Engineers work together and collaborate with one another to solve technical problems in specialized fields. Engineers work to increase efficiency and solve issues in the real world." Another student, mentioning more diverse teams, wrote, "Engineers collaborate with other professions to develop or enhance ideas to positively change human lives and interactions." Additionally, students also commented that engineers are often responsible for managing a team or overseeing a project. One student responded, "They use math and sciences to lead and participate in teams to design changes for companies and society."

Students included that engineers spend their time collaborating and in leadership in their responses is related to the outcome expectations construct in SCCT. Because outcome expectations are concerned with the future consequences of an action, both positive and negative, for a student who is interested in working with others and/or leadership opportunities, earning an engineering degree would be an option in order for those outcome expectations to become actual outcomes. Of course, a student simply wanting to work with others or be in leadership does not mean it will happen, but being aware of the potential outcome would allow students to create a goal and then make choices, including earning an engineering degree, to help reach and achieve that goal.

5.5.12 Creative and Critical Thinking

The ability to be creative and offer creative solutions to problems was another theme in students' responses to what engineers do for a living. Because the ability to think creatively and/or critically is commonly regarded as a skill, this category could have been merged with *Applying Knowledge and Skills* but was kept separate because the skills included previously are those that are the subject of traditional engineering coursework whereas rarely, if ever, are classes offered explicitly for *Creative and Critical Thinking*. Offering such a class may prove difficult because of the range of potential definitions for these ways of thinking.

In their responses, students did not provide much elaboration on what being a creative or a critical thinker meant, but a few did suggest that engineers "think outside of the box." One such student wrote, "I believe engineers work to improve the world by thinking outside the box and creating new systems." Other responses surrounding creative thinking highlighted the idea that engineers also create ideas; for example, "Engineers create ideas that develop and improve technology." This connects back to the *Creating and Designing* category at face value but is qualitatively different because the result is an idea, something that you cannot touch, compared to a physical product or machine. Finally, when students mentioned critical thinking, it was often an important or central skill in an engineer's proverbial toolbox. One student wrote, "Engineers [sic] work ranges from a variety of different jobs. The biggest thing they do is use critical thinking to find the answer to a problem."

5.5.13 Planning and Testing

Two other ideas that students stated in their responses were that engineers spend some of their time *Planning and Testing*. In almost all instances, responses that fit this category provided more details and thus fit with additional categories as well. As an example, at the end of the course, one student included planning in a list of activities that engineers accomplish to successfully solve a problem: "Engineers are problem solvers. They identify problems and work to make solutions. There are many different facets to this, including quality, planning, design, repair, product production, and other parts of the manufacturing workplace." Because engineers' work impacts other people, engineers have to test their work, as noted by this student: "They can literally do so many different things mostly to do with designing products and running tests on them as well making the products better."

Similar to the *Maintenance* category, the connections here to SCCT are moderate at best, especially given that the increased frequency in the *Planning and Testing* category is very small. However, for students to learn and recall that practicing engineers have to plan their projects and test their work allows for students to gain a deeper understanding of the field of engineering. This is important to make sure that students' interests and choice actions to date still align with their academic and career goals. This information about *Planning and Testing* could be of additional value to students when deciding which specific engineering major to pursue.

5.5.14 Quality, Safety, and Cost Constraints

The final category that actually describes what students believe engineers do for a living is that they design solutions to problems or make products under *Quality, Safety, and Cost Constraints*. The frequency of responses that mentioned an element of this category was higher at the end of the course compared to the beginning. Some students also mentioned additional constraints that an engineer may face, including time: "Engineers improve and create technologies that benefit the whole of society, improve the standard of living, and improve the environment. Engineers find the most time, cost, and ecologically effective ways to produce goods."

Another student who also mentioned the quality aspect of this category highlighted four additional categories: "Engineers do a variety of jobs at work including testing, designing, and inspecting the quality of products, machines, and new ideas." This response was coded as *Variety of Work* because the student mentions the variety of jobs available, *Planning and Testing* because the student mentions that engineers test the products, *Designing and Creating* because the student mentions that engineers design products and machines, and finally as *Creative and Critical Thinking* because the student includes that engineers come up with new ideas.

As many engineers would likely attest, the responses in this category are an essential part of the engineering design process and would be part of most engineers' jobs. With that in mind, this is critical information for students to be aware of as they are exploring their decision to major in the field of engineering. The choice model of SCCT includes performance domains that are a method to provide a feedback loop to the learning experiences that inform self-efficacy and outcome expectations which in turn inform interests and choice goals. By enrolling in this course, a learning experience, students can further develop and reflect on their self-efficacy and outcome expectations for engineering as both an academic and career decision to determine and allow the experience to moderate their interests so that they make the most informed major decision. If students continue with engineering, these additional learning experiences and refined interests will also be valuable when making their decision about a specific engineering major.

5.5.15 Unsure

The last category is different in almost every aspect from each of the previous categories. At the beginning of the course when asked what engineers do for a living, 13 students responded that they did not know; one student simply stated, “Honestly, I have no idea.” A few other students offered similar responses but continued and offered an explanation based on “what my family has told me” or what they think. These responses were not dissimilar to the responses that have been described.

At the end of the course, 12 of these 13 students were able to write, as least briefly, about what engineers do for a living. While there are nearly 1,700 student responses in this analysis, it seems like a safe assumption that there were more than 13 students with uncertainty in answering this question prior to completing the major exploration course. So, seeing that 92% of those who were willing to express that uncertainty no longer need to express it at the conclusion of the course speaks to the value students found in the course and what they were able to learn from it.

As an example, the student quoted earlier who said before the course, “Honestly, I have no idea” wrote at the end of the course that, “Engineers do basically everything in most fields. The biggest things are solve problems, test current solutions and be innovative with things that have never existed before.” This student’s responses transitioned from a single category of *Unsure* before the course to three different categories at the end of the course – *Problem Solving*, *Innovation*, and *Planning and Testing*.

5.5.16 Conclusions

Collectively, students' perceptions of the work engineers do for a living is broader at the end of the major exploration course compared to the beginning. Some students related two perceptions of engineering – *Problem Solving* and *Applying Knowledge and Skills* – to their interests and connected those interests to choice goals of earning an engineering degree, consistent with the SCCT framework. At the end of the course, the categories that had the largest increases in the number of mentions compared to the beginning of the course were *Problem Solving*, *Societal Impact and Quality of Life*, and *Variety of Work*.

Students heard about the work engineers do during course presentations, including the problems they face and solve in their roles. This is likely the cause of the increase in the *Problem Solving* category and the *Real-World Problems* subcategory. Additionally, students could connect the speakers' engineering expertise to their work and ultimately to their work's *Societal Impact and Quality of Life* enhancements. Because students were exposed to engineers from a variety of industries, it logically follows that the *Variety of Work* category would have more mentions because of the diversity of engineering backgrounds and industries represented by the invited speakers.

Students are also aware that engineers are involved in *Teamwork and Leadership* and have to consider *Quality, Safety, and Cost Considerations*. While the former category saw a small decrease over the course duration, it is still encouraging that these perceptions exist, especially given their presence in engineering in general and in engineering classrooms, particularly when working on senior design projects.

5.6 RQ4 – Perceptions of the Individual Engineering Majors

5.6.1 Overview of Majors

Students' responses to the item "What do engineers in your top choice major do at work." generated a total of 173 categories across all 10 engineering majors. Within each major, students often mentioned multiple ideas that belonged to more than one category and were categorized as such. Across the majors, some of the categories are identical to each other and/or identical to categories identified from students' perceptions of engineering in general (see Table 5.2).

Because students were only asked to describe engineering in their top choice major at each timepoint they completed the survey, some students described a different major at the end of the course than they did at the beginning. To accommodate these differences, students were assigned a status of "no change" or "change" to differentiate between students who reported the same major as their top choice at both the beginning and end of the course and those who changed their top choice major, respectively.

The tables below include the categories used to describe students' perceptions of what engineers in each major do at work. The number of students in each of three categories is also presented. First are those who reported the major as their top choice major at the beginning and end of the course ("No Change in Major"). These students gave descriptions of the same major at the beginning and end of the course. Second are the students who indicated the major as their top choice at the beginning of the course but did not list that major as their top choice at the end. The third and final group is those students who did not list the major as their top choice at the beginning of the course, but did choose it as their top choice at the end. Therefore, while the students in the “No Change in Major” columns are the same students at each time point, the students in the “Change in Major” columns are different students at each time point, with no overlap. For this reason, there will only be comparisons before and after the course for students without a change in major. Students who did have a change in major will be compared to the group of students without a change in major at the respective timepoints for which the groups reported the same major. In other words, there will not be any comparisons of the “Change in Major” students before and after the course because they are not the same students at the two timepoints.

The percentages presented in these tables are the percentage of students in that group (change in major or not and timepoint) that mentioned that category. Because students could mention more than one category in their responses, these numbers will always add to more than 100%.

To help differentiate the ten engineering majors, each of the following sections will include a short description of the major from the college’s website. These descriptions are provided for informational purposes only and are not used to judge or assess the accuracy of students’ perceptions of the majors. The descriptions are from publicly available webpages that students have access to during their major selection process.

5.6.2 Bioengineering

According to the college's website, "Today's bioengineers are on the job in research and development labs in all areas of medicine, from investigating the physiological behavior of single cells to designing implants using living and nonliving materials for the replacement of diseased or traumatized body tissues." The same website also reports that "Bioengineers find employment in industry, hospitals, research facilities of educational and medical institutions, and government regulatory agencies."

Students who expressed Bioengineering (BioE) as their top choice major used 15 different categories to explain what engineers in the field do at work. One of the more common categories mentioned both before and after the course by all students, regardless of if they still listed BioE as their top-choice major at the end of the course, was that bioengineers work to design and improve prosthetics and artificial limbs. The complete list of categories used by students who expressed an interest in BioE to describe what bioengineers do at work is shown in Table 5.9.

Table 5.9 – Categories Used to Describe what Bioengineers do at Work

Category	Definition	Example Quote	No Change in Major		Change in Major	
			Pre	Post	Pre	Post
			N = 121		N = 78	N = 36
Prosthetics	Bioengineers design and improve prosthetics and artificial limbs.	Work to create synthetic human body parts/prosthetics	48%	35%	33%	28%
Medical Devices and Equipment	Bioengineers design and improve medical devices and equipment.	I believe they create and design medical devices that help people and save lives.	33%	40%	40%	19%
Societal Impact and Quality of Life	Bioengineers' work has a positive societal impact and increases quality of life.	They help design products that improve people's quality of life	24%	18%	23%	22%
Medical Technology	Bioengineers design and improve medical technology.	they develop medical technology and experiment	21%	12%	10%	11%
Medicine and Health	Bioengineers design and improve medicine and are concerned with the health of patients.	Design treatments and healthcare improvements to better human health	16%	26%	21%	36%
Solve Problems	Bioengineers solve problems.	Help solve problems in the biology side of engineering.	15%	15%	18%	14%
Create Materials	Bioengineers design and improve materials, especially those used to make prosthetics and artificial limbs.	They develop materials that are made for the human body.	14%	12%	21%	14%
Research and Advancement	Bioengineers complete research and help advance the field.	Bioengineers help better advance the medical field as they invent new medical devices.	12%	14%	13%	14%

Apply Knowledge and Skills	Bioengineers apply their knowledge and skills, especially in math and biology.	I believe that bio-engineers, specifically in biomaterials, use biology and chemistry skills alongside general engineering skills to solve medical problems, as well as conduct research to create more efficient solutions.	10%	10%	14%	6%
Surgery and Surgical Equipment	Bioengineers design and improve surgical equipment and other items related to surgery.	Bioelectrical engineers design equipment to use during surgery or to implant into people during surgery.	7%	3%	5%	0%
Continuing Education	Bioengineering graduates often continue their education, including to medical school.	I believe bioengineering is a good major to get into medical school and will lead to me working as a doctor.	5%	2%	1%	3%
Broad Field with Options	Bioengineering is a broad field that offers multiple options for graduates.	Bioengineers work in a variety of fields, from healthcare to the automotive industry, doing everything from prosthetics to clean fuel.	4%	2%	4%	0%
Design Things, Products	Bioengineers design and improve things and products, but that are not necessarily medical related.	Applying math and science to biology and biological systems to design things.	2%	3%	4%	3%
Collaborate	Bioengineers collaborate with physicians and other engineers.	In bio-engineering, engineers work with those in the medical profession to create and improve new solutions to medical equipment.	2%	4%	13%	3%
Not Sure	I am not sure what bioengineers do at work.	Honestly not sure.	2%	1%	6%	0%

Among students who intended to major in BioE at both the beginning and end of the course, the category with the largest increase in the percentage of students mentioning an idea at the end of the course compared to the beginning is *Medicine and Health* (16% vs 26%). One student at the beginning of the course wrote a response that was coded only as *Prosthetics*, the most common pre-course category – "They design artificial replacements for biological systems such as joints or organs." – but at the end of the course had expanded this thought to explain the impact of bioengineers' work. This same student's response at the end of the course – "They design artificial systems that replicate biological systems such as joints or organs in the pursuit of better health for the patient." – was also categorized as *Medicine and Health* because of the added focus on the patient in the later response.

Another student, who maintained an intention of majoring in bioengineering and mentioned the *Medicine and Health* category in both the beginning and end-of-course responses, wrote, at the end of the course, "I want to go into biomedical engineering because people who work in this field get to create medical advancements and design concepts to advance health care." The student's response connects the perception of bioengineering to the student's future career plans or goals which is indicative of a high utility value for earning a BioE degree in the EVT framework.

It is also of note that students who did not have a change in their intended engineering major were less likely to mention *Medicine and Health* compared to students who did have a change in their major. At the beginning of the course, only 16% of students who did not have a change in major mentioned the category while 21% of students who switched their intention mentioned it. This same pattern holds true at the end of the course – 36% of students who had a change in their top-choice intended major to BioE mentioned *Medicine and Health* while only 26% of students who maintained a first choice in the major did so. This is coupled with the fact that students without a change in major did have a sizeable increase in the number of mentions at the end of the course compared to the beginning. These findings indicate that highlighting Bioengineering's connections to *Medicine and Health*, to the extent the perceptions are accurate, could be a good strategy to both retain students and recruit new students to the major.

There were also some categories that were mentioned by fewer "No Change in Major" students at the end of the course compared to the beginning; the two categories with the largest decreases are *Prosthetics* (48% vs 35%) and *Medical Technology* (21% vs 12%). For both of these categories, students who did not have a change in major were more likely to mention both these categories at the beginning of the course than their peers who changed their top-choice major. At the end of the course, while the differences are smaller, students who did not have a change in intended major were more likely to mention both of these categories compared to the students who were indicating BioE as their top choice for the first time. Especially for *Prosthetics* since it was the most common category for both groups of students at the beginning of the course, but also for *Medical Technology,* which is a relatively broad category, it is possible that students were initially attracted to the major because of the perceived focus on these topics, but as students learned more about the major, they were able to describe more and different work that bioengineers do. As an example, at the beginning of the course, one student wrote that bioengineers "[w]ork with medical technology to make sure everything functions properly within the body." At the end of the course, the same student no longer mentioned *Medical Technology* but listed multiple different kinds of work bioengineers do: "They work with the human body to improve medical processes such as developing new prothstetics [sic], improving drug delivery systems, and engineering new types of tissues and cells."

The students who changed their major intention from BioE mentioned that bioengineers *Collaborate* at a much higher frequency than those maintained a top-choice major in BioE (13% vs 2%). The fact that many students who mentioned this category left BioE could be the result of them finding another major that they perceived as better allowing for this interest to be met, which would be in alignment with the interest value in EVT or outcome expectations in SCCT.

Lastly, one student with a broad perception of BioE, including what is likely a misconception, wrote at the beginning of the course that bioengineers "Work construction management jobs, work on developing technology/materials for construction, medical, and other related processes." Because the construction element of this response was unique to this student, a category was not created, and this response was categorized as *Medical Technology* and *Create Materials*. However, at the end of the course, the student still indicated BioE as a top choice major and wrote that bioengineers "Design medical devices that replace body parts and organs, develop medical equipment." This is an additional example to highlight the value in this course – students are able to learn about the majors available to them and correct any misconceptions they may have about a major before they enter it, as is the case here, or change their intended major if their perceptions of a major do not agree with those observed in the course.

5.6.3 Biosystems Engineering

The college reports that "Biosystems engineering is a field dedicated to studying the footprints our bright ideas may leave on the earth and determining the best courses of action to prevent permanent harm." Additionally, students who earn a degree in Biosystems Engineering "have found fulfilling industry positions in a wide array of fields such as biofuels production, nutraceutical/ pharmaceutical production, environmental design and environmental protection."

Students who expressed Biosystems Engineering (BioSys) as their top choice major used 11 different categories to explain what engineers in the field do at work. One of the more common categories mentioned both before and after the course by all students, regardless of if they still listed BioSys as their top-choice major at the end of the course, was that biosystems engineers work to protect the environment. The complete list of categories used by students who expressed an interest in BioSys to describe what biosystems engineers do at work is shown Table 5.10.

Biosystems Engineering is the smallest engineering major being studied with only 13 students listing the major as their top-choice major at both the beginning and end of the course. An additional 17 students listed the major at the beginning of the course but switched their intention to another major before the end of the course while 30 students switched their intention to the major from another. Because of these very small sample sizes, the changes in the percentage of students expressing an idea in a category changes dramatically even if only one more or fewer students mentions that category.

Of the categories, all were identified in the beginning of course data except *Alternative, Sustainable, and Clean Energy* which was created as an emergent code while categorizing the end-of-course data. The beginning of course data was then reviewed to appropriately categorize any responses mentioning that category at that timepoint.

Table 5.10 – Categories Used to Describe what Biosystems Engineers do at Work

Category	Definition	Example Quote	No Change in Major		Change in Major	
			Pre	Post	Pre	Post
			N = 13		N = 17	N = 30
Protect Environment	Biosystems engineers protect the environment both proactively and reactively.	They design ways to protect and save the environment	38%	46%	35%	63%
Sustainability	Biosystems engineers promote sustainability in industry.	Use biology and environmental science to institute sustainable practices for ecosystems and development	38%	31%	29%	40%
Conservation	Biosystems engineers promote conservation, including preservation of natural resources.	Biosystems engineers find ways to use and reuse natural resources…	38%	8%	6%	7%
Ecological Impact	Biosystems engineers investigate and attempt to minimize the ecological impact of humans.	I believe they solve problems in nature to help reduce human footprint, to help plants and animals in their habitat, etc.	23%	8%	41%	30%
Not Sure	I am not sure what biosystems engineers do at work.	To be honest, I do not know much about this major…	23%	0%	0%	0%
Prosthetics, Medical	Biosystems engineers design and improve prosthetics and study the human body.	Solve different problems with our environment. My main reason for choosing biosystems is to be able to work with prosthetics.	15%	0%	18%	3%
Alternative, Sustainable, and Clean Energy	Biosystems engineers design and improve clean energy sources like biofuels and the methods to create them.	Engineers in the biosystems bioprocess emphasis mostly find new ways to produce biofuels…	15%	15%	12%	17%

Apply Knowledge and Skills	Biosystems engineers apply their knowledge and skills, especially in math, biology, and environmental science.	They come up with solutions to problems which effect people and our natural world using their knowledge of the fields of biology and engineering.	15%	38%	6%	17%
Solve Problems	Biosystems engineers solve problems.	I believe they solve problems in nature to help reduce human footprint, to help plants and animals in their habitat, etc.	8%	23%	12%	17%
Research	Biosystems engineers complete research.	they sit at a desk and research at some point and at others they're in the field actually doing work.	0%	0%	6%	7%
Societal Impact and Quality of Life	Biosystems engineers' work has a positive societal impact and increases quality of life.	Make the world a better place, reduce pollution and minimize effects on the earth.	0%	15%	6%	7%

The category that had the largest increase in mentions among students who reported a top-choice intention of majoring in BioSys both before and after the course was in *Apply Knowledge and Skills* (15% vs 38%). One student who was initially *Not Sure* what biosystems engineers do at work, but mentioned a "hope" they do *Conservation* work because it is the student's passion, wrote at the end of the course that a biosystems engineer "[u]ses biology and chemistry to work with earth's natural processes to help with conservation and other issues." The *Conservation* category is still present in the end-of-course response, but is coupled with the perception that biosystems engineers *Apply Knowledge and Skills* in biology and chemistry. Because this student had selected BioSys because "I hope that's sort of what they do [*Conservation*], because that's my passion" it is clear, in the SCCT framework, that this student made a choice goal to pursue BioSys based on interests.

Conservation was the category that had the largest decrease (38% vs 8%) in the number of mentions at the end of the course compared to the beginning among students without a change in their intended major. At the beginning of the course, one student who mentioned *Conservation* among many other categories wrote that "Biosystems engineers use life sciences to protect the environment and conserve resources including crop sustainability, renewable energy, and habitat restoration." At the end of the course, this same student wrote that biosystems engineers "use biology and ecology to solve problems caused by pollution and prevent these problems from happening. Work to fix damage done to ecosystems, flood control." Because the end-of-course response still included many different categories, including *Protect Environment*, *Solve Problems*, and

Apply Knowledge and Skills, it is likely that the initial perception of *Conservation* being part of biosystems engineers' work was not reinforced during the course. It is also possible that students collapsed elements of *Conservation* in their responses using language that was categorized as *Protect Environment* given the similarity of the two categories.

When comparing responses either before or after the course across the groups of students who did and did not have a change in their top-choice majors, two additional categories are of interest – *Ecological Impact* and *Protect Environment*. The first of the two was much more likely to be mentioned by students who switched their intended major from BioSys or switched to the major at the end of the course. As an example, a student who expressed an intention to major in Environmental Engineering at the beginning of the course and changed their top choice to BioSys wrote that "[biosystems engineers] solve problems and invent ideas for lessening our environmental impact, and find ways to utilize biological processes for completing that goal." A change in intended major between two majors that, at least in name, seem to have overlap speaks to the value added in the course that provide students with additional information to help make an informed major decision. Other students were also seemingly attracted to the major because the *Protect Environment* category was mentioned more often at the end of the course by students who were listing BioSys for the first time compared to those who listed it both before and after the course (46% vs 63%). This is also interesting because very similar categories, that use the same name, are also found in other majors including Chemical, Civil, and Environmental Engineering, though not always at the same frequency as BioSys.

The final category of interest in BioSys is the *Prosthetics, Medical* category which would generally seem more appropriate in Bioengineering. There were a total of five students, some of whom changed their intended major at the end of the course and some who did not, that listed prosthetics or something from the medical field as part of their perception of what biosystems engineers do at work. For example, one student who changed their intended major from BioSys to Bioengineering wrote at the beginning of the course that biosystems engineers "Solve different problems with our environment. My main reason for choosing biosystems is to be able to work with prosthetics." It is encouraging to see that this student switched majors and made a choice action, in the SCCT framework, that allowed the student to study in the major that is more representative of the listed interests. This also highlights an area where misconceptions about the majors is being addressed in the major exploration course.

5.6.4 Environmental Engineering

The college's website describes Environmental Engineering by saying that "As an environmental engineer, you can help solve many of the environmental problems faced by society using the principles of biology, chemistry, and the earth sciences. Our complex world faces many challenges, including contaminated water supplies, hazardous wastes, air pollution, increasing populations and limited resources."

Students who expressed Environmental Engineering (ENVR) as their top choice major used 15 different categories to explain what engineers in the field do at work. The most common category mentioned both before and after the course by all students, regardless of if they still listed ENVR as their top-choice major at the end of the course, was that environmental engineers work to protect the environment. The complete list of categories used by students who expressed an interest in ENVR to describe what environmental engineers do at work is shown in Table 5.11.

The Biosystems Engineering and Environmental Engineering degrees are offered by the same department at the institution being studied. For that reason, and the overall similarity in students' perceptions of the two fields, these sections are presented sequentially.

Table 5.11 – Categories Used to Describe what Environmental Engineers do at Work

Category	**Definition**	**Example Quote**	**No Change in Major**		**Change in Major**	
			Pre	**Post**	**Pre**	Post
			N = 40		N = 43	N = 23
Protect Environment	Environmental engineers help protect the environment and consider environmental impacts.	Environmental engineers use the design process to help protect the environment and to come up with new regulations.	58%	55%	37%	61%
Pollution	Environmental engineers monitor air and water pollution as well as clean it up.	They help figure out ways to eliminate pollution…	28%	25%	26%	9%
Waste Management	Environmental engineers design and improve waste management solutions.	Waste management, sustainability, and new energy.	25%	30%	14%	22%
Solve Problems	Environmental engineers solve problems.	They will be solving problems that are involved with the environment	23%	28%	30%	39%
Sustainability	Environmental engineers promote sustainability in industry.	Environmental engineers improve the health of our natural environment through making sure facilities are sustainable and creating natural and beneficial practices	23%	23%	23%	22%
Energy	Environmental engineers design and improve clean and renewable energy sources.	Engineers in environmental engineering help to use resources efficiently and aid in the advancements of reusable energy.	20%	8%	14%	13%

Water Supply	Environmental engineers manage the water supply as well as treat and purify water.	Environmental engineers find ways to make water as available for use as possible.	15%	33%	14%	43%
Societal Impact and Quality of Life	Environmental engineers' work has a positive societal impact and increases quality of life.	Better the world, insuring a comfortable, affordable, and efficient future.	13%	10%	9%	4%
Apply Knowledge and Skills	Environmental engineers apply their knowledge and skills, especially in math and science.	Use mathematics and sciences to reduce environmental impact.	10%	5%	2%	17%
Efficiency	Environmental engineers are concerned with efficiency of products and processes.	The part that I'm thinking about focuses on making renewable energy more efficient.	5%	5%	12%	0%
Testing	Environmental engineers run tests for the presence of containments in the environment.	Work with many different fields of engineering to test for harmful things in the environment	3%	0%	5%	0%
Research and Advancement	Environmental engineers complete research and help advance the field.	I think Environmental Engineers ... research ways to minimize the negative human impact on the environment.	3%	0%	2%	0%
Not Sure	I am not sure what environmental engineers do at work.	No clue, honestly.	0%	0%	9%	0%
Broad Field with Options	Environmental engineering is a broad field that offers multiple options for graduates.	I believe that environmental engineers do a wide range of things including…	0%	0%	2%	0%
Collaborate	Environmental engineers collaborate with other engineers and work as consultants.	I believe they can do a variety of things, from consulting to working in plants.	0%	13%	5%	0%

The *Water Supply* category saw the largest increase in percentage of students mentioning that category at the end of the course compared to the beginning among students who listed ENVR as their top-choice major at both the beginning and end of the course (15% vs 33%). At the beginning of the course, the percentage of students mentioning the category but who eventually switched their intention to major in something other than ENVR mentioned *Water Supply* at very similar rates to those who listed ENVR both times (15% vs 14%); however, at the end of the course, the students who were newly listing ENVR as their top-choice major mentioned *Water Supply* more frequently than their peers without a switch in intended major (43% vs 33%). These increases point to the fact that this category resonated with students who had already expressed an interest in ENVR and with students selecting it as their new top-choice. Given these increases, it is likely that students responded positively to an invited speaker's talk about work as an environmental engineer that highlighted water supply issues.

Two other categories that were mentioned more at the end of the course by students listing ENVR as their top-choice major than students who listed it twice are *Solve Problems* (39% vs 28%) and *Apply Knowledge and Skills* (17% vs 5%). While these categories are not unique to ENVR, their frequency by students attracted to the majors could point to a difference in these categories in ENVR compared to other engineering majors. One student who originally indicated a top-choice major of Biosystems Engineering but switched that intention to ENVR at the end of the semester wrote that "Environmental Engineers work to solve problems regarding our relationship as humans with our environment. They help to make our ways of living more sustainable, and they improve ways of living we have in place to make it safer and healthier for those using them." For the *Apply Knowledge and Skills* category, a student who listed ENVR at the both the beginning and end of the course wrote that "Environmental engineers use the principles of engineering, soil science, biology, and chemistry to develop solutions to environmental problems…" While these science fields are not unique to ENVR, they are not mentioned in every discipline, with soil science being a rare topic. Civil Engineering is the only other major to have any references to soil in student responses. The perceived need for a scientific background in ENVR could be contributing to the increase in the *Apply Knowledge and Skills* category. Explaining to students how environmental engineers use knowledge and skills from many different fields could prove beneficial in developing students' interests leading to greater recruitment and retention.

The *Collaborate* category also has a sizeable increase in the percentage of students mentioning this category at the end of the course relative to the beginning for students who listed ENVR as their top-choice major at both timepoints (0% vs 13%), especially because no students who maintained ENVR as their top-choice mentioned this category at the start of the course. This category also included multiple instances of collaboration in the form of consulting. While this idea did come up in a few responses outside of ENVR, it was most prevalent in this major. As an example, one student wrote at the end of the course that "…The most popular sector of environmental engineering is consulting, where companies bring in an environmental engineer on a temporary basis to work for them."

A final category that was only mentioned by students who ultimately switched their major away from ENVR before the end of the course was *Not Sure*, which was mentioned by four students at the start of the course. No students mentioned the category at the end of the course. This speaks to the value of the course and the information it provides to students as they are making a decision about what major to pursue. This also highlights that some students who may not have a top choice major are able to use the information they gain in the course to explore options and make a knowledgeable choice. According to the SCCT framework, students will select choice goals that align most closely with their interests. When taking this course, if students realize that their initial choice goal (their first intended, top-choice major) does not align with their interests, they will make a change. We have seen those changes in every major, including in ENVR.

5.6.5 Chemical Engineering

According to the college's website, "Based on the sciences of chemistry, biology, physics and mathematics, chemical engineering is at the forefront of environmental pollution prevention and remediation and is also leading the way in medical and health-related research." Students who earn a degree in Chemical Engineering "are prepared for jobs in many fields, including (but not limited to) biotechnology, business services, dentistry, electronic and advanced materials, energy and fuels, environmental industries, food processing, law, medicine, pharmaceuticals and specialty chemicals."

Students who expressed Chemical Engineering (CHE) as their top choice major used 18 different categories to explain what engineers in the field do at work. One of the more common categories mentioned both before and after the course by all students, regardless of if they still listed CHE as their top-choice major at the end of the course, was that chemical engineers work with chemicals and use their chemistry knowledge. This is very similar to results in the literature about high school students' perceptions of CHE [70]. The complete list of categories used by students who expressed an interest in CHE to describe what chemical engineers do at work is shown in Table 5.12.

Of the categories, all were identified in the beginning of course data except *Collaborate* which was created as an emergent code while categorizing the end-of-course data. The beginning of course data was then reviewed to appropriately categorize any responses mentioning that category at that timepoint, but none were found.

Table 5.12 – Categories Used to Describe what Chemical Engineers do at Work

Category	Definition	Example Quote	No Change in Major		Change in Major	
			Pre	Post	Pre	Post
			N = 95		N = 46	N = 24
Chemicals, Chemistry	Chemical engineers work with chemicals and use chemistry.	They manipulate chemicals for a variety of purposes.	62%	52%	52%	38%
Chemical Processes	Chemical engineers design and improve chemical processes, including mass production.	Design and improve processes for creating, storing, and transporting chemicals	39%	52%	26%	25%
Create Materials, Products	Chemical engineers create and improve materials and products.	Create new products or fix older products to make them more efficient.	26%	23%	22%	33%
Broad Field with Options	Chemical engineering is a broad field that offers multiple options for graduates.	What I like most about chemical engineering is the endless job opportunities…	17%	14%	9%	17%
Medicine and Healthcare	Chemical engineers design and improve medicine and other healthcare products.	Use chemistry to make innovations in various fields, such as pharmaceuticals.	15%	19%	17%	25%
Apply Knowledge and Skills	Chemical engineers apply their knowledge and skills, especially in math and biology. (Note: chemistry was tagged in another category.)	I believe that chemical engineers use the principles of chemistry, math, physics, biology, etc. to manufacture chemicals, quality test, etc.	15%	14%	13%	8%
Efficiency	Chemical engineers are concerned with efficiency of products and processes.	Create new products or fix older products to make them more efficient.	15%	15%	11%	17%
Solve Problems	Chemical engineers solve problems.	They use a knowledge of chemistry to solve problems.	13%	20%	17%	13%

Oil and Energy	Chemical engineers work in the oil and energy industry.	Span over a large area from managing to working with energy and polymeric materials.	11%	26%	11%	17%
Food and Agriculture	Chemical engineers work in the food and agriculture industry.	use chemistry to produce food, drugs, fuel or other products	7%	9%	13%	4%
Work in Industry	Chemical engineers work in other industries.	They use chemistry to solve problems especially in industry	6%	9%	9%	8%
Work in a Lab	Chemical engineers work in a laboratory.	I believe Chemical Engineers are working in labs and are working with chemicals and other substances…	6%	1%	4%	0%
Research and Advancement	Chemical engineers complete research and help advance the field.	They research and come up with new chemicals like plastics and dyes…	4%	6%	9%	4%
Protect Environment	Chemical engineers help protect the environment and consider environmental impact in their designs.	They use chemicals in order to create products that are better for the environment and its primary use…	3%	3%	9%	0%
Societal Impact and Quality of Life	Chemical engineers' work has a positive societal impact and increases quality of life.	Use chemicals, science, and math to solve problems and make this world a better place.	2%	1%	7%	4%
Safety	Chemical engineers are concerned with the safety of products and processes.	Engineers in Chemical Engineering design chemical processes to optimize efficiency and safety.	2%	5%	4%	4%
Not Sure	I am not sure what chemical engineers do at work.	I don't really have much of an idea…	2%	0%	2%	0%
Collaborate	Chemical engineers collaborate with other engineers.	…they are able to work with most engineers…	0%	3%	0%	4%

The *Oil and Energy* category had largest increase (11% vs 26%) at the end of the major exploration course compared to the beginning among students who expressed a top-choice major of CHE both before and after the course. At the beginning of the course, the rates at which this category was mentioned varied little between students who maintained a top choice in CHE compared to those students who switched their top-choice major to another (11% vs 11%). However, at the end of the course, students who had expressed CHE at the beginning of the course were more likely to mention this category than the students listing the major for the first time (26% vs 17%). One student who did not discuss anything in the *Oil and Energy* category at the beginning of the course wrote at the end of the course that "Chemical engineers help develop more efficient and safer ways to process materials wether [sic] that be fuel, medicines, food, chemicals, or structural substances." This response is an example of the broadened perceptions of the major after completing the major exploration course because this response also includes references to *Medicine and Healthcare* and *Food and Agriculture* along with *Oil and Energy*, none of which were mentioned in the before class response. It is worth noting that the institution being studied does not offer a Petroleum Engineering major where this response might be even more common and some students who may otherwise major in Petroleum Engineering may be majoring in CHE instead.

Another student who maintained a top choice in CHE and wrote at the beginning of the course that, "Specifically, my goal is to land a job in the oil industry or something pertaining to alternative fuels." The student then wrote another sentence and mentioned a large oil and gas company with operations around the world. At the end of the course the student was still interested in the same type of work: “Personally, with this major, I would like to end up in the field of alternative fuels of some sort.” In the SCCT framework, this student is making a choice action in declaring an intention to major in CHE in line with the choice goal of working in alternative fuels. In the EVT framework, this student is placing a high utility value on the CHE major because it is perceived as the necessary preparation for a career in alternative fuels.

The category that saw the largest decrease in the percentage of students who listed a top-choice major of CHE at both time points was *Chemicals, Chemistry* (62% vs 52%). While this category was still very popular, many of the responses in this category were very vague, so the reduction is a promising indicator of enhanced perceptions of the major. For example, at the beginning of the course, one student wrote that “[chemical engineers] use chemistry to solve problems especially in industry.” At the end of the course, this student had shifted the focus from *Chemicals, Chemistry* to *Chemical Processes* by writing that “If the [sic] work in industry, they work on big picture chemical processes, such as how the chemicals can move from one end of the factory to the other. They work on mass production and getting the highest yield.” This is another example of the expanded perceptions students have of their top-choice engineering major after completing the exploration course.

The *Chemical Processes* category was another category that was mentioned more often at the end of the course compared to the beginning by students who intended to major in CHE at both timepoints (39% vs 52%). Additionally, at both the beginning and end of the course, students who listed CHE as the top-choice major each time included *Chemical Processes* in their responses more often than students who listed CHE at only the beginning or the end of the course. This indicates that the perception that chemical engineers work with *Chemical Processes* was not necessarily a factor that attracted new students to the major.

Students who initially listed CHE as their top-choice major but switched their intention to another field at the end of the course mentioned the *Protect Environment* category more frequently than students who listed CHE at both time points (3% vs 9%). While this impacted only a small number of students, this is an example of a category that, insofar as the perception is accurate to the work of chemical engineers, could be highlighted by the discipline to help retain students who have expressed an interest. Similarly, at the end of the course, students who listed CHE for the first time were more like to mention the *Create Materials, Products* category, which could be used to help market the major to students to the extent that it is accurately representative of the major.

Students also commented that CHE is a *Broad Field with Options* which was attractive. For example, one student wrote at the beginning of the course that "From my research, I have learned that chemical engineers deal with a lot of different things, which is why I like this option as a top choice major. […] Chemical engineers work with everything, but I am specifically interested in more pharmacy, food, makeup, etc." Based on this response and that the student's top-choice major at the end of the course was still CHE for similar reasons, in the SCCT framework, this student has made a choice goal of pursuing CHE based on interests and is likely to follow the choice goal with a choice action of officially declaring the major.

5.6.6 Civil Engineering

The college website describes Civil Engineering as “the broadest of the engineering professions, serving as the stem from which most other branches of engineering have developed. Civil engineers plan, design, construct, maintain and operate facilities and systems that control and improve the environment for modern civilizations.” Graduates of the program often work in “traffic and transportation engineering, structural engineering, construction engineering, soils and foundation engineering, coastal and water resources engineering, public works and much more.”

Students who expressed Civil Engineering (CIV) as their top choice major used 21 different categories to explain what engineers in the field do at work. Two of the more common categories mentioned both before and after the course by all students, regardless of if they still listed CIV as their top-choice major at the end of the course, were that civil engineers work to design and improve roads and bridges as well as structures and buildings. The complete list of categories used by students who expressed an interest in CIV to describe what civil engineers do at work is shown in Table 5.13.

Table 5.13 – Categories Used to Describe what Civil Engineers do at Work

Category	Definition	Example Quote	No Change in Major		Change in Major	
			Pre	Post	Pre	Post
			N = 159		N = 61	N = 75
Roads and Bridges	Civil engineers design and improve roads and bridges and other transportation-related needs.	Help design things such as bridges, roads, etc.	52%	53%	77%	48%
Structures and Buildings	Civil engineers design and improve structures and buildings.	They direct how to build large structures.	49%	60%	61%	52%
Infrastructure	Civil engineers design and improve other infrastructure.	Design and implement infrastructure.	38%	30%	43%	31%
Water, Wastewater, and Dams	Civil engineers design and improve water and wastewater systems as well as dams.	Civil engineers design, and construct different things like roads, bridges, dams and so on.	18%	17%	15%	12%
Construction	Civil engineers are involved in the construction of infrastructure.	Work on infrastructures and construction projects	16%	14%	10%	13%
Planning, Blueprints	Civil engineers create and follow plans and blueprints.	Assess blueprints and floor plans of homes and buildings…	12%	8%	8%	8%
Safety	Civil engineers are concerned with the safety of products and processes.	Civil engineers work to make structures safe for use.	11%	12%	18%	12%
Efficiency	Civil engineers are concerned with efficiency of products and processes.	I think that they create things like roads and bridges and find out how to make them the most efficient.	11%	6%	11%	5%

Maintenance and Repairs	Civil engineers are responsible for the maintenance and repairs of infrastructure.	Create and maintain infrastructure in new and better ways	8%	9%	11%	8%
Societal Impact and Quality of Life	Civil engineers' work has a positive societal impact and increases quality of life.	Improves what is in society in order to cause less congestion or problems.	8%	13%	10%	7%
Solve Problems	Civil engineers solve problems.	Civil engineers design and construct buildings, bridges, and roads that help solve problems.	7%	6%	8%	4%
Management	Civil engineers are often involved in management.	Manage construction sites and deal with infrastructure	6%	6%	5%	4%
Protect Environment	Civil engineers help protect the environment and consider environmental impact in their designs.	Create better infrastructure that benefits the most people while causing the least damage to the environment.	6%	6%	2%	9%
Broad Field with Options	Civil engineering is a broad field that offers multiple options for graduates.	Civil engineers can do pretty much anything as it's such a wide field	5%	8%	2%	3%
Apply Knowledge and Skills	Civil engineers apply their knowledge and skills, especially in math and science.	Civil engineers use math, science, and engineering techniques to improve infrastructure and design, construct, and maintain the physical world around us.	4%	3%	8%	4%
Work in Cities	Civil engineers often work in or for cities.	They work in cities and help make things more efficient	4%	2%	3%	7%

Surveying	Civil engineers survey land.	Civil engineers survey the land where buildings are to be constructed and also focus on infrastructure creation like roads and bridges.	4%	1%	2%	1%
Cost Considerations	Civil engineers consider the cost of products and processes in their designs.	Design practical, cost effective, and structurally sound structures such as bridges, buildings, etc.	4%	3%	3%	0%
Public vs Private Business	Civil engineers work for both the general public and for private businesses.	They construct and design public and private construction projects whether it be roads, bridges, buildings, etc.	3%	3%	2%	1%
Not Sure	I am not sure what civil engineers do at work.	I'm not completely sure as to what civil engineers do specifically for a living…	3%	1%	0%	0%
Collaborate	Civil engineers collaborate with other engineers, architects, and the community.	Consult with architects and clients to create structures for civilization.	1%	1%	10%	5%

Compared to other majors, students held relatively consistent views of CIV at the two points responses were collected which could be due to the popularity of the major. However, some differences still exist; students who initially indicated a top-choice major in CIV at the beginning of the course but switched their intention at the end of the course mentioned the two most popular categories more often than students who listed CIV at both the beginning and end of the course: *Road and Bridges* (77% vs 52%) and *Structures and Buildings* (61% vs 49%). Because these were the two most popular categories mentioned, it indicates that students who leave are more likely to perceive of CIV by its more traditional focus areas. In Elrod and Cox's 2006 study [70], they reported that the most common descriptors high school students used to describe Civil Engineering were "bridges, buildings, people, [and] roads" which is in agreement with the most common categories of the current work.

Students who reported CIV as their top-choice major at the beginning and end of the course did have an increase in the *Structures and Buildings* category when comparing the frequency at the beginning of the course to the end (49% vs 60%). One student who was initially *Not Sure* what civil engineers did for a living wrote at the beginning of the course: "I honestly have no clue. I believe they do a lot of calculating equations and turn them into real life situations dealing mainly with construction." While this student did offer an initial perception of the major, those perceptions were more solidified and included the *Structures and Buildings* category at the end of the course: "They work on the structure and integrity of buildings and bridges, trying to make them stable." So, while this category is popular, it is not universally perceived by students and could be valuable to promote in the recruitment or retention of interested students. However, given that students who initially mentioned this category were those who switched away from CIV, explanations of how civil engineers' work with *Structures and Buildings* would likely need a greater level than detail to explain the accuracies, and any inaccuracies, of the perception.

Another student who listed CIV at both the beginning and end of the course as the top-choice major wrote at the end of the course that "I want to be a structural engineer, a subsection of civil engineering. Structural engineers create man made [sic] structures such as bridges." In the EVT framework, this student expresses both a high attainment value and a high utility value for majoring in CIV. Because the student expresses a desire to be a structural engineer as part of their self, pursuing a major in Civil Engineering will allow the student to attain that identity. Additionally, because this is a forward-looking image, the student is placing a utility value on majoring in CIV because it will allow the goals to be met.

The *Work in Cities* category was the category with the largest percentage of students who first listed CIV as their top-choice major at the end of the course compared to students who listed the major at both time points (2% vs 7%). While the number of students who mentioned this category is low, it is a rather unique category with no similar categories in the other majors studied here. As an example, a student who listed CIV as the top-choice major for the first time at the end of the course and wrote that civil engineers "Aid in the construction and design of systems (primarily in cities) that will be used by people." was likely partially attracted to the major because of the ability to work in a city, which is not always a common feature of other engineering majors.

Finally, the *Collaborate* category was mentioned less by students who maintained a top choice in CIV across the course compared to students who listed Civil Engineering at the beginning and a different major at the end of the course (1% vs 10%). While this category is common in many of the engineering disciplines studied, this is one of very few majors where this gap between these two groups of students is as large. Given this disparity, it could be beneficial for CIV to highlight aspects of the major and the field that allow civil engineers to collaborate with other engineers and other professionals as they go about their work when discussing with prospective students.

5.6.7 Computer Engineering

The college's website notes that while Computer Engineering and Electrical Engineering are different disciplines, they "both deal with computers and communications." These degrees are offered in the same department at the institution being studied. For that reason, Electrical Engineering will be presented in the next section. Computer Engineering focuses "mostly on the design, implementation and applications of computers and computer-controlled equipment, including computer architecture and software engineering."

Students who expressed Computer Engineering (CPE) as their top choice major used 19 different categories to explain what engineers in the field do at work. Two of the more common categories mentioned both before and after the course by all students, regardless of if they still listed CPE as their top-choice major at the end of the course, were that computer engineers work to design and improve computer hardware as well as computer software. The complete list of categories used by students who expressed an interest in CPE to describe what computer engineers do at work is shown in Table 5.14.

Table 5.14 – Categories Used to Describe what Computer Engineers do at Work

Category	Definition	Example Quote	No Change in Major		Change in Major	
			Pre	Post	Pre	Post
			N = 106		N = 34	N = 23
Computer Hardware	Computer engineers design and improve computer hardware.	Design computer hardware	47%	48%	29%	48%
Computer Software	Computer engineers design and improve computer software	They create software that let others do their jobs.	39%	37%	29%	57%
Computers	Computer engineers design and improve computers, in general.	I believe that computer engineers work with both the hardware and software of computers to innovate and make them more efficient.	28%	24%	38%	22%
Coding and Programming	Computer engineers spend time coding and programming computers.	I think they do types of coding for programs and they program different things to do certain actions	20%	23%	12%	35%
Computer & Electronic Components	Computer engineers design and improve computer and electronic components, in general.	They program and design components for machines, robots, and other computers.	15%	12%	26%	17%
Computer Systems and Networks	Computer engineers design and improve computers systems and networks.	design integrated computer systems	15%	26%	6%	17%
Technology	Computer engineers design and improve technology.	They create systems and software that protects and advances technology.	11%	12%	26%	4%

Efficiency	Computer engineers are concerned with efficiency of products and processes.	Make computers work more efficiently	9%	8%	9%	17%
Solve Problems	Computer engineers solve problems.	They are using their skills to solve problems using computers.	8%	13%	15%	4%
Circuits, Motherboards, and Hard Drives	Computer engineers design and improve circuits, motherboards, hard drives, and other specific computer components.	They design computer components and circuitry, such as motherboards.	6%	5%	12%	13%
Research and Advancement	Computer engineers complete research and help advance the field.	Research, develop, design, and test software and computer components.	5%	5%	0%	0%
Maintenance and Repairs	Computer engineers are responsible for the maintenance and repairs of computer hardware, software, and systems.	Computer engineers design and fix computer systems	4%	2%	6%	0%
Societal Impact and Quality of Life	Computer engineers' work has a positive societal impact and increases quality of life.	Computer engineers improve the world by using software and hardware.	4%	6%	6%	9%
Broad Field with Options	Computer engineering is a broad field that offers multiple options for graduates.	It is such a wide field of work to describe…	4%	1%	0%	4%
Not Sure	I am not sure what computer engineers do at work.	To be frank, I have no idea…	3%	0%	0%	0%
Bridge between CS and EE	Computer engineering as a field is a mix between computer science and electrical engineering.	They bridge the gap between electrical engineers and computer scientists. They work both with software and electrical components to ensure that the systems can function.	3%	7%	0%	0%

Apply Knowledge and Skills	Computer engineers apply their knowledge and skills, especially in math and science.	Use principals of coding, math, and science to solve problems.	3%	2%	0%	4%
Security, Safety, Cybersecurity	Computer engineers are responsible for computer and internet security and safety as well as cybersecurity.	Engineers in my top choice develop new software for computers, some do cyber security (anti-hacking), and others program robotics like cars.	3%	2%	3%	13%
Collaborate	Computer engineers collaborate with other engineers.	I believe that they work in teams and design new electric based systems or program systems.	2%	1%	3%	0%

The two most common categories mentioned by students who listed CPE as their top-choice major at both the beginning and end of the major exploration course were *Computer Hardware* and *Compare Software*. While many students mentioned both of these categories in their responses, some only mentioned one, but others, who did mention both, added qualifiers or conditions to their statements to convey a perception that *Computer Hardware* is more generally the focus, but that *Computer Software* is also common, just less so. To illustrate this idea, one student wrote at the end of the course that "Computer Engineers design computer hardware and consider software in context to hardware design." So, while many students have a perception that computer engineers work with both *Computer Hardware* and *Computer Software*, at least some students believe there is a hierarchy in that relationship.

These same two categories were also mentioned frequently by students who initially expressed CPE as their intended major but ultimately switched that intention to another major by the end of the course. This indicates that of the students initially attracted to the major, those who maintained it as a top choice were more likely to perceive of the major as working with *Computer Hardware* and/or *Computer Software.* However, at the end of the course, students who were listing CPE as their top-choice major for the first time mentioned *Computer Software* much more often than those who listed the major at both time points.

Related to these two categories, another category that was mentioned less frequently was that CPE is a *Bridge between CS and EE* (Computer Science and Electrical Engineering).

As an example, a student at the end of the course wrote that "[Computer engineers] serve as the bridge between electrical engineers and computer scientists. They have a background in both hardware/software and can solve problems/design systems within both areas." This category is also similar to the *Broad Field with Options* category that highlights how computer engineers can work in many different fields as one student wrote at the beginning of the course: "Like many other engineering majors, computers engineers work in a variety of fields. However, they emphasize on the specialization of electronic components that do their part within a design or operation."

While more traditionally associated with Computer Science, consistent with the idea that CPE is a *Bridge between CS and EE*, many students wrote that computer engineers also spend time *Coding and Programming* at work. At the end of the course, this category was also mentioned more often by students who had changed their intended engineering major to CPE compared to students who listed CPE at both timepoints (23% vs 35%). One student who indicated a top choice major of Electrical Engineering at the beginning of the course, but listed CPE as the top-choice major at the end of the course wrote that "[computer engineers] work with software, programming, and other components to a computer improving efficiency and quality." Because "new" students in CPE listed the *Coding and Programming* category more often, this could be a valuable category to mention when discussing this major with students to improve retention and help spur recruitment, to the extent that it is an accurate description of the field.

Lastly for this major, the *Computer Systems and Networks* category was the category that had the highest increase in the number of mentions from students who expressed CPE as their top choice at both timepoints. These students were also more likely to mention *Computer Systems and Networks* at both time points than students who had a change in their intended engineering major. One student, who did not have change in intended major, wrote at the beginning of the course, "I believe computer engineers work towards building and improving computer systems. With this degree, I would want to apply this to robotics". In the SCCT framework, this student had made a choice goal of intending to major in CPE in alignment with the interest of working in robotics. This also aligns with EVT's interest value for pursuing a CPE degree because there is likely to be enjoyment in working with robotics as a result of completing the degree.

5.6.8 Electrical Engineering

The college's website reports that "Electrical engineers concentrate on the laws of physics that govern electricity, magnetism and light to develop systems and services." The website also says that the Electrical Engineering program "encompasses circuits, computer engineering, electromagnetic fields, electronics, controls, signal analysis, power systems and communications."

Students who expressed Electrical Engineering (EE) as their top choice major used 18 different categories to explain what engineers in the field do at work. The more common categories mentioned both before and after the course by all students, regardless if they still listed EE as their top-choice major at the end of the course, were that electrical engineers work to design and improve things that involve electricity, including electrical systems and electronics, which is similar to high schools students most common perceptions of “electricity, circuits, wires, [and] wiring” [70]. The complete list of categories used by students who expressed an interest in EE to describe what electrical engineers do at work is shown in Table 5.15.

Table 5.15 – Categories Used to Describe what Electrical Engineers do at Work

Category	**Definition**	**Example Quote**	**No Change in Major**		**Change in Major**	
			Pre	**Post**	**Pre**	**Post**
			N = 80		N = 38	N = 22
Electrical Systems	Electrical engineers design and improve electrical systems and plans.	They design electrical systems for buildings or machines.	38%	33%	32%	45%
Electronics	Electrical engineers design and improve electronics and consumer electronic goods.	They create electronics or use electronics to make something easier	33%	44%	34%	32%
Electricity	Electrical engineers work with processes that involve electricity.	They work with electricity	23%	16%	13%	23%
Solve Problems	Electrical engineers solve problems.	An electrical engineer uses electricity to do useful work and to solve problems.	16%	19%	18%	14%
Power, Power Grids	Electrical engineers design and improve power grids and other power related equipment.	Designing layouts for electrical grids	16%	23%	13%	18%
Circuits	Electrical engineers design and improve electrical circuits.	Create more efficient circuits to do more complicated work as the years progress.	15%	21%	18%	23%
Apply Knowledge and Skills	Electrical engineers apply their knowledge and skills, especially in math and physics.	I think electrical engineers use their knowledge of mathematics and physics to solve problems and create solutions involving electrical systems.	10%	6%	8%	5%

Wiring	Electrical engineers design and improve wiring, including the wiring of buildings.	Working with wires and electrical components	8%	5%	11%	5%
Broad Field with Options	Electrical engineering is a broad field that offers multiple options for graduates.	What attracts me to electrical engineering is that it is very broad and can go into many different jobs and I have heard of electrical engineers going off and doing many different things.	8%	10%	8%	9%
Computers	Electrical engineers design and improve computers and their components.	work on electrical systems such as computers, robots, cell phones, and wiring	6%	6%	11%	9%
Technology	Electrical engineers design and improve technology.	Innovate technology and systems	6%	10%	8%	5%
Testing	Electrical engineers test electrical equipment and systems.	Electrical engineers design and test different electrical systems and try to make them work together.	5%	9%	3%	0%
Not Sure	I am not sure what electrical engineers do at work.	Not exactly sure but I am excited to find out	5%	0%	3%	0%
Collaborate	Electrical engineers collaborate with other engineers.	I believe those engineers sit at a desk or collaborate with others to design something in order to make it the best possible way.	5%	6%	0%	5%
Maintenance and Repairs	Electrical engineers are responsible for the maintenance and repairs of electrical equipment and systems.	Repair or design the wiring or machinery.	4%	6%	5%	0%

Societal Impact and Quality of Life	Electrical engineers' work has a positive societal impact and increases quality of life.	Design and upgrade technology, especially electronics, for the betterment of society	4%	8%	5%	14%
Research and Advancement	Electrical engineers complete research and help advance the field.	Research and work with different electrical devices in order to improve the device	3%	0%	3%	5%
Efficiency	Electrical engineers are concerned with efficiency of products and processes.	They create, innovate, or invent technology to make things more efficient, easy, and more appealing.	5%	4%	0%	5%

Similar to Civil Engineering, students' perceptions of EE are relatively stable with only a few large changes across the duration of the course. The *Electronics* category was the category that saw the largest increase in percentage of students who had a top-choice major in EE at both the beginning and end of the major exploration course (33% vs 44%). At the beginning of the course, the students who maintained a top choice in EE and those who changed their choice to any other major reported *Electronics* at nearly even rates (33% vs 34%) but given the sizeable increase among those who maintained a top interest in EE, at the end of the course the gap between the groups was larger (44% vs 32%). One student who maintained EE as the top-choice major wrote at the end of the course that "[electrical engineers] create electronics or use electronics to make something easier" and at the beginning had written only about being *Not Sure* what electrical engineers do.

In the end-of-course response, another student who mentioned the *Electronics* category as well as that EE is a *Broad Field with Options* and indicated EE as the top-choice major at both time points wrote "I believe electrical engineering to be my top choice because of the versatility of the degree and because of the interest I have already had in electronics." In line with the SCCT framework, this student had an existing interest and has made a choice goal of majoring in EE as a result. Similarly, in the EVT framework, the student is placing a high attainment value on majoring in EE because of this existing interest that the student has connected with becoming an electrical engineer as well as a high utility value because of the perceived versatility of the degree.

Different from the *Electronics* category, the *Electrical Systems* category saw fewer students who maintained EE as their top-choice major mention the category compared to students who listed EE as their top-choice major for the first time at the end of the course (33% vs 45%). This difference suggests that students who are "new" to EE were attracted by the idea that electrical engineers work with *Electrical Systems*. At the end of the course, a student who had previously listed Environmental Engineering as the top-choice major but switched that top-choice to EE wrote that "[electrical engineers] design and improve electrical systems for use in society." combining the *Electrical Systems* category with the *Societal Impact and Quality of Life* category. Given that the *Electrical Systems* category was already popular at the beginning of the course and mentioned more by students changing their intended major to EE at the end of the course, discussing this category, as much as it accurately represents the major, would likely be beneficial in the recruitment of new students and retention of some current students who may otherwise switch majors.

The two next largest differences in perceptions about EE are instances where students who listed EE at both timepoints hold the perception more broadly than students who listed EE as their top-choice major at only one timepoint: *Electricity* at the beginning of the course (23% vs 13%) and *Testing* at the end of the course (9% vs 0%). The fact that the *Electricity* category was not mentioned by more students overall is encouraging because of its vagueness and that the category was included in the list of the most frequent responses from high school students when asked about EE in Elrod and Cox's study [70] – "electricity, circuits, wires, [and] wiring." The category also sees a modest decline in the number of mentions by students who listed EE as their top-choice major at both the beginning and end of the course (23% vs 16%).

5.6.9 Industrial Engineering

Industrial engineers are described by the college website as engineering “who help companies and government agencies operate effectively and competitively.” Graduates from the program work “at many companies in the manufacturing and service sectors” which includes many large and international companies.

Students who expressed Industrial Engineering (IE) as their top choice major used 15 different categories to explain what engineers in the field do at work. Two of the more common categories mentioned both before and after the course by all students, regardless of if they still listed IE as their top-choice major at the end of the course, were that industrial engineers focus on the efficiency of products and processes as well designing and improving processes. The complete list of categories used by students who expressed an interest in IE to describe what industrial engineers do at work is shown in Table 5.16.

Table 5.16 – Categories Used to Describe what Industrial Engineers do at Work

Category	Definition	Example Quote	No Change in Major		Change in Major	
			Pre	Post	Pre	Post
			N = 113		N = 29	N = 117
Efficiency	Industrial engineers are concerned with efficiency of products and processes.	Efficiency analysis, streamlining, improving efficiency and productivity.	63%	66%	62%	62%
Develop and Improve Processes	Industrial engineers design and improve processes.	Create and refine processes and systems	50%	62%	55%	76%
Processes that Involve People	Industrial engineers design and improve processes in the workplace that involve people.	They solve problems due to how people interact in the world.	16%	21%	21%	11%
Consider Cash Flow	Industrial engineers consider the cost of products and processes in their designs.	They work to save money and improve efficiency in engineering applications.	15%	19%	3%	12%
Solve Problems	Industrial engineers solve problems.	Industrial Engineers solve more everyday problems and issues	10%	17%	28%	11%
Develop and Improve Products	Industrial engineers design and improve products.	They design items or processes to facilitate production of goods or services	10%	12%	14%	9%

Management	Industrial engineers are often involved in management.	I think that industrial engineers work more on the management side of the field than their engineering counterparts…	9%	5%	0%	4%
Collaborate	Industrial engineers collaborate with other engineers.	Work together to figure out how to improve something or fix a problem.	8%	5%	3%	1%
Work in Industry	Industrial engineers work in industry.	IEs work to fix problems in an industrial setting and streamline industrial processes	6%	4%	21%	3%
Consider Time	Industrial engineers consider the time required to make products and execute processes.	Make systems more efficient to save time/money	6%	10%	7%	9%
Societal Impact and Quality of Life	Industrial engineers' work has a positive societal impact and increases quality of life.	Industrial engineers use optimization and supply chain logistics to improve society and operation systems.	6%	9%	0%	3%
Broad Field with Options	Industrial engineering is a broad field that offers multiple options for graduates.	Work in the logistics branch of industrial companies. Variety of different paths and positions with concern to logistics.	5%	4%	7%	6%
Apply Knowledge and Skills	Industrial engineers apply their knowledge and skills, especially in math and science.	Make systems more efficient using math and science.	4%	3%	7%	9%

Not Sure	I am not sure what industrial engineers do at work.	I honestly don't know. That's why I took this course.	3%	1%	3%	1%
Research and Advancement	Industrial engineers complete research and help advance the field.	They can either work in a factory making the machines work better or they can do research.	1%	3%	0%	0%

The perception that industrial engineers are concerned about *Efficiency* is a broadly held perception with nearly two-thirds of students mentioning an idea related to this category while discussing IE. The *Develop and Improve Processes* category is also broadly held, though to a lesser degree than *Efficiency*, but is more commonly mentioned at the end of the course by students who indicated a top-choice major in IE for the first time compared to student who indicated IE at both timepoints. Therefore, as much as the category is representative of what industrial engineers do at work, sharing how industrial engineers *Develop and Improve Processes* could be beneficial for recruitment. However, IE has does not really have any issues recruiting students; at the end of the course, there are fewer students who listed IE as their top-choice major at the beginning of the course than who did not (113 vs 117). IE is the only highly enrolled major for which this is true (the other two majors are Biosystems Engineering and Materials Science and Engineering, both of which have considerably lower enrollment).

One of the more unique categories that students perceive about IE is that industrial engineers work with *Processes that Involve People*. This category saw a slight increase in the percentage of students who mentioned this category at the end of the course relative to the beginning among students who listed IE as their top choice at points times. Additionally, those same students mentioned the category more often than students who listed IE as their top choice for the first time at the end of the course. As an example, one student, whose intended engineering major changed from Mechanical Engineering to IE, wrote at the end of the course that “Industrial engineers optimize different systems in their workplace, whether it be a system of people or technology.”

At the beginning of the course, two categories that were mentioned more often by students who ended up changing their intended major to something other than IE compared to those who maintained IE as their top-choice major were *Solve Problems* (10% vs 28%) and *Work in Industry* (6% vs 21%). While these categories are not unique to IE, it is of interest that the group that mentioned them more often were those that switched their intended major away from IE. Given that these categories are not unique, it is likely that these students were able to easily find another major that met these perceptions of IE within engineering or another STEM field. As an example, one student who started with a top-choice major in IE wrote "Fixing problem in the industry. For example, helping people who work in factories become the most efficient in the healthiest ways." At the end of the course this student's top-choice major was Chemical Engineering, which also has *Solve Problems* and *Work in Industry* categories.

Two other rather unique aspects of students' responses about IE are the perceptions that industrial engineers *Consider Cash Flow* and *Consider Time*. While these are ideas are related to *Efficiency*, they were specific enough to warrant their own category. Students who listed IE as their top-choice major at both times points were more likely to mention the *Consider Cash Flow* category at the beginning of the course compared to students who switched their top-choice away from IE. This category did have similar categories in both Civil Engineering and Mechanical Engineering. However, the *Consider Time* category was unique to IE and reinforces the idea, from a perceptions standpoint instead of an enrollment standpoint, that IE is a unique major.

One perception about IE that was uncommon in the data, but that is prevalent (or at least has been prevalent) about IE is that the major is “easy” or is “imaginary” engineering [66]. In this data, at the end of the course, one student wrote that industrial engineers “Solve problems on a less technical level. i.e., in a business setting where you're dealing with people and processes rather than physical parts.” This student did intend to major in IE at both timepoints, so it is difficult to say if the student would have agreed with the narrative of “easy” or “imaginary” engineering. It is encouraging that these types of responses were low, but students who never intended to major in IE were never asked to describe it, so it is possible that this perception still exists in the larger engineering community, though it is largely not held by students when they intend to major in IE.

Finally, a student with a top-choice major of IE at both the beginning and of the course wrote that “Industrial engineering from what I have gathered focuses mostly on efficiency whether that is in a company or in the way technology works. It seems like they tend to work with other engineers like mechanical or civil engineers on projects. Ultimately I would like to go into ergonomics and work with efficiency of people.” This response mentions multiple categories, including *Efficiency*, *Processes that Involve People*, and *Collaborate*. The student also connects the perceptions of IE to interests in both ergonomics and the efficiency of people. This is in agreement with the SCCT framework that people create choice goals and take choice actions, like enrolling in IE, in alignment with interests. Similarly, in the EVT framework, the student has placed a high utility value on majoring in IE because it will allow for future employment and a career working in areas of interest to the student.

5.6.10 Materials Science and Engineering

The college's website describes Materials Science and Engineering as "a vast, interdisciplinary, 21st century renaissance field based around the creation of materials that will change and define how we go about our everyday tasks. Those who study [the major] research the properties of polymers, glasses, ceramics and metals in bulk (chunks), thin film and fiber forms"

Students who expressed Materials Science and Engineering (MSE) as their top choice major used 14 different categories to explain what engineers in the field do at work. The most common category mentioned both before and after the course by all students, regardless of if they still listed MSE as their top-choice major at the end of the course, was that materials scientists create new materials. The complete list of categories used by students who expressed an interest in MSE to describe what materials scientists do at work is shown in Table 5.17.

Table 5.17 – Categories Used to Describe what Materials Scientists do at Work

Category	**Definition**	**Example Quote**	**No Change in Major**		**Change in Major**	
			Pre	**Post**	**Pre**	**Post**
			N = 30		N = 26	N = 31
Create Materials	Materials scientists create new materials.	They design and develop new materials	67%	70%	65%	65%
Improve Materials	Materials scientists improve materials	They improve materials.	27%	20%	8%	32%
Make, Improve Products	Materials scientists design and improve products using materials.	Make things useful to society	23%	20%	23%	13%
Efficiency	Materials scientists are concerned with efficiency of products and processes.	They create and test old and new materials for better efficiency	17%	3%	23%	3%
Work with Materials	Materials scientists work with materials	materials science engineers use materials such as metal and plastic to create newer and improved things	13%	20%	19%	10%
Analyze Materials	Materials scientists analyze materials.	Materials Scientists develop and analyze materials for specific purposes.	13%	13%	8%	6%
Test Materials	Materials scientists test materials.	Designing and testing new materials	13%	0%	4%	3%
Apply Knowledge and Skills	Materials scientists apply their knowledge and skills, especially in math and science.	Materials science and engineering combines engineering, physics and chemistry, and uses them to solve real-world problems…	10%	13%	8%	16%

Choose Materials	Materials scientists choose materials.	Figure out the best materials to use for certain situations	7%	7%	12%	16%
Societal Impact and Quality of Life	Materials scientists' work has a positive societal impact and increases quality of life.	Works with the process of materials	3%	10%	12%	3%
Not Sure	I am not sure what material scientists do at work.	Not really sure…	3%	0%	0%	3%
Research and Advancement	Materials scientists complete research and help advance the field.	Research and develop new and revolutionary materials	0%	3%	0%	6%
Solve Problems	Materials scientists solve problems.	Create solutions to materials based problems.	0%	3%	12%	10%
Broad Field with Options	Materials science and engineering is a broad field that offers multiple options for graduates.	...They solve problems in several different engineering fields…	0%	0%	0%	3%

The categories that students used to describe their perceptions of what materials scientists do at work are relatively vague, but all center around the idea of working with materials – creating, improving, analyzing, testing, etc. While many students did use the rather generic “materials” term in their responses, other did provide more specific examples including polymers and composites. For example, at the end of the course, a student who had expressed a top choice in MSE at both timepoints wrote that materials scientists “[w]ork with solids [sic] materials such as ceramics, polymers, plastics, and metals to develop new materials or improve existing ones.”

Because MSE is the second smallest major by enrollment, second to BioSystems Engineering, changes of only one or two students are more sizeable in the overall percentages compared to other majors. However, there were still some sizeable differences in *Improve Materials* category. At the beginning of the course, students who retained a top-choice major in MSE mentioned the category more often whereas at the end of the term, students who were listing MSE at their top-choice major for the first time listed it more often. Given this switch that more students who were “new” to MSE mentioned *Improve Materials* at the end of the course, could be the result of a response to a speaker’s talk to the class or another related experience. Regardless, highlighting this aspect of MSE, to the extent it is accurate, could be beneficial to share with potential students.

Two sizeable changes among students who indicated that MSE was their top-choice major at both time points were in the *Efficiency* and *Test Materials* categories. In both of these categories, the frequency of each being mentioned was lower at the end of the course than at the beginning – 17% vs 3% for *Efficiency* and 13% vs 0% for *Test Materials*. For example, a student who mentioned *Test Materials* at the beginning of the term but not at the end, wrote at the end of the term that material scientists "research and develop new and revolutionary materials." Given the omission of the *Test Materials* category in this response with the fact that no other students who maintained the MSE intention included the category indicated that this perception, rightly or wrongly, was not reinforced.

At the beginning of the course, a student whose top-choice major was MSE wrote the following: "I love Formula 1 racing; for each team there is a group of materials engineers working on utilizing different materials to solve problems and make the car quicker or more reliable. An example of this would be Mercedes AMG using an [sic] non-stick Teflon spray to try and keep debris out of the brake cooling ducts." The level of detail the student provides proves the level of interest in racing as well as its connection to MSE. This also agrees with the SCCT framework because the student has made a choice goal that is in agreement with the student's interests. Surprisingly, however, at the end of the course, this student switched to a top-choice major in Civil Engineering and wrote that civil engineers "[d]esign roads, bridges, storm water systems, and other things. The speaker who came to talk about traffic design was really interesting, I think I'd like that." Not only does this end-of-course provide an explanation for the major switch given the students is also interested or developed an interest in traffic design, but also provides an example of the value of the course and the invited speakers as students are making a decision about their major.

5.6.11 Mechanical Engineering

According to the college's website, studying Mechanical Engineering "encompasses physical and engineering sciences, design and laboratory experience, the humanities, social sciences, communication and computer skills." Most students who graduate from the program "accept positions in professional practice in industry in fields including advanced alternative energy systems, natural resource harvesting, materials, transportation vehicles (air, space, ground, sea) and systems, manufacturing, health and bio-systems, and consumer products of all types."

Students who expressed Mechanical Engineering (ME) as their top choice major used 27 different categories to explain what engineers in the field do at work. Two of the more common categories mentioned both before and after the course by all students, regardless of if they still listed ME as their top-choice major at the end of the course, were that mechanical engineers develop and improve both machines and equipment as well as parts and products. The complete list of categories used by students who expressed an interest in ME to describe what mechanical engineers do at work is shown in Table 5.18.

Table 5.18 – Categories Used to Describe what Mechanical Engineers do at Work

Category	Definition	Example Quote	No Change in Major		Change in Major	
			Pre	Post	Pre	Post
			N = 411		N = 127	N = 90
Develop and Improve Machines, Equipment	Mechanical engineers design and improve machines and equipment.	Develop and improve upon different types of machinery.	44%	35%	46%	36%
Develop and Improve Parts, Products	Mechanical engineers design and improve products and parts.	Design products or parts, help build products.	31%	35%	29%	39%
Develop and Improve Processes, Systems	Mechanical engineers design and improve processes and systems.	They work on improving mechanical systems.	17%	20%	17%	22%
Efficiency	Mechanical engineers are concerned with efficiency of products and processes.	They design more efficient ways to make parts or objects work.	16%	15%	14%	18%
Vehicles	Mechanical engineers design and improve vehicles, including cars and airplanes.	Mechanical engineers help make cars, airplanes, and other vehicles for people to use. They also test these machines to make sure they are safe.	15%	15%	9%	16%
Solve Problems	Mechanical engineers solve problems.	Use mechanical and physical aspects of the world to solve problems	15%	22%	14%	14%

Broad Field with Options	Mechanical engineering is a broad field that offers multiple options for graduates.	Mechanical engineers are the most broad form of engineering where they can work in basically any kind of work area and thrive.	13%	14%	13%	18%
Movement	Mechanical engineers work with machines, parts, and processes, that have motion or move.	Work with moving parts.	8%	10%	6%	8%
Apply Knowledge and Skills	Mechanical engineers apply their knowledge and skills, especially in math and science.	Mechanical engineers deal with the physics behind the way things work.	7%	11%	5%	14%
Societal Impact and Quality of Life	Mechanical engineers' work has a positive societal impact and increases quality of life.	Create new machines and safer machines to make our lives easier	7%	7%	4%	12%
Engines, Motors	Mechanical engineers design and improve engines, motors, and turbines.	Mechanical Engineers design engines and other moving things.	7%	6%	6%	4%
Technology	Mechanical engineers design and improve technology.	They solve problems, create, and test new technology or improve the current ones.	5%	5%	3%	4%
Testing	Mechanical engineers test machines, parts, and processes for failure and quality.	...They also test products to make sure they are mechanically sound.	5%	12%	2%	18%
Hands-on Work	Mechanical engineers do a lot of hands-on work.	Hands on work to improve items.	4%	4%	2%	1%
Energy and Power Systems	Mechanical engineers design and improve energy and power systems.	They design and operate on machinery and power-producing machines.	4%	3%	6%	1%

Maintenance and Repairs	Mechanical engineers are responsible for the maintenance and repairs of machines, parts, and processes.	They maintain and improve mechanical systems	3%	4%	6%	4%
Not Sure	I am not sure what mechanical engineers do at work.	I am not completely sure.	3%	0%	5%	0%
Work in Industry	Mechanical engineers work in industry or in factories.	To maintain or improve mechanical systems in factories or other buildings	2%	1%	2%	1%
Robotics	Mechanical engineers design and improve robots.	They design or work on machines/robotics	2%	0%	2%	0%
Collaborate	Mechanical engineers collaborate with mechanics and other engineers.	Mechanical engineers can work with all types of engineers to make sure equipment meets all standards.	2%	3%	2%	1%
Research and Advancement	Mechanical engineers complete research and help advance the field.	A lot of mechanical engineers work in quality control, R&D, and systems design.	2%	2%	0%	0%
Safety	Mechanical engineers are concerned with the safety of machines and products.	Help a company work efficiently and safely	2%	4%	2%	9%
Management	Mechanical engineers are often involved in management.	They oversee other workers and create procedures for others to follow.	2%	2%	0%	2%
Consider Cash Flow	Mechanical engineers consider the cost of products and processes in their designs.	I think mechanical engineers plan and create machines for large companies to increase their efficiency to cut spending.	1%	2%	3%	0%

Design Software	Mechanical engineers use design software like SolidWorks and AutoCAD.	design and modify things using programs such as AutoCAD and Solidworks	1%	1%	0%	1%
Constraints	Mechanical engineers design and improve machines and products within a given set of constraints.	Manufacture and design parts to make a process more efficient, or solving complex problems given constraints.	1%	1%	2%	0%
Construction & Manufacturing	Mechanical engineers are involved with the construction and manufacturing of machines and products.	They can work in a variety of areas and are well-rounded. They look at designs and adjust them, but also participate in the building process.	2%	4%	2%	3%

Like Civil Engineering and Electrical Engineering, ME has very constant perceptions that are arguably the most consistent of all majors studied. Part of this could be due to the large enrollment in ME and its history as the oldest engineering discipline. However, there are still two larger changes in perceptions – the first is among students who listed ME as their top-choice major at both times had a decrease in the percentage of mentions of the *Develop and Improve Machines, Equipment* category (44% vs 35%). Given that this category was the most frequently mentioned at the start of the course, the decrease could be evidence of increased understanding and more nuanced perceptions gained over the duration of the course. This is not dissimilar to other majors, including Chemical Engineering, that saw decreases in popular categories.

The second category of note due to a difference in perceptions is the *Solve Problems* category which was more likely to be mentioned at the end of the course by students who ranked ME as their top-choice major at both timepoints compared to students who were listing it as their top-choice majors for the first time (22% vs 14%). This was also accompanied by an increase in the percentage of students who maintained an intention to major in ME who mentioned the *Solve Problems* category at the end of the course relative to the beginning. As an example, at the beginning of the course a student wrote that mechanical engineers "[d]esign new things" and at the end of the course the same student wrote that "[mechanical engineers] solve problems by doing tests and recording the information, and then reacting to the said [sic] results."

Kajfez *et al.* [14] have reported that students perceive that ME offers students the most *Options* for their students in terms of career opportunities and areas of expertise. This perception is also found among students in the current study, categorized as *Broad Field with Options*, at nearly the same rates. This perception of a broad field is not unique to ME and was found in many other disciplines, though normally at lower levels, but Chemical Engineering did have a similar percentage of students mentioning as ME. In the Kajfez *et al.* study, Chemical Engineering had the second highest rate of their *Options* category being mentioned. One student with a consistent intention to major in ME wrote at the end of the course that "[mechanical engineers] work in almost all engineering subfields and are somewhat a jack of all trades. They create and design mechanisms using math, mechanics and cad design." The "jack of all trades" comment was also present in the student's beginning-of-course response.

Another frequent perception about what mechanical engineers do at work was *Vehicles*. Of note, there is no Automotive Engineering degree at the undergraduate level at the institution being studied. At the end of the course, one student who had changed from an intended major of Computer Engineering to ME wrote that "I was most interested in the woman who spoke from Boeing. I believe she was taking about mechanical engineers working on the planes, and that is what I'm interested in." This student was able to connect the invited speaker's talk with interests in working with airplanes that led to listing ME as the top-choice major at the end of the course. This is in agreement with SCCT because the theory assumes that students will make academic choices based on their goals which are informed by interests. Another student wrote at the end of the course that “I want to work on cars, so in that field engineers use their skills to fix and improve transportation.” In the EVT framework, this student has placed a high interest value and a high utility value on becoming a mechanical engineer because will allow the student to work on cars, which are of interest.

Another rather unique category mentioned as a perception is that ME allows for *Hands-On Work*. While some students did mention similar perceptions about other majors, it was not mentioned broadly enough to create its own category. One student seemed to imply that this option to work hands-on was always an option in other engineering disciplines by writing that “[a]s shown by our ME guest speaker, even though I'll be an engineer, I'll be engaged in hands-on work.” Another student even perceived that *Hands-On Work* is a requirement for ME by writing that “I believe that engineers that have degrees in Mechanical Engineering are required to work with hand held components (like engines) to make that engine work more efficiently…” Because this is a perception that is more frequently associated with ME than other majors, it is an opportunity for ME to market themselves as offering a unique experience, so far as the perception is accurate, but is also an opportunity for other engineering majors to be able to describe to students how work in other fields also has hands-on opportunities.

Movement is another category unique to ME because students perceive that mechanical engineers often work with moving parts or process that involve motion. As an example, one student wrote that “I believe mechanical engineers mainly focus on the moving aspects of machines.” One final category that students perceived about ME was that mechanical engineers work under given *Constraints*. While versions of this category appeared in other majors, primarily related to time and money, this category is generally broader. As an example, a student wrote that mechanical engineers "[d]esign new mechanical systems and components based on a client's given constraints and design requirements." While costs and money are likely to be included in a design requirement, there are likely other, possibly more important, constraints as well. This category also shares some themes with the *Quality, Safety, and Cost Constraints* category about the perceptions of engineering in general.

5.6.12 Conclusions

Overall, perceptions of what engineers do at work in each of the majors studied were broadened at the end of the course compared to the beginning. Similarly, some categories in the individual majors did see smaller percentages of students mention certain categories at the end of the course, but these were sometimes encouraging because more generic perceptions were being replaced with more detailed or comprehensive perceptions of what engineers in that field do at work. For example, in Chemical Engineering, the *Chemicals and Chemistry* categories saw a decrease in perceptions among students who indicated the major at both timepoints while the *Chemical Processes* category saw an increase among the same group of students. Similarly, in Electrical Engineering, the *Electricity* category had a decrease in perceptions among students who indicated the major at both timepoints while the *Electronics* category saw an increase.

Many students were able to connect specific aspects of their intended engineering major with their interests and/or future career goals. Students who made these connections often wrote about how their interests informed the major they selected as their top choice. The process these students described, while brief, is evidence that the SCCT framework can be a useful tool to describe and understand students' major selection process. Similarly, many students indicated how their individual engineering major aligned with their self-concept, their interests, or their future career goals which parallel the Attainment, Interest, and Utility values from EVT, respectively.

Additionally, at the beginning of the course, there were students who were *Not Sure* what engineers in that major did at work. By the end of the course, the percentage of students reporting they were still *Not Sure* dropped in all majors (expect Materials Science and Engineering, where it remained constant at one student). This is strong evidence that the major exploration course is beneficial to students by helping them expand their perceptions of what engineers do at work in many different engineering fields.

5.7 Conclusions

Overall, the results of this study provide evidence that an optional, half-semester, one credit, pass / no pass major exploration course can expand students' perceptions of both engineering in general and the individual engineering majors. Students generally have broader perceptions of both engineering in general and the engineering majors at the end of the course compared to the beginning. The broader perceptions are also coupled with more detailed responses at the end of the course compared to the beginning. For example, the “Quality, Safety, and Cost Considerations” for engineering in general has a modest increased frequency at the end of the course compared to the beginning. Similar examples of more detailed perception categories being more popular at the end of the course also appear in many of the engineering majors including Chemical Engineering and Electrical Engineering.

5.8 Future Work

In addition to the written survey responses analyzed for this study, the surveys also requested information about confidence in major selection, second-choice majors, reasons for changes in major when applicable, and if students were surprised by anything they learned about engineering during the course. Using this additional data, the measure of confidence could be attached to responses to see if there are any differences in engineering in general or within the majors by confidence.

For students who switched majors, further exploring the reasons listed for the change could provide additional insights about what prompted the changes. Connecting the second-choice majors would also be useful to see if students switched from the top-choice major to their second-choice or to another major.

6 Study of Exploration[3]

While some students begin their undergraduate careers with a major already selected, other students are unsure, or would like to continue to explore their options during their first year. In engineering, some institutions offer first-year engineering programs where students do not have to make a formal commitment to a specific engineering major until the end of their first year at the institution. Within these first year programs, some offer specific courses to help students select a major or incorporate similar components into other courses with more traditional, physics-based engineering content [24]. Institutions that do offer dedicated engineering major exploration courses often have different structures for the exploration course [73], [74].

This study focuses on a single institution with a first-year engineering program and an optional major exploration course. The course, described in Section 5.3.2, is designed to expose students to all the engineering majors available at the institution. This study will use propensity score matching to compare students who completed the optional course with students who did not take it to understand the course's impacts on students' confidence in their major selection and future major switching as well as their fit and satisfaction in both engineering in general and their intended engineering major.

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The course structure being studied is similar to other structures [73], [74], but does include some unique components like the alumni presentations, so the findings of this study can support another approach to helping students explore engineering majors. This study will also help highlight the impact of the course because other studies typically use a pre / post technique and are not able to compare to a group of students who did not enroll in the course.

6.1 Theoretical Framework

Person-environment fit is the level of similarity between personal and environmental characteristics important for a beneficial, working relationship in a professional setting. This construct is thought to include four domains – person-job, person-organization, person-group, and person-supervisor – that contribute to a person's overall person-environment fit [75]. Additionally, person-environment fit, and specifically the person-organization domain, is important for an individual's intentions of remaining at or leaving an institution [76].

Person-environment fit has also been described as having both supplementary and complementary components [77]. In this context, with supplementary person-environment fit, a person may join an organization because they believe they will share common attributes with their peers and colleagues. This view is consistent with Holland's RIASEC typology [78]. Alternatively, a person joining an organization due to a complementary person-environment fit is likely bringing a unique skill or contribution to the group of organization. In this view, the organization is the focus because it is being made better by the additional person, whereas in the supplementary view the focus is on the individual.

Fit is central to Schneider's Attraction-Selection-Attrition Framework (ASA) [31] and Tinto's Student Integration Model [32]. ASA assumes that students who do not find fit will leave or switch majors; in this context the environment being considered is an academic major. The Student Integration Model assumes that students are more likely to persist if they are both academic and socially integrated into the programs. This is very similar to the person-organization and person-group fit domains of person-environment fit. In this study, these two frameworks will guide the work in investigating the frequency of students switching from their initial intended majors and their levels of fit and satisfaction with their intended majors.

6.2 Research Questions

The research questions in this chapter focus on the impact of a major exploration course intended to introduce students to both the engineering profession and the engineering majors available to them on students' confidence in their major choice, their major switching, as well as fit and satisfaction in both engineering in general and in engineering majors. Ideally, the course can help students integrate into the academic and social systems of the institution, engineering, and their intended major.

RQ5. What impact does a major exploration course have on confidence in major selection and major switching?

RQ6. What impact does a major exploration course have on fit and satisfaction in both engineering in general and in engineering majors?

6.3 Data and Methodology

6.3.1 Data Source

The majority of the data for this study is from a survey that is collected as part of the "Empowering Students to be Adaptive Decision-Makers" project [79]–[81]. The survey is included as Appendix B – Fit, Satisfaction, and Confidence Survey (Relevant Questions). This project has collected data on student decision-making activities and includes items that ask students about their fit and satisfaction [82] in engineering in general as well as in their intended engineering major. Because this project's intended population includes the same population that was studied in Chapter 5, there are many students who are in both datasets. Whether a student completed the major exploration course described in Chapter 5 will be used as a variable in this study.

For each of the survey scales – fit and satisfaction in engineering in general and intended engineering major – the average score of the items is used as the variable of interest. One item, the third item in fit in engineering in general ("My current courses are not really what I would like to be doing."), was reverse coded before averaging it with the remaining items on that scale.

The survey with questions about fit, satisfaction, and confidence was distributed at the beginning and end of the fall and spring semesters beginning in Fall 2017. Data in this study includes the Fall 2017 and Fall 2018 cohorts. Other data, including students' gender, race, SAT Math score (or converted ACT Math score [83]), age, and transfer status were collected directly from institutional records and linked with survey responses for those who consented.

6.3.2 Inclusion Criteria

To be included in the sample, students had to be enrolled in the first-year engineering program in either Fall 2017 or Fall 2018 and complete both the beginning and end of semester surveys in that semester. Depending on students' degree requirements, some students will still be enrolled in courses that are part of the first-year engineering program in their second year and may complete the survey a second time; other students may also need to repeat the first-year courses due to low performance. Any student who appears in the Fall 2018 data that previously appeared in the Fall 2017 data was removed. The final sample of students available for propensity score matching is 864; of those students, 289 completed the major exploration course and the remaining 575 did not.

For analysis of changes in major in Section 6.5.2, students are included for each major change assuming they are still enrolled and have a declared major at both the beginning and end of the timeframe of reference. If a student is not enrolled or does not have a major, the student is excluded from that timeframe only. For example, if a student enrolls in August and is enrolled for three semesters before dropping out, the student is included in the first two analyses (first semester and second semester) but is excluded from the final analysis of changes during the second year because the student does not have a major at the end of the timeframe. The sample size for each of these analyses is included with each table of results.

6.4 Analysis

6.4.1 Planning for Propensity Score Matching

Propensity score matching was first introduced by Rosenbaum and Rubin [84] as a technique to account for the differences between groups of people who did and did not receive a treatment when provided the appropriate variables, or covariates, that are predictive of receiving the treatment. In other words, using the covariates, it is possible to predict the likelihood that each participant would have received a treatment and then match participants based on that likelihood. This is important when variables that could be related to the outcome are also related to whether the participant receives the treatment when random assignment to the treatment is not possible or would be unethical. For example, if studying the impacts of extreme social media consumption, it would be unethical to prescribe participants to extreme amounts of consumption. However, using propensity score matching, two groups of participants can be created, control and treatment groups, while controlling for factors that may predict both the outcome under study and whether or not the person is an extreme consumer of social media, like age and gender.

In this study, students had the opportunity to enroll in a major exploration course as part of a first-year program. Enrollment in the course was optional, though members of certain learning communities with lower math preparation were required to enroll.

Because students could not be assigned to the treatment or control groups randomly, propensity score matching can be used to study the effects of the course and mitigate effects based on who registered and completed the course and who did not.

The first step to complete propensity score matching was to collect the covariates that are predictive of enrollment in the treatment group. For this study the covariates were identified as students':

1. Score on the math section of the ACT or SAT,
2. Gender, as reported in institutional records,
3. Race, as reported in institutional records,
4. Age,
5. Transfer status,
6. Confidence in their major choice at the beginning of the term, and
7. Term of enrollment.

While the seventh covariate could be predictive of enrollment, it was added to the list of covariates later than the others because of a data availability issue. Data for students' fit and satisfaction in engineering in general and their intended engineering major is not available for the first cohort of students, but all other data is available. Therefore, for some of the analysis, the first cohort had to be removed, which warranted the inclusion of the students' term of enrollment in the major exploration course. Additionally, to be included in the sample, all seven covariates had to be available for a student.

6.4.2 Matching

To complete the propensity score matching, the MatchIt package [85]–[87] was used in the R programming environment [54]. The goal of the matching process is to create a matched sample between students who did and did not complete the major exploration course such that enrollment in the course could not be predicted based on the provided covariates. The matching process can involve weighting which makes sure that the covariates used in the planning phase are balanced across the treatment and control groups. The propensity score is calculated using logistic regression because the treatment variable is a binary outcome.

Because the matching phase is accomplished and assessed before any results are produced, it is possible to try multiple different matching methods and assess each one to make sure the best method is selected [86]. The matching method ultimately used in this this study is optimal full matching (method = "full" in MatchIt), which uses all the participants in the study and weights the sample as necessary to achieve the matching. In order to complete the process, the MatchIt package [85] relies on the optmatch package [88].

Before deciding on optimal full matching, nearest neighbor matching and optimal pair matching were both tried but did not achieve the same level of matching as the selected method. The assessment of the optimal full matching will be presented in the next subsection.

While optimal full matching is the primary method used in this study, the seventh covariate, the term of enrollment in the major exploration course, was matched using exact matching. As the name implies, participants from the treatment and control groups are matched exactly on this variable. Because the term of enrollment was a binary variable depending on which of the two cohorts the student was enrolled in the first-year engineering program, this did not pose a significant challenge for the matching process. Having an exact match on the term of enrollment allows the first cohort, with incomplete outcome data for the fit and satisfaction items, to be removed from the matched sample as necessary for that analysis.

6.4.3 Assessing Quality of Matching

To assess the quality of matching, two plots were generated. The first is a Love plot of the standardized mean differences of the covariates shown in Figure 6.1.

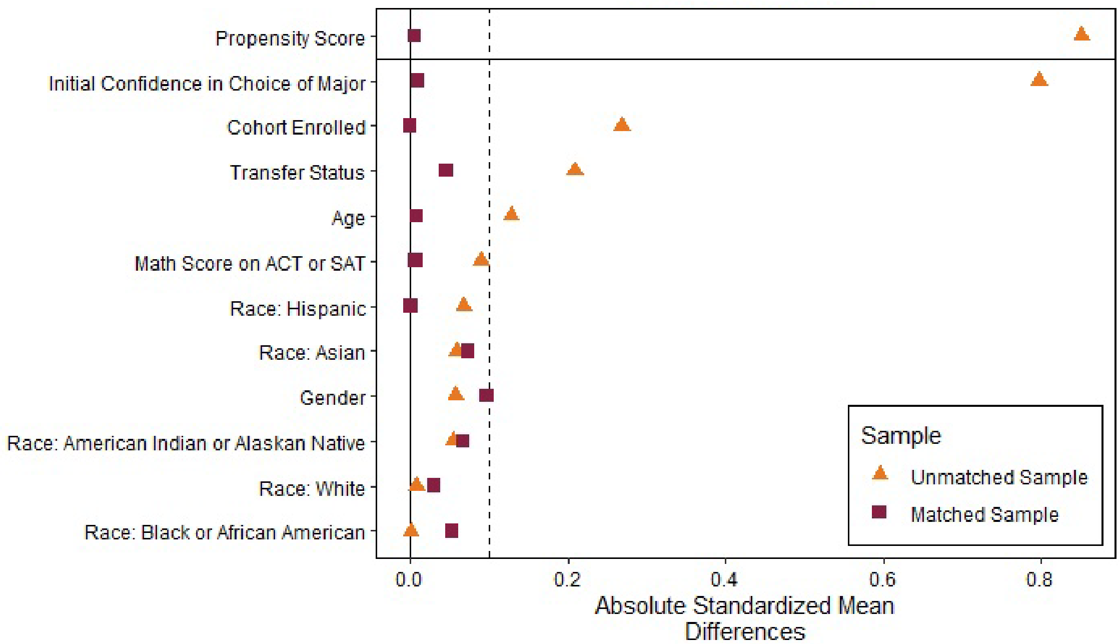

Figure 6.1 – Love Plot of Covariates used in Propensity Score Matching

The plot shows the difference between the treatment and control groups both before and after matching. For example, before matching there was a large difference in initial confidence in major choice for students who did and did not enroll in the major exploration course. After matching though, this difference is very small. In propensity score matching, it is possible that not all participants are included in the matched sample; however, in this study all participants were matched due to the use of full optimal matching.

Standardized mean differences closest to zero are ideal. The dashed vertical line is an absolute standardized mean difference of 0.1, the recommended threshold for differences in the matched sample [89]. The rows of the Love plot are sorted by decreasing absolute standardized mean differences (ASMDs) before matching. The first variable is the calculated propensity score. The Cohort Enrolled, Transfer Status, and Gender variables are all binary variables. There are five levels for the race variable. The remaining variables – Initial Confidence in Choice of Major, Age, and Math Score on ACT or SAT– are all continuous. While there are a few covariates that have worse balance after matching, all those covariates had good balance before matching and still have acceptable balance after matching and are therefore of little concern.

The second plot generated is a density plot of the propensity scores before and after matching shown in Figure 6.2. The plot was created using the cobalt package [90].

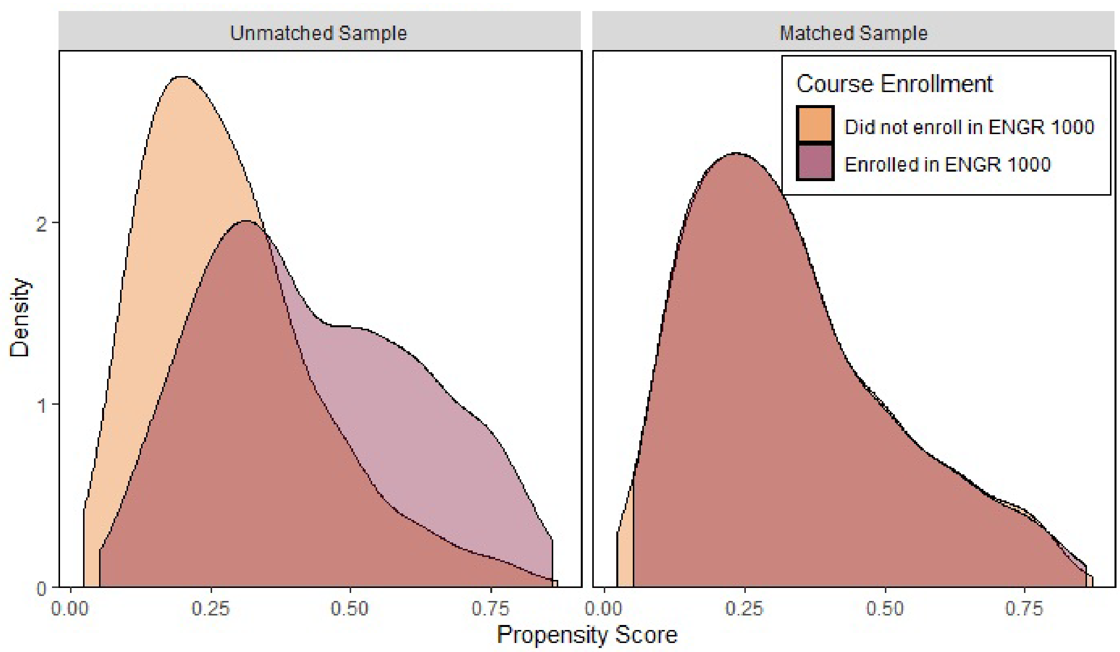

Figure 6.2 – Density Plot of Propensity Scores

Figure 6.2 (left side) shows that in the unmatched sample, there are many students who do have similar propensity scores, shown by the overlap of the two areas, but overall there is a discrepancy in whether or not students chose to complete the major exploration course. However, on the right side of the figure, after matching there is almost complete overlap of the two areas indicating almost perfect matching between those who did and did not complete the major exploration course using the provided covariates, with weighting. With the matched samples, there are now control and treatment groups.

Together, both the Love plot and density plot indicate successful matching using full optimal matching. The matched sample generated will be used in the analysis.

6.4.4 Estimating Treatment Effect

Using full optimal matching, the average treatment effect in the population can be calculated. This is different from the average treatment effect in the treated which only includes participants in the treatment group. Calculating the average treatment effect in the population is only possible when no participants are removed from the sample due to not matching. Because full optimal matching was used, no participants were removed.

After matching using full optimal matching, the matched data allows for the calculation of marginal effects, which are the same effects as calculated by completely randomized experiments. Most of the effects calculated will be for continuous outcome variables; these will be estimated using simple linear regression. Effects for binary outcome variables, like whether a student changed majors, will be estimated using simple logistic regression.

6.4.5 Simple Linear Regression

Simple linear regression is used to model the relationship between a continuous outcome variable, Y, and a single explanatory variable, X, that can be either continuous or categorical. The simple linear model is given by:

$$Y = \beta_0 + \beta_1 X \tag{6.1}$$

The β_1 coefficient is generally the most important because it indicates the relationship between the explanatory and outcome variables. Using a null hypothesis that the β_1 coefficient is equal to zero and an alternative hypothesis that it is not equal to zero, a test of significance is conducted, and a p-value is calculated. Interpreting the p-values allows for a determination of the level of significance where values closer to zero provide greater evidence of statistical significance and values greater than 0.10 generally provide only weak evidence of significance.

In this chapter, the only explanatory variable investigated is a binary, categorical variable for whether students enrolled in the major exploration course. Therefore, the value of X in the model equation will only be one or zero. For students who did enroll in the major exploration course, the value of one is used; for students who did not enroll, the value of zero is used. While other possible explanatory variables may also influence the outcome variable, other relevant data was not collected during this study and thus only the one explanatory variable will used. In future work, data for other possible explanatory variables should be collected and analyzed including professional memberships, research experiences, and prior industrial experience like co-ops or internships.

6.4.6 Simple Binary Logistic Regression

Simple binary logistic regression is used to model the relationship between the proportion of "successful" outcomes, π, and a single explanatory variable, X, that can be either continuous or categorical. The simple binary logistic model is given by:

$$\pi = \frac{e^{\beta_0 + \beta_1 X}}{1 + e^{\beta_0 + \beta_1 X}} \tag{6.2}$$

Similar to simple linear regression, the β_1 coefficient is generally the most important. In this study, simple binary logistic regression will only be used to analyze the prevalence of major switching at different time points among first-year engineering students who did and did not enroll in the major exploration course. For the purpose of analysis, a "successful" outcome will be switching majors. Treating switching majors as a "successful" outcome is only for the purposes of assigning variables in the simple binary logistic regression model. The coefficients will be subject to a test of significance like that described for simple linear regression. While switching majors (or intended majors) is hopefully in students' best interests, it is possible that it is ultimately a poor choice, but that is beyond the scope of this study.

Additionally, the odds ratio can be reported to compare the two possible outcomes for the binary explanatory variable. The odds of a given outcome for a single value of the explanatory variable are the ratio of the probability of success to the probability of failure given by:

$$\text{odds} = \frac{\pi}{1 - \pi} \tag{6.3}$$

The odds ratio is then calculated as the ratio of the two odds.

6.5 RQ5 – Confidence in Major Choice and Major Switching

6.5.1 Confidence in Major Choice

The literature reports that confidence in major choice is a significant predictor of students enrolling in their intended major one year later [28]. Therefore, for students who are unsure about their major choice, learning about the options available in a major exploration course would be beneficial. At the beginning and end of the first required engineering course, students were asked to report their confidence in their choice of their intended engineering major. Because this item was asked in a required course, students who completed the optional major exploration course were enrolled in both courses.

Using the matched, weighted sample from the propensity score matching, I compared students' confidence in their major choice at the end of their first semester between students who did and did not complete the major exploration course. At the end of the semester there was no statistical difference between the two groups of students with respect to their confidence in their major choice at the end of the semester (Table 6.1).

Table 6.1 – Linear Regression Results for Confidence in Choice of Engineering Major

Variable	**β**	**p-value**
Intercept	8.041	< 0.001
Course Enrollment	0.041	0.748

Students who complete the major exploration course might not have a statistically significantly higher confidence in their major choice, but the average confidence in major choice is high for all students at the end of the semester The intercept value from Table 6.1 tells us that students who did not complete the major exploration course had an average confidence in their major choice at the end of the semester of 8.041 on a scale of 1 to 10. The β-value for course enrollment variable is the expected difference in confidence at the end of the semester for students enrolled in the course compared to those who did not enroll; the value of 0.041 is both small and not significant as shown by the p-value that is greater than 0.05.

This is only about confidence at the end of the course, not a change in confidence. One possible explanation for this result is that students with lower-than-average confidence at the beginning of the semester have an increase in confidence as they explore the options available to them. At the same time though, students with average than higher confidence could also learn about other major options of interest and then have a lower confidence in their choice at the end of the semester because of the new options.

While the literature reports about the importance of confidence in major choice, it also reports that nearly half of students who report an initial confidence in their major choice of 10 on a 10-point scale do not enroll in their original intended major [28]. This may make investigating changes in confidence in major choice worthwhile in future work.

While the major exploration course does not result in enrolled students ending the course with a higher confidence in their major selection, those students may have more major changes in their intended engineering majors because of taking the course. In this context, changes in intended major are the product of a student's confidence in their major choice. The following subsection will explore whether students who enroll in the major exploration course are more likely to change their major in both the short and long terms.

6.5.2 Major Changes

Even though students who complete the major exploration course do not report being significantly more confident in their choice of major than their peers who do not enroll in the course, there are significant differences on whether those students had a change in their intended engineering major in the first semester ($p = 0.021$). Comparing students' intended majors at the beginning and end of the semester in which they were enrolled in the required first-year engineering program course and were optionally enrolled in the major exploration course, students in the major exploration course changed their intended majors more frequently that their peers who did not enroll (Table 6.2). The odds ratio for the course enrollment variable, β_1, is 1.619 which indicates that the odds of a student who is enrolled in the major exploration course changing their intended engineering major during the first semester are 1.619 times those of a peer who did not enroll in the course.

Table 6.2 – Logistic Regression Results for Changing Intended Engineering Major in the First Semester

Variable	β	Odds Ratio	p-value
Intercept	– 1.364		< 0.001
Course Enrollment	0.482	1.619	0.021

N = 841 students

Given that the propensity score matching used students' initial confidence in their major choice as a covariate, the higher frequency of changes among students enrolled in the exploration course is not because those students were more unsure about their major. However, given the structure of the course where students were exposed to many of the engineering majors they could pursue, it is reasonable that students found other majors of interest beyond their initial intention leading to more changes of intended engineering major during the first semester.

Using Equation 6.2, and the coefficients in Table 6.2, the probability that students will change their majors whether they complete the major exploration course can be determined. In the equation, the intercept variable is β_0 and the course enrollment variable is β_1. For students who do not complete the major exploration course, the variable X in the equation is 0, eliminating the β_1 coefficient. For students who do complete the course, the variable X in the equation is 1 such that the β_0 and β_1 are summed. Plugging the values into the equation, the probability that a student who does not complete the major exploration course is 20% and the probability for a student who does complete the course is 29%.

As a follow-up to changes in intended engineering major during the first semester, I also investigated changes between intended engineering major at the end of the first semester and actual majors at the beginning of students' second year of study a semester later. At this timepoint, there is no significant difference in the frequency of students initially enrolling in their intended major among students who did and did not complete the major exploration course (Table 6.3).

Table 6.3 – Logistic Regression Results for Changing Engineering Major in the Second Semester

Variable	**β**	**Odds Ratio**	**p-value**
Intercept	– 0.899		< 0.001
Course Enrollment	0.314	1.368	0.116

N = 825 students

While the difference is not significant, students who enrolled in the major exploration course still had more major changes than their peers who did not. Using the odds ratio for course enrollment, students who completed the course had 1.368 times greater odds to switch majors than students who did not take the course.

Because students have their first opportunity to enroll in a degree-granting major at the beginning of their second year, the final comparison is between that major and one year later to the major at the start of students' third year. The frequency of major changes at this time point is significantly higher for students enrolled in the major exploration course at the $\alpha = 0.10$ level (Table 6.4). While the expectation might be that students who enroll in a major exploration course will have fewer major changes, the goal of the course is not to prevent future switching but to showcase the engineering majors available to students. For students who do complete the course but still switch their major later could have had another change in intended engineering major before the end of the first year or after enrolling in their top choice intended engineering major and realized that their second choice is a better fit for them.

Table 6.4 – Logistic Regression Results for Changing Engineering Major in the Second Year

Variable	β	Odds Ratio	p-value
Intercept	– 1.459		< 0.001
Course Enrollment	0.406	1.501	0.069

N = 808 students

Another potential explanation for this finding could be that students who complete the major exploration course are more likely to still be enrolled as a General Engineering major at the beginning of their second year. Students who still have this designation and then enroll in a degree-granting major during their second year are recorded as switching majors. However, as shown in Table 6.5, there is not a significant relationship between being enrolled in the major exploration course and still being enrolled as a General Engineering major at the beginning of the second year.

Table 6.5 – Logistic Regression Results for General Engineering as Major in August of the Second Year

Variable	β	Odds Ratio	p-value
Intercept	– 1.927		< 0.001
Course Enrollment	0.287	1.333	0.286

N = 847 students

In summary, students who enroll in the major exploration course change their major more frequently during the term in which they are enrolled in the course and at similar rates in the semester following the course. Using a larger value for significance, students who enrolled in the course change their actual majors more frequently from the beginning of their second year to the beginning of their third year.

6.6 RQ6 – Fit and Satisfaction in Engineering in General and in Engineering Majors

6.6.1 *Internal Consistency of Scales*

Students were also asked to respond to items about their fit and satisfaction in both engineering in general and their intended engineering major. Because these items were lightly edited from Schmitt [82] to ask students about their fit and satisfaction in "engineering in general" and in their intended engineering major, Cronbach's alpha was calculated for each of the four scales as a measure of internal consistency. The alpha values for each scale from this study are presented in Table 6.6 with the alpha values from the original publication of the scales. All the alpha values are in the acceptable to good range and generally agree with the values from the source paper.

Table 6.6 – Cronbach's Alpha Values for Fit and Satisfaction Scales

Scale		**Alpha from Source** [82]	**Alpha from This Study**
Fit	**Engineering**	0.75	0.75
	Major		0.72
Satisfaction	**Engineering**	0.81	0.88
	Major		0.89

6.6.2 *Fit and Satisfaction in Engineering in General*

Even though the major exploration course is focused on the engineering majors, data about students' fit and satisfaction in engineering in general was also collected. Comparing students who did complete the major exploration course with those who did not using the propensity score matched sample, there is no statistically significant difference in students' fit (Table 6.7) nor satisfaction (Table 6.8) in engineering in general at the end of students' first semester.

Table 6.7 – Linear Regression Results for Fit in Engineering in General

Variable	**β**	**p-value**
Intercept	3.949	< 0.001
Course Enrollment	− 0.059	0.490

Table 6.8 – Linear Regression Results for Satisfaction in Engineering in General

Variable	**β**	**p-value**
Intercept	4.274	< 0.001
Course Enrollment	0.039	0.640

Because the focus of the engineering major exploration course is on the individual engineering majors, this result is not too surprising. Additionally, because the students in this study are already enrolled in a first-year engineering program and actively trying to decide which specific engineering major to enroll in, the lack of a significant difference is less surprising. It is possible that some students in the course and the program overall are not studying engineering on their own volition but due to external pressure from family among other reasons, but these students are likely fewer than the alternative. While the impact of these students is a limitation on the results, those who both did and did not enroll in the major exploration course could discover during their first semester that engineering is actually a good major for them and have increased fit and/or satisfaction in engineering.

6.6.3 Fit and Satisfaction in Engineering Majors

The survey also asked students about their fit and satisfaction in their intended engineering major. While there are not significant differences between students who did and did not complete the major exploration course, the coefficients reported are larger than their counterparts for engineering in general. This is encouraging because the major exploration course aims to provide students with information about their options in engineering to make a more informed major choice. The regression results are shown in Table 6.9 and Table 6.10.

Table 6.9 – Linear Regression Results for Fit in Intended Engineering Major

Variable	**β**	**p-value**
Intercept	4.249	< 0.001
Course Enrollment	0.026	0.786

Table 6.10 – Linear Regression Results for Satisfaction in Intended Engineering Major

Variable	**β**	**p-value**
Intercept	4.443	< 0.001
Course Enrollment	0.079	0.356

These results speak to the fact that a major exploration course can have impacts on students' fit and satisfaction in their intended engineering major. However, it must be noted that it is an intended engineering major. Unlike the previous results for fit and satisfaction in engineering in general, students who enrolled in the major exploration report both a greater fit and greater satisfaction in their intended engineering major at the end of their first semester compared to non-enrollers. Even though the differences are not significant, these results indicate that providing students with information about their intended engineering major from both alumni and program faculty as a part of the course can positively impact students' fit and satisfaction in their intended engineering majors.

6.7 Conclusions

While there are few significant differences presented among confidence in major choice, major switching, and fit and satisfaction in engineering in general and in intended engineering major, the majority of the differences are what would generally be expected from the result of a major exploration course. Students who complete the course have slightly higher confidence, more major changes early in their academic careers, and increased fit and satisfaction in their intended engineering majors.

Students who complete the major exploration course do not have a significantly higher confidence in their major choice than students who do not, but at the end of the semester the average confidence of all students' choice of major is high. There is also a need to investigate changes in confidence, which was not possible here due to the propensity score matching. The significant differences in students' switching majors more often during the first semester and in their second year can possibly be attributed to information learned in the course about the different engineering majors available at the institution.

There are no significant differences between students who enrolled in the major exploration course and those who did not with respect to fit and satisfaction in engineering in general and in the majors. For engineering in general, this is not too surprising because all the students in the course are already enrolled in engineering and have already made a commitment to engineering. For the engineering majors, it must be noted that students were not actually enrolled in a degree-granting major but only speculating about their fit and satisfaction in their intended major. Some of the changes could also be the result of information learned outside of the major exploration course given that it is a part of a larger first-year engineering program. However, it is not possible to isolate the students enrolled in the course from having other impactful experiences during their major selection process.

These quantitative measures show that the major exploration course can have positive impacts on students' confidence, major changes, and fit and satisfaction even if the effects of the course are not often significant. Combined with the qualitative results from Chapter 5, there is a need for additional investigation, likely with additional metrics, to understand the impacts the course has on students during their major exploration.

6.8 Future Work

Results from the regression analyses using the propensity score matched sample could be expanded in future work by using covariate adjustments. Including the covariates in the model would allow for any effects as the result of a covariate to be reported. Additionally, if any interactions were suspected, they could also be included in the model. This study also assumed a linear relationship of course enrollment and the Math ACT or SAT score; future work should consider relationships other than only linear.

Follow-up studies should include additional items to specifically investigate changes to engineering identity, motivations for studying engineering, self-efficacy for engineering and engineering coursework, and outcome expectations. Items specifically addressing the impact of the course could also be included in the end of course survey. Future work could also include following-up with students a few years after completing the major exploration course but before graduation to reassess fit and satisfaction in their actual engineering major. Because the data used in this study was about students' intended majors, adding this level would provide additional ways to investigate the impact of the major exploration course. Students could also be asked about their perceptions of their actual major and compare that to responses obtained during their first year while enrolled in the major exploration course.

7 Conclusions

7.1 Addressing the Research Questions

Overall, the goal of this work was to better understand the process surrounding first-year engineering students' major selection through three complementary studies. The Study of Enrollment investigated when students enroll in the major that will become their graduation major as well as the rate of persistence in the first major among graduates. These results showed differences in enrollment patterns that could be due to differences in understanding of what the majors are and served as one piece of evidence that there may be differences in perceptions of the engineering majors that were investigated in the Study of Perception. This study looked at perceptions of both engineering in general and of the individual engineering majors and found that students generally have broader perceptions of engineering at the end of a major exploration course than the beginning. Finally, the Study of Exploration looked at the impact of the same major exploration course to understand other impacts of instruction on the major selection process. The variables investigated included confidence in major choice, major switching, and fit and satisfaction in both engineering in general and in the engineering majors. The study shows students enrolled in the course have more frequent major changes earlier in their careers than students who did not enroll in the course.

RQ1. When did engineering graduates enroll in the major they graduated in?

How does this vary by discipline-specific major and/or matriculation model?

RQ2. What proportion of engineering graduates persisted in their first engineering major? How does this vary by discipline-specific major and/or matriculation model?

The research questions for the Study of Enrollment, RQ1 and RQ2, addressed when and where first-year engineering students enroll in their graduation majors. Overall, students enrolled in the major that would become their graduation major at their first opportunity to do so, which varies based on the matriculation model used by the institution. More students switch their initial major at institutions with direct matriculation compared to institutions with first-year engineering programs. Comparing across the matriculation models, students enrolled in first-year engineering programs only enroll in their graduation major an average of 1.32 semesters later than students at direct matriculation institutions even though the difference between first opportunities is two semesters. Additionally, students do not enroll in engineering majors at meaningful different frequencies based on matriculation model which is expected because first-year programs do not attempt to encourage students to enroll in specific majors, but to provide additional information and/or time to make a more informed decision. However, it is somewhat surprising that generally lesser-known disciplines do not have meaningfully more students enrolled after the first year when students are learning about the majors available to them and making a decision on which to select.

RQ3. How do first-year engineering students perceive the field of engineering prior to and after completing a major exploration course?

RQ4. How do first-year engineering students perceive the engineering majors they are most interested in pursuing prior to and after completing a major exploration course?

The research questions for the Study of Perception, RQ3 and RQ4, addressed how first-year engineering students' perceptions of engineering in general as well as their individual majors of interest changed after completing a major exploration course. Overall, students' perceptions were broadened such that students mentioned more categories of perceptions at the end of the course relative to the beginning about engineering in general and their major of most interest. Additionally, some students' perceptions provided an additional level of detail at the end of the course, changing from a vague perception or being unsure to being able to provide more detailed comments about their perceptions both of engineering and their top-choice major. The different perceptions of the individual engineering majors also serves as additional evidence of the different cultures of the majors [16], [17]. These perceptions are described in Section 7.2.

RQ5. What impact does a major exploration course have on confidence in major selection and major switching?

RQ6. What impact does a major exploration course have on fit and satisfaction in both engineering in general and in engineering majors?

The research questions for the Study of Exploration, RQ5 and RQ6, addressed the impacts of an optional major exploration course on students' confidence in major choice, major changes, and fit and satisfaction in engineering in general and in the engineering majors. Propensity scores were used to create a matched sample for comparing students who did and did not take the major exploration course. Results show that students are not significantly more confident, nor do they have a higher degree of fit or satisfaction in either engineering in general or their intended engineering major if they enrolled in the course, but the impact of the course was still positive even if not significantly so. Students who enrolled in the course changed their intended engineering major more frequently in the first semester than their peers who were not enrolled. There is also moderately strong evidence of significance that students who completed the course also had more major changes during their second year, after their first opportunity to enroll in a degree-granting major.

The results from all three studies are summarized in Figure 7.1. From left to right, the figure includes the data source, the study in which the results were obtained, a consolidated answer to the research questions addressed in the study, and some of the implications of those results, which will be discussed later in this chapter.

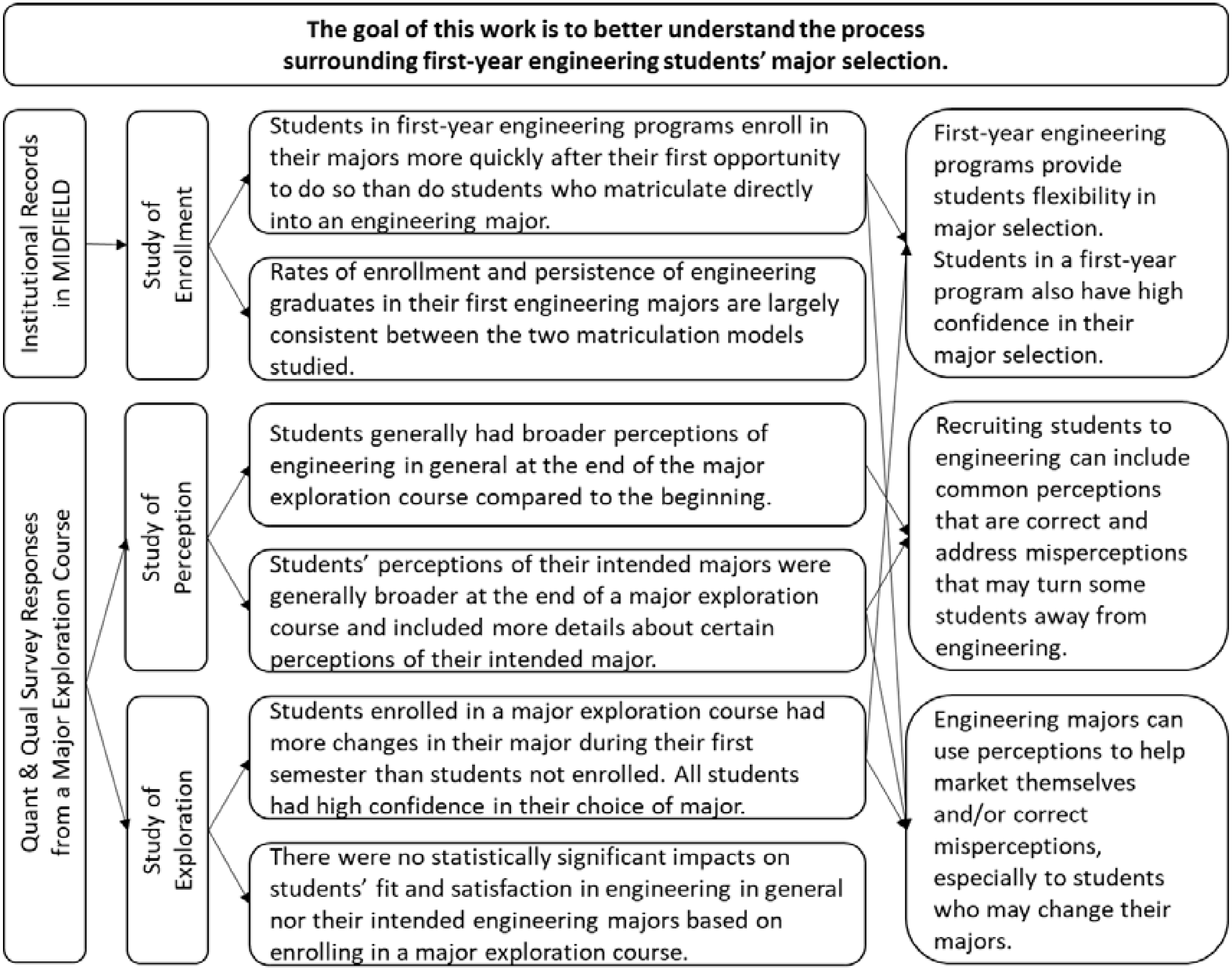

Figure 7.1 – Summary of Results and Select Implications

7.2 Perceptions of the Engineering Majors

This section is a brief, high-level summary of students' perceptions of the individual engineering majors available at the institution studied. The perceptions were collected from students who were intending to enroll in the major when the data was collected.

Students intending to major in Bioengineering largely perceived the major as having a medical focus with perceptions centered around *Prosthetics*, *Medical Devices and Equipment*, *Medical Technology*, and *Medicine and Health*. Some students also mentioned that bioengineers *Create Materials* used in medicine like the prosthetics already mentioned.

Students intending to major in Biosystems Engineering largely perceived the major as having an environmental and sustainability focus with perceptions centered around *Protect Environment*, *Sustainability*, *Conservation*, and *Ecological Impact*. Some students also mentioned that biosystems engineers design and create *Alternative, Sustainable, and Clean Energy*. A few students did have misperceptions that the major shared medial aspects with Bioengineering.

Students intending to major in Environmental Engineering largely perceived the major as having an environmental and preservation focus with perceptions centered around *Protect Environment*, *Pollution*, *Waste Management*, and *Sustainability*, which are similar to Biosystems Engineering. Some students also mentioned that environmental engineers create renewable energy sources, again similar to Biosystems Engineering.

Students intending to major in Chemical Engineering largely perceived the major as having a focus on chemical creation and production with perceptions centered around *Chemicals, Chemistry*, *Chemical Processes*, and *Create Materials, Products*. Some students also mentioned that chemical engineers work in or with *Medicine and Healthcare* as well as in the *Oil and Energy* and *Food and Agriculture* fields.

Students intending to major in Civil Engineering largely perceived the major as having a building and construction focus with perceptions centered around *Roads and Bridges*, *Structures and Buildings*, *Infrastructure*, and *Construction*. Some students also mentioned that civil engineers are responsible for *Planning, Blueprints* and *Safety*.

Students intending to major in Computer Engineering largely perceived the major as having both hardware and software foci with perceptions centered around *Computer Hardware*, *Computer Software*, *Computers*, and *Coding and Programming*. Some students also mentioned that computer engineers are responsible for *Computer & Electronic Components* as well as *Computer Systems and Networks*.

Students intending to major in Electrical Engineering largely perceived the major as having a focus on things about electricity with perceptions centered around *Electrical Systems*, *Electronics*, and *Electricity*. Some students also mentioned that electrical engineers work with *Power, Power Grids* and *Circuits*.

Students intending to major in Industrial Engineering largely perceived the major as having an efficiency focus with perceptions centered around *Efficiency* and *Develop and*

Improve Processes. Some students also mentioned that industrial engineers work with *Processes that Involve People* and *Consider Cash Flow* while designing products and processes.

Students intending to major in Materials Science and Engineering largely perceived the major as having a focus on different phases of material selection with perceptions centered around *Creating*, *Improving*, *Analyzing*, and *Testing Materials*. Some students also mentioned that materials scientists consider the *Efficiency* of products and processes as well as make and *Improve Products*.

Students intending to major in Mechanical Engineering largely perceived the major as having foci on machines and products with perceptions centered around *Develop and Improve Machines, Equipment* and *Develop and Improve Parts and Products*. Some students also mentioned that mechanical engineers are concerned with *Efficiency* and others work with *Vehicles*, both for land and air. Mechanical Engineering was also perceived as a *Broad Field with Options* for its graduates.

7.3 Implications for Research

The theories used in this study provide additional conceptualizations of Social Cognitive Career Theory [26], [27], Expectancy-Value Theory [42], [43], the Attraction-Selection-Attrition Framework [31], and the Student Integration Model [32] as described in Figure 3.2. These theories provide possible explanations for students' actions and perceptions during their major exploration process.

Understanding the impact of matriculation models in engineering along with academic and enrollment policies will continue to be important. Future work can build on the results of the Study of Enrollment by considering additional matriculation models and more institutions that share similar matriculation models. Studying the level of similarity among matriculation models would also be valuable. Because students' enrollment decisions can be impacted by many factors, understanding students' thoughts during changes to their major as well as reactions to academic policy would also be important areas for future work.

The literature contains a few examples of the perceptions of first year engineering students about engineering in general and about the individual majors [14], [70]. This prior work is valuable but does not contain any longitudinal components. The Study of Perception presented in this work expands the literature by exploring how perceptions evolve over the first semester during a major exploration course. The level of detailed perceptions is also expanded for a larger number of majors than in previous studies. Future work can build on this work by exploring changes in perceptions for greater durations or differences in perceptions between first-year engineering students and upper-level engineering students.

As I was unable to find any examples in the literature, the Study of Exploration is presumably the first study to investigate the effects of a major exploration course confidence in major, major switching, and fit and satisfaction in engineering in general and the engineering majors using propensity score matching on students in the same cohort. To the extent that relevant variables are captured, propensity score matching allows for students to be compared on their likelihood (propensity) of taking the course, thus eliminating, or at least greatly reducing, selection effects present in many pre-post test studies. While this study focused on only one type of a major exploration course, future work should attempt to use the same constructs on different course models to determine which practices have the most impact on students and identify any differences surrounding the discussion of changing intended engineering majors within a major exploration course. This future work could help create a course that maximizes students' understanding of engineering in general and the individual majors available to them.

7.4 Implications for Practice

By understanding when students enroll in their engineering majors, as presented in the Study of Enrollment, we can improve in-major retention and graduation rates so that students find their engineering major quickly without having multiple major changes during their undergraduate studies by providing students with additional information about the majors with longer timelines to enrollment. This could include providing more information to potential students about opportunities in specific majors during the recruitment process. These improvements can help mitigate any actual or perceived shortfall of engineers on the labor market and minimize spending tuition dollars on classes that become unnecessary for a student's major after experiencing a major change. For majors that lose a large portion of their original students and majors that attract larger proportions of their students later in their academic careers, these results may serve as starting points to identify why students switch from or to their programs. Engineering administrators can also use these results to compare the average time to enrollment in graduation major as well as graduates' persistence at their institutions to overall average times to enrollment in graduation major in their college or at their university. Depending on that comparison, these results may also serve as evidence of the advantage of making policy changes to implement a different matriculation model at their institution.

If first-year engineering students' perceptions of engineering and the engineering majors are not in agreement with the perceptions of students enrolled in the major or faculty in that major, this disconnect could lead to dissatisfaction and retention issues. By understanding first-year engineering students' perceptions of engineering and the engineering majors as presented in the Study of Perception, first-year engineering instructors and advisors will be better prepared for conversations with students about major selection and can make sure that students' intended majors are in agreement with their chosen discipline and not only with the popular perceptions, though many may be accurate. This study also serves as evidence of another type of engineering major exploration course that has benefits for the students who enroll.

Because the perceptions collected at the beginning of the major exploration course are largely the perceptions that students bring to the institution, they were likely not influenced by higher education as much as by experiences during secondary education and before. These results can help inform how engineering is presented as a possible major and career path by primary and secondary school educators and administrators as well as higher education recruiters prior to students enrolling in higher education. Being able to correct common misperceptions during recruitment can help attract more students to engineering that may otherwise be turned off due to a misperception and may help other students avoid lost time and tuition who would have pursued engineering due to a misperception only to switch out shortly after enrolling.

While there are multiple kinds of major exploration courses, the course studied here is similar to other structures, but includes some unique components like alumni presentations and thus provides another style of course that could be used at other institutions. The results presented in the Study of Exploration as well as the Study of Perception provide evidence of the usefulness of the course in helping students understand their options in engineering majors and the value that students were able to take from the major exploration course. Understanding the impacts of the course also allows for improvements and modifications to the course, as necessary, to improve students' understanding of the engineering majors available to them.

Because students enrolled in a major exploration course were more likely to change their majors than students not enrolled, these results provide evidence for first-year engineering instructors and administration to consider including a major exploration course as part of their curriculum. Faculty and administration from the engineering disciplines may also support the addition of such a course, especially among the programs that are most likely to gain students as well as those that need to dispel common misperceptions about their majors, as shown in the Study of Enrollment and the Study of Perception, respectively.

7.5 Limitations

The Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD) contains data about students' entire academic histories at partner institutions, but the data is historical beginning in the Fall 1987 term. Some institutions keep their records up to date in the database while others lag behind. The age of the dataset presents limitations to the results because some of the most recent trends in student enrollment patterns may be not seen in the data available and the sample population contains more White graduates than the graduating engineering population in the United States. Additionally, while a large volume of data is available, only two matriculation models were able to be studied. The similarities and differences between institutions with the same matriculation model that could explain some of the trends seen in the data were also not studied. The results presented in the Study of Enrollment are limited to only students who graduate in engineering and cannot be generalized to students who ultimately leave engineering.

Data in the Study of Perception was collected from students in a first-year program at a single institution and therefore is not necessarily generalizable to students in all academic classifications nor from other institutional contexts. The data about perceptions of the engineering majors was only collected from students intending to major in the major being described. This does limit the perceptions data because students intended to pursue other engineering majors or majors outside of engineering may hold different perceptions that were not studied.

The Study of Exploration was conducted using data from one first-year engineering program and focuses on a single major exploration course that is part of that program. Because the major exploration course has a unique format, the results are limited to similar contexts. The factors studied are also not all encompassing; other factors may have been impacted by course enrollment but were not included in the study. The data studied was collected over two years, but is still a somewhat small sample size, especially compared to the sample sizes of the Studies of Enrollment and Perception.

7.6 Future Work

Future work surrounding the Study of Enrollment can determine the most common paths students who switch majors both within and outside of engineering take to graduation. This can also include students who leave engineering but graduate in other majors. These paths would likely be beneficial for students who are not satisfied in their major or students who are doing poorly in a major and need to switch. This work could still utilize MIDFIELD data, which is currently being expanded, or institutional records from individual institutions. Future work also needs to consider institutional characteristics not included in the study described, especially barriers to enrollment such as minimum GPA requirements.

The Study of Perception was based on survey data collected in the four years immediately prior to the COVID-19 pandemic using survey questions that were initially written for course assessment and not necessarily for research purposes. Future work should first include developing or piloting new survey or interview questions to compare possible alternatives to the current questions and to better align the questions with the theoretical frameworks. Additionally, it may be beneficial to conduct interviews to generate richer data. Asking the survey questions of all students in first-year engineering programs, instead of only those in a major exploration course, would also allow for a more representative understanding of the perceptions of all students and allow for comparisons between students who do and do not enroll in a major exploration course.

In addition to collecting the perceptions of first-year engineering students during their major selection process, future work should also study the perceptions of other groups including upper-level undergraduate students, faculty members in the engineering majors, and recent graduates working in industry. Because a mismatch of perception of an engineering major and the reality of it could be cause for a student to be unhappy and/or switch their major, understanding perceptions of the major at different time points would be helpful when advising students during the major selection process. In instances where perceptions are different among the groups, additional work could seek to understand what causes those changes by following certain participants throughout their undergraduate careers and documenting their perceptions of their major at regular intervals.

In future work related to the Study of Exploration, additional items to specifically investigate changes to engineering identity, motivations for studying engineering, self-efficacy for engineering and engineering coursework, and outcome expectations should be collected and investigated. Future work could also include following-up with students a few years after completing the major exploration course, but before graduation to reassess fit and satisfaction in their actual engineering major. Because the data used in the work to date was about students' intended majors, adding this level would provide additional ways to investigate the impact of the major exploration course. Students could also be asked about their perceptions of their actual major and compare that to responses obtained during their first year while enrolled in the major exploration course.

Appendices

Appendix A – Major Exploration Course Survey (Relevant Questions)

7. If you know an engineer personally, what is your relationship to that engineer? *

Mark only one oval.

- ( ) immediate family member (your parent, a brother or sister)
- ( ) other family member (grandparent, aunt or uncle)
- ( ) non-family connection (parent of friend, someone you know in your home community)
- ( ) I don't know any engineers
- ( ) Other: ____________

8. What attracts you most to the idea of becoming an engineer? *

Mark only one oval.

- ( ) Good pay & job security
- ( ) Intellectually challenging, non-boring work
- ( ) Earning respect from others
- ( ) Make the world a better place to live
- ( ) Other: ____________

9. What do engineers do for a living? *

Describe in general terms what you believe engineers do at work.

____

____

____

____

____

Major choice

If you had to choose ONE major today in which to earn an undergraduate degree at Clemson, what would it be?

10. Choice of engineering major

Mark only one oval.

- ( ) Bioengineering - Bioelectrical Concentration
- ( ) Bioengineering - Biomaterials Concentration
- ( ) Biosystems Engineering - Bioprocess Emphasis
- ( ) Biosystems Engineering - Ecological Emphasis
- ( ) Chemical Engineering
- ( ) Chemical Engineering - Biomolecular Concentration
- ( ) Civil Engineering
- ( ) Computer Engineering
- ( ) Electrical Engineering
- ( ) Environmental Engineering
- ( ) Industrial Engineering
- ( ) Materials Science and Engineering
- ( ) Mechanical Engineering
- ( ) Other: ____________

11. Confidence of Major Choice *

How confident are you, on a scale from 1 to 10 with 10 as completely confident and 1 as very much NOT confident, about your choice of major.

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Not confident at all -- no idea what to choose	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Completely Confident - no d

Second-Choice Major

What is your 2nd-choice major, if any?

12. Choice of engineering major

Mark only one oval.

- ◯ Bioengineering - Bioelectrical Concentration
- ◯ Bioengineering - Biomaterials Concentration
- ◯ Biosystems Engineering - Bioprocess Emphasis
- ◯ Biosystems Engineering - Ecological Emphasis
- ◯ Chemical Engineering
- ◯ Chemical Engineering - Biomolecular Concentration
- ◯ Civil Engineering
- ◯ Computer Engineering
- ◯ Electrical Engineering
- ◯ Environmental Engineering
- ◯ Industrial Engineering
- ◯ Materials Science and Engineering
- ◯ Mechanical Engineering
- ◯ None
- ◯ Other: ______________________

13. Describe what you believe engineers in your top-choice major do at work. *

In no more than 50 words, describe what you engineers in your top-choice major do for a living.

Appendix B – Fit, Satisfaction, and Confidence Survey (Relevant Questions)

Fit and Satisfaction in Engineering

Please answer the following with respect to **engineering in general**.

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
The courses available in engineering match my interests.	○	○	○	○	○
I know other students here whose academic interests match my own.	○	○	○	○	○

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
My current courses are not really what I would like to be doing.	○	○	○	○	○
All things considered, engineering suits me.	○	○	○	○	○
I feel that my academic goals and needs are met by the faculty in engineering.	○	○	○	○	○
I am able to use my talents, skills, and competencies in my current courses.	○	○	○	○	○

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
All in all, I am satisfied with the education I can get in engineering.	○	○	○	○	○
I'm satisfied with the intelligence of my teachers here.	○	○	○	○	○
I'm satisfied with the extent to which my education will be useful for getting future employment.	○	○	○	○	○
I'm happy with the amount I learn in my classes.	○	○	○	○	○
I'm satisfied with the extent to which engineering will have a positive effect on my future career.	○	○	○	○	○

Major & Confidence

Which of the following majors are you **most likely** to pursue?

○ Bioengineering
○ Biosystems Engineering
○ Chemical Engineering
○ Civil Engineering
○ Computer Engineering
○ Computer Information Systems
○ Computer Science
○ Electrical Engineering
○ Environmental Engineering
○ Geology
○ Industrial Engineering
○ Materials Science and Engineering
○ Mechanical Engineering
○ ________ Another major:

Rate your current level of confidence in your choice of major.

- ○ 1 - not very confident
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ 6
- ○ 7
- ○ 8
- ○ 9
- ○ 10 - very confident

Fit and Satisfaction in Your Intended Major

Please answer the following with respect to your intended major, **${q://QID85/ChoiceGroup/SelectedChoicesTextEntry}**. Please answer as many as you can, however if you don't know or are not sure how to respond, leave that item blank.

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
The courses available in my intended major match my interests.	○	○	○	○	○
I know other students in my intended major whose academic interests match my own.	○	○	○	○	○
All things considered, my intended major suits me.	○	○	○	○	○

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
All in all, I am satisfied with the education I can get in my intended major/program.	O	O	O	O	O
I'm satisfied with the extent to which my education will be useful for getting future employment.	O	O	O	O	O

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
I'm satisfied with the extent to which my intended major will have a positive effect on my future career.	O	O	O	O	O

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