UNIVERSITY OF OKLAHOMA GRADUATE COLLEGE

A NOVEL FRAMEWORK FOR EVALUATING ENGINEERING SELF-CONCEPT: EXPLORING ITS EFFECTS ON SELF-EFFICACY AND IDENTITY STATUS TRANSITIONS AMONG FIRST-YEAR STUDENTS

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the Degree of

DOCTOR OF PHILOSOPHY

By

JAHNAVI DIRISINA

Norman, Oklahoma

2024

A NOVEL FRAMEWORK FOR EVALUATING ENGINEERING SELF-CONCEPT: EXPLORING ITS EFFECTS ON SELF-EFFICACY AND IDENTITY STATUS TRANSITIONS AMONG FIRST-YEAR STUDENTS

A DISSERTATION APPROVED FOR THE

SCHOOL OF INDUSTRIAL AND SYSTEMS ENGINEERING

BY THE COMMITTEE CONSISTING OF

Dr. Randa L. Shehab, Chair

Dr. Susan E. Walden

Dr. Ziho Kang

Dr. Rui Zhu

Dr. Edward T. Cokely

Dedications

To my younger self, who had big dreams, but was directionless and often took leaps of faith.

To my husband Abhilash Kolanapaka, my rock, who believed in me more than I ever did.

And to all the girls out there who were told “mediocre grades are good enough because you wouldn’t have a career anyway”, overlooked due to their gender, hesitant to step forward for fear of failure, reluctant to reach for help, and too naïve to know that opportunities befall those who ask.

May this work serve as a beacon of possibility, illuminating paths for those who dare to dream beyond the boundaries set by others.

Acknowledgements

Firstly, acknowledging my mother, Asha Ramani Jakka, whose courage and grit have been a constant source of inspiration for me. Despite having to give up on her PhD, she forged a path for herself through endless challenges, demonstrating a resilience that inspires me every day. Thank you, *Amma*, for your endless love.

I would like to extend a million thanks to Dr. Randa Shehab, for being the most inspirational, understanding, supportive, patient, and compassionate advisor, anyone could ever ask for. Thank you for creating an environment that fosters growth, advocating for continuous improvement, and motivating me to strive for excellence. Your mentorship has been truly transformative.

Next, my eternal gratitude to Dr. Susan Walden, for believing in me, being my sponsor in places that I am not present, offering me chances, introducing me to engineering education, recognizing that I needed help when I was spiraling down into a pit, helping me make connections that led me towards wins, and so much more than I can list. I am forever indebted to you for everything that you have done for me; none of this would have been possible without your unwavering support.

I am also grateful for many others who have left a lasting impact on my journey at OU:

Dr. Brian McSkimming and Dr. Dominique Pittenger for always having their door open for me and for going above and beyond as my mentors.

Dr. Doyle Dodd, who offered me my first Teaching Assistantship at OU, and for continuing to provide a supportive space with no judgements.

My colleagues Dr. Ricardo Palma Fraga, Terri Possehl, Buket Cilali, Rachel Lindsay Bennett, and Deniz Emre for the camaraderie, insightful conversations, and tolerating my venting sessions.

Dr. Edward Cokely, whose seminar class in cognitive psychology served as a steppingstone for my research trajectory.

Dr. Shivakumar Raman, Director for the School of ISE during my time at OU, for believing in me from the moment I applied for the program. I will forever remember the phone call with you in March of 2020, during which you urged me apply for the program right on that day and make no delays.

All the faculty of the Engineering Pathways department at OU, for helping and allowing me to collect data in their classrooms.

Table of Contents

List of Tables

List of Figures

Abstract

Engineering education research can benefit from comprehensive tools for assessing student self-concept and its relationship to identity development. This research addresses this gap by introducing a novel framework for evaluating engineering self-concept and exploring its influence on identity status transitions among first-year students. Key sub-constructs of engineering self-concept were identified through an extensive literature review, distinguishing it from self-efficacy. A new survey instrument for assessing engineering self-concept was developed, pre-tested with subject matter experts and was statistically validated. Confirmatory factor analysis was used to validate the theoretical framework and to examine the relationship between engineering self-concept and self-efficacy.

After establishing the framework for engineering self-concept, measures of identity status were integrated into the analysis to investigate identity status transitions in first-year engineering undergraduates. Significant transitions were observed amongst cohorts of students. A qualitative interview methodology provided insights into specific transition patterns that were observed. Interpretations further explored connections between engineering self-concept and various identity statuses.

Findings contribute to the field of engineering education by providing a validated tool for assessing engineering self-concept and insights into the relationship between self-concept and identity development. Implications extend to structural adaptations to enhance undergraduate student identity development, improve student performance and commitment to engineering, and inform educational strategies for increasing retention and persistence in engineering programs. This work lays the foundation for future research aimed at supporting the holistic development of engineering students during their critical first year.

Chapter 1 – Introduction

This research comprises a series of interconnected experiments, each designed to systematically address the primary research questions while simultaneously exploring emergent issues and inquiries that arose during the investigative process. This approach allowed for an iterative and adaptive research methodology, enabling deeper investigation into unexpected findings and refine the hypotheses as new insights emerged. The experimental sequence deals with two key components: engineering self-concept and identity development. This study features a structured approach in which certain chapters build upon the findings of previous chapters, creating a cohesive narrative that effectively addresses the research questions

The primary goal was to examine "How engineering self-concept and identity status types are influenced during the first college semester for an engineering student." This goal was pursued incrementally and was organized into several phases. The major steps in this process include: (i) developing a framework for engineering self-concept by identifying its underlying constructs and (ii) examining how identity develops during the first semester of engineering undergraduate students, shaped by their reflective experiences. This study addresses the following research questions:

RQ1: How does engineering self-concept relate to task-related engineering self-efficacy?

RQ2: How does identity status change in a first semester engineering experience course?

RQ3: How is identity status related to self-concept of a first-year engineering student?

Data collection was conducted in the academic year 2023-24 at multiple junctures as depicted in Figure 1. Three different quantitative surveys were conducted, along with a qualitative interview to address the set of research questions.

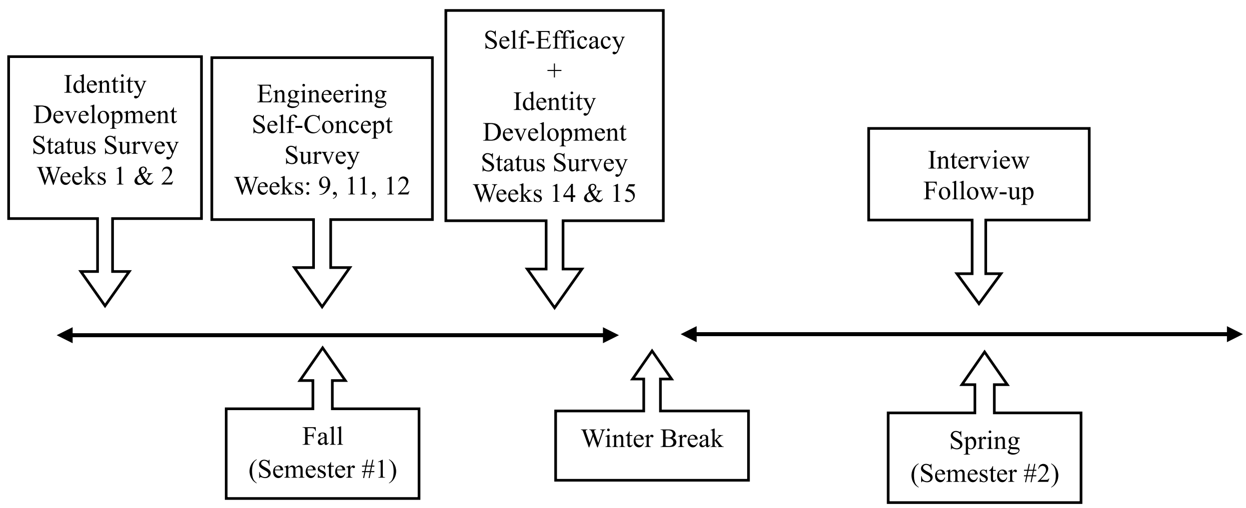


Figure 1: Research timeline representation.

A 8-item identity development status survey was administered to engineering students at the beginning and at the end of the first semester. The pre and post-scores allowed observation of how identity statuses held by the students as they entered an engineering program changed after experiencing a full semester in the program. In addition, an engineering self-concept survey was administered in the middle of the first semester. This survey consists of items to assess all sub-constructs that were important to engineering self-concept. An engineering self-efficacy scale was administered at the end of the first semester. This survey addressed the hypothesized relationship between engineering self-concept and engineering self-efficacy. Finally, the qualitative interview explored any identified identity status changes within the first semester. The questions probed on how circumstances or thoughts changed, leading to the change in identity status. Specific explicit details are furnished in the following chapters.

Chapter 2 – A Systematic Review of Academic Self-Concept Measures in First-Year Engineering Education

The research began by understanding self-concept and its distinctions from closely related concepts in educational psychology. The aim for this chapter was to build a framework to assess self-concept that is specific to the context of engineering education. It also allowed the examination of distinctions between self-concept and self-efficacy. This paper was presented at the American Society for Engineering Education (ASEE) Annual Conference 2023 (Baltimore, MD), and published in the ASEE 2023 conference proceedings. Minor modifications were made to the original paper to integrate it into this document.

2.1. Motivation

The research on self-concept has been occupying a significant portion of the studies contributing to the advancement of educational psychology. As much as the topic has gained popularity in the past decades, it suffered due to the lack of a concrete definition in its early years of advent (Shavelson et al., 1976). As interest in it grew, self-concept also gained strength, clarity, and structure. It grew strong as it gained a definition explaining how it might play an important role for a student and for an educator (Shavelson et al., 1976). Clarity was provided when it was differentiated from some parallel concepts in self-theory and affixing a space for self-concept in an individual's perceptions, and not a just placeholder (Bong & Clark, 1999). Structure was added by delving into the depths of the construct and understanding its multidimensional and hierarchical properties (Marsh & Shavelson, 1985). As the gray areas began to fade away, self-concept gained popularity.

However, debates sparked about how different self-concept and self-efficacy were, in their assessment areas and outcomes. After deeper digging, it was found that there were some fundamental differences in literature dealing with each of the two constructs (Bong & Clark, 1999). Despite constant conceptual developments and growing popularity, the adoption of self-concept in engineering education remains sparse. Instances of self-concept being referred to as confidence (Ifenthaler et al., 2015) or self-efficacy (as discussed in further sections) is still found in recent engineering education literature.

Educational psychology literature has distinguished between self-concept and self-efficacy. It was established that self-concept is important for building ability perceptions (Shavelson et al., 1976) and self-efficacy important for producing desired behaviors or performance (Bong & Clark, 1999). However, in engineering education literature, a clear differentiation between the concepts is not found. This study posits that the two constructs are disparate and attempts to demonstrate that they are critical in addressing engineering student attrition. They are among the prominently noted reasons for persistence (Thiry et al., 2019), but a clear definition and structure for the two in the context of engineering, conforming to the theoretical frameworks presented in educational psychology, is needed. Identifying which factors or sub-constructs commingle to form the self-concept of a student in engineering undergraduate education is the crux of this study. To accomplish that, a systematic review was performed over recent studies, related to engineering education, that assessed self-concept as part of their methodology.

This paper first introduces self-concept and self-efficacy, the two constructs that are often used interchangeably in literature, followed by a database search for recent studies measuring self-concept. Based on the results this study enlists the variables assessing either of the constructs that were introduced. Then a detailed analysis of the differences between the two constructs is provided. Extensions to the current structure of self-concept and explanations about how it can be adapted to self-referent domains of an individual is discussed. The distinctions between the terms posed in this study are then used to identify which sub-constructs are most pertinent for measuring self-concept in engineering education.

Identifying the variables (sub-constructs) within self-concept has beneficial applications in first-year engineering education due to the noted levels of attrition in the first two years of an engineering curriculum (Desai & Stefanek, 2017). Building a scale and consequent interventions to influence those sub-constructs will help improve student retention due to the direct relation of self-concept with academic achievement; less importantly in terms of high grades but more so as an active contributor to human attainment (Bong & Clark, 1999; Wu et al., 2021).

2.2. Self-Concept

Self-concept is defined as the broad view of one's own abilities that are formed by self & social evaluations and interactions (Shavelson et al., 1976). The multifaceted and hierarchical properties of self-concept were later studied by Marsh and Shavelson (1985). These properties were examined, supported, and validated in other following studies along with describing self-concept in a multidimensional structure (Marsh, 1987; Marsh et al., 1988; Marsh, 1990; Byrne, 1990). This research laid a reliable foundation for future considerations, in that self-concept is multifaceted, hierarchical, and multidimensional – meaning that it varies with age, education, vocation, and one's social standing. These dimensions and facets can be self-referent or as established by an authority/institution.

The multifaceted property states that a person's self-concept will be categorized by "self-referent" domains/activities in which the individual shows interest (Marsh & Shavelson, 1985).

The hierarchal nature of an individual's self-concept puts general self-concept at the apex of ability inferences, and distinguishes it into domains like academic and non-academic, followed by further distinction into sub-domains (e.g., non-academic self-concept is further categorized into physical and social self-concepts) (Marsh & Shavelson, 1985). The multidimensionality of self-concept posits that these perceptions and inferences are volatile, vary with age and/or achievement levels of an individual, and display varied properties at each dimension (Marsh, 1990).

2.3. Self-Efficacy

Bandura, in his work involving Social Cognitive Theory (Bandura, 1994), defined self-efficacy as one's expectancy to perform and produce desired results in a task. Efficacy expectations reflect confidence in producing certain patterns in a behavior (Bandura, 1978) and do succeed in achieving the desired results (Bandura, 1997). In the domain of academic attainment, the role of self-efficacy was extended to utilizing learning strategies, setting effective goals, endurance, and success (Miller et al., 1999). Self-efficacy in individuals is known to be affected by several factors. Psychological reactions (i.e., nervousness or excitement before a big meeting) are known to negatively influence self-efficacy. Social persuasion, (i.e., belief, feedback, and support received from peers) positively influences self-efficacy. Lastly, mastery experiences – a known record of one's previous grades/results, and vicarious experiences – skill or content acquired by observing advanced peers and role models play a large role in improving self-efficacy (Rittmayer & Beier, 2009).

However, it should be noted that self-efficacy once improved, say through factors listed before, does not hold constantly at that level. Research has found that when an individual has a high perceived self-efficacy, it could result in less preparation or effort from the individual, leading to undesired results, and eventually low self-efficacy (Rittmayer & Beier, 2009). Critical differences between self-concept and self-efficacy, that are considered crucial for this study are discussed in the following chapters.

2.4. Method

Early researchers (Shavelson et al., 1976) posited that there was a lack of an agreed upon standard definition and assessment for self-concept, which is still the case for assessing self-concept in science and technology majors (Rüschenpöhler & Markic, 2019). A possible reason is, assessment of self-concept in the domain of engineering requires a multi-facet amalgamation within academic self-concept, i.e., a combination of science, math, and technical self-concept.

A Google Scholar search with “academic self-concept” and “engineering education” as Boolean terms produced 548 results. The search criterion was restricted to the years 2020 to 2022, to capture the current and state of the art methods to assess self-concept in STEM fields. Using Google Scholar as the search database allows for coverage across global research publications, leaving room for the researchers to shortlist suitable publications focused on relevant disciplines. Initial results consisted of a mixed bag of instruments that were dedicatedly assessing self-concept, but were thought to be assessing self-efficacy, and vice-versa. But they qualified as research related to STEM and didn’t exactly match criterion of engineering education.

After excluding the manuscripts that didn’t deal with measuring self-concept among engineering or STEM undergrads, and the ones that weren’t translatable, a total of 16 research (empirical) studies were available for analysis. The selected studies used some form of survey to assess self-concept. It included 2 critical case articles that were selected, that did not quite qualify for the criterion of measuring self-concept among stem undergraduates but were worth studying.

This systematic review sought to find the essence of the construct measured in the identified surveys. This study investigated which component(s) the survey claimed to measure, and to which construct, self-concept or self-efficacy, the component was described to represent. The components and their associated construct(s) are listed in the results. Although the search was limited to papers assessing self-concept, the search revealed papers that measured self-efficacy using scales that the authors described as self-concept. So, it seemed befitting to classify both constructs in the analysis.

It is likely that these components or sub-constructs would vary for any given domain due to the multidimensionality of self-concept and self-efficacy. So, the key to this review is to identify which components are suitable for a scale to measure self-concept in engineering education. The analysis consists of a re-classification to align components based on which constructs they measure, according to the established theories identified in literature.

2.5. Results

The selected papers utilized documented surveys which formulated questions targeted towards specific sub-constructs. The goal and methods in these papers were examined to classify the measured constructs. Table 1 below shows the sub-constructs, referred to as variables from here on, and the classification of whether they were described to assess self-concept or self-efficacy.

2.6. Discussion

2.6.1. Critical Comparison of Concepts

As mentioned in the previous section, there is research that postulates the structural and functional differences between self-concept and self-efficacy. This paper uses the previous research to elucidate differences between the two concepts and proceeds to differentiate them in terms of the current study considerations. Clarity about which construct a given scale is assessing is sometimes confounded so distinguishing between the two is especially important. The results of this discussion can provide insights into any future work dealing with self-efficacy and self-concept in engineering education. Given that a theoretical framework distinguishing between the two constructs exists in educational psychology literature, extending it to engineering education would ensure consistency and adaptability. The applications can be extended to consider pedagogical techniques targeted at a certain sub-construct.

Table 1: Classification of variables, as provided by the shortlisted studies, to be assessing either self-concept or self-efficacy.

Self-Concept	Self-Efficacy
Math ability (Bringula et al., 2021; Carroll et al., 2022)	Academic self-description (Qiu et al., 2022)
College persistence (McKoy et al., 2020; Pawlecki, 2022)	STEM intrinsic value (Bradford et al., 2020)
STEM interest (Bringula et al., 2021; Salgado, 2020)	Academic competence (Jin et al., 2020)
Perceived competence (Mahadeo et al., 2020; Salgado, 2020)	
Perceived STEM performance (Bringula et al., 2021)	
Belief in performance (Mahadeo et al., 2020)	
Professional identity (vocational identity) (McKoy et al., 2020)	
STEM identity (Salgado, 2020)	
Sense of belonging (Betz et al., 2021; Gulati, 2022)	
Resiliency (Betz et al., 2021)	
Future goals/intentions (Betz et al., 2021)	
Academic ability (Hofer et al., 2020; Bringula et al., 2021; Carroll et al., 2022; Pawlecki, 2022)	
Intellectual self-confidence (Carroll et al., 2022; Yullyaningsih et al., 2022; Pawlecki, 2022)	
Drive to achieve (Carroll et al., 2022; Pawlecki, 2022)	
Self-acceptance (Yullyaningsih et al., 2022)	
Self-esteem (Yullyaningsih et al., 2022)	
Academic involvement (Sadia, 2022; Pawlecki, 2022)	
Expectancy for success (Wille et al., 2020)	
Attainment value (Salgado, 2020)	
Utility value (Salgado, 2020)	
Recognition (Salgado, 2020)	
Motivation (Gulati, 2022)	

Although the terms self-concept and self-efficacy were prevalent through the 20th century, attempts to classify the two began close to the turn of the century. Bong and Clark (1999) posited that academic self-efficacy has a comparatively more straightforward structure than self-concept. One of the major differences between academic self-concept and academic self-efficacy is the presence of a social component in the former, and absence of same in the latter. Self-concept is largely dependent on the degree of both self and socially perceived competence. Influences of stereotypes, age, confidence levels, and experiences can be found among such feedback. Additionally, self-concept relies heavily on one's social standing and comparison. Behavioral differences in predicting academic accomplishments were expected to be because of academic self-efficacy's prominent use of past experiences and mastery levels. This study also highlighted that the two constructs may share a similar "within-construct network", referring to the strong support for the multifaceted and hierarchical structure of self-concept and the limited but present evidence received for the multidimensionality and hierarchical structure of self-efficacy. But it was insisted that future studies should verify these findings (Bong & Clark, 1999).

The study by Bong and Skaalvik (2003) clarified the findings in the work of Bong and Clark (1999). Their study stated that a central element to both self-concept and self-efficacy is an individual's view of their competence. However, they remarked that the similarities in the perceptions of competence should be studied further. Domain-specific previous experiences are posited to be driving both self-efficacy and self-concept but differentiating that the conclusion formed by the individuals through either of the constructs may not be the same. "Temporal stability" and "malleability" of self-concept was established while self-efficacy was considered the dynamic variable. By definition, self-concept is the "knowledge and perceptions about oneself in achievement situations" while self-efficacy is "convictions for successfully performing given academic tasks at designated levels." Among pertinent task-specific demonstrations, a comparison of the two constructs was tabulated in terms of definition, centrality, composition, influence of competence, domain-specificity, structure, time orientation, dimensionality, temporal, and predictive qualities. The other dimensions of comparisons stated self-concept operates with "perceived competence" as its central element, comprising both mental and emotional assessment of oneself, forcing judgment of past events with a normative lens based on domain. Self-concept embodies a multidimensional and hierarchical structure, stable through passing time and events with "motivation, emotion and performance" as predictive outcomes. Self-efficacy's central element is "perceived confidence", comprised of only mental assessment of oneself in comparison to a norm or a set goal. It is domain specific like self-concept but is also task specific. Self-efficacy embodies a multidimensional but loosely hierarchical structure that is unstable or easily influenced, and the predictive outcomes are "motivation, emotion, cognitive and self-regulatory processes, and performance" (Bong & Skaalvik, 2003).

Analyses performed on assessment data of 15-year-old Belgian students (Ferla et al., 2009) identified conceptual differences between academic self-concept and academic self-efficacy, along with causal and predictive properties within them. This lent support to the findings of Bong and Skaalvik, (2003). Self-concept has a strong causal influence on academic self-efficacy beliefs and is predictive in the sense that academic self-concept was found to be a predictor of motivational variables among an individual. On the other hand, academic self-efficacy was found to mediate (or contribute to) one's academic achievement (Ferla et al., 2009).

In a recent study by Marsh and colleagues (Marsh et al., 2019), the subtle and clear differences between the two constructs were documented. Self-concept was said to be formed through environmental, personal, and experiential influences. Self-efficacy on the other hand is influenced by comparison with an absolute criterion and was said to lead to success in activities. The task specificity of self-efficacy was emphasized. One of the crucial findings of this study was that “generalized self-efficacy” and “outcome expectancies”, which by definition and functionality were considered a measure for self-efficacy, closely represent self-concept. Another valuable finding was a clear guideline for identifying which construct the data represent. It was found that data that are “purely descriptive and future oriented” represent self-efficacy while “descriptive, evaluative and based on past accomplishments” data point towards self-concept (Marsh et al., 2019).

Previous research sparks the thought of whether the construct that is being considered gets mixed up process of interpretation or the measurement process. This was said to be the case in some instances where data was labelled to be representing self-efficacy, while in actuality, self-concept was being measured. Clear instructions were laid out in the recent study by Marsh et al., (2019), about how future researchers can be wary of selecting the appropriate measure for the construct that is being studied, while also avoiding misinterpretation of data.

Based on the studies listed above, this study was guided by the representation that self-efficacy measures are particularly task-specific, but this is valid only if the “focus of prediction” is also narrow. A way to identify and assign a measure/response to either of the constructs is using the “rule” that self-efficacy responses are descriptive in nature, while self-concept responses are broad opinions (Marsh et al., 2019). Otherwise, the assessment of which construct a response represents gets confounded by lack of clarity. It is also crucial to note that self-concept references are focused on one’s perceived competence, formed by past experiences and are relatively stable. Whereas self-efficacy relates to one’s perceived confidence, focus on future activities, and is easily influenced (Bong & Skaalvik, 2003).

For the sake of this paper, research and findings about self-concept and self-efficacy over the years were studied to form an identifying criterion for the related assessors. Additionally, only the academic dimension of self-concept, based on the hierarchical model (Shavelson et al., 1976), is considered. Self-concept is a general conception of one's abilities, wherein a global self-concept (e.g., "I am a good human being") is considered self-esteem (Marsh, 1993). Domain specificity, in reference to the hierarchical model of self-concept discussed above, gets streamlined based on the activities an individual is involved in on a regular basis. For example, a student has perceptions that range from "I am an adept student" to "I perform well in biology", which hints at the streamlining within academic self-concept. Furthermore, if a student is actively involved in extra-curricular activities, those perceptions are refined toward non-academic self-concept, which also get streamlined according to the non-academic activities one is involved in (e.g., sports, debates, etc.). Perceptions of one's self-concept get stronger as one grows older because as a child there is minimal or no past evidence or performances and a limited peer network, which is essential for comparisons among others which helps form their self-concept (Marsh, 1986; Marsh et al., 1991). Self-efficacy, however, is competence judgements pertaining to a specific task (e.g, I will score well in the math exam). It is known to be unstable with experience, time, and situations, hence age is not an accurate comparison dimension (Bong & Skaalvik, 2003). Knowing that readiness, knowledge acquisition, and one's self-concept in that domain influences their self-efficacy score (probably not in equal or regular degrees) is a key point to note when performing response interpretations.

Considering the domain-specific nature of self-concept and task-specific (within the said domain) nature of self-efficacy, there exists a possibility of causality among the two. Figure 2 presents a simple model of the proposed causation. It shows self-concept as the overarching perception of oneself in a certain domain, and self-efficacy as the task-specific construct within that domain. This was also referenced by (Ferla et al., 2009), as in the example, “I generally enjoy my history class, and I am confident that I will score well in the upcoming history test.” While this is true in most cases there is a possibility of the contrary, as illustrated in the hypothetical statement, “I have struggled in my statistics class since the beginning of the year, but I have worked hard for the final exam, and I am confident that I will score well.” The causality between the two constructs is also described as the self-expansion model, which posits that the strength and specificity of self-concept directly influences self-efficacy (Mattingly & Lewandowski Jr, 2013).

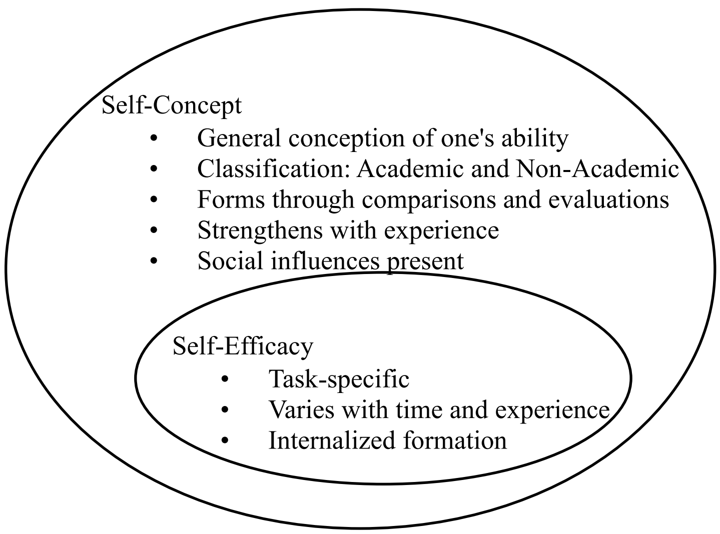


Figure 2: A Venn-diagram depicting the perceived causality among self-concept and self-efficacy.

The situation of “most cases” is best illustrated through the dimensional comparison theory (DCT) (Möller & Marsh, 2013), which is an extension to the internal and external frame of reference (I/E) theory (Marsh et al., 2018) – a theory stating that an individual’s self-concept is influenced by both social (peer) and self-feedback. The DCT states that academic self-concept in an individual is formed by temporal and social comparisons in the various subjects/classes that they are enrolled in at school. Digging further, self-concept operates on the reciprocal effects model (REM) – self-concept is formed through prior domain standing and prior self-concept (Marsh et al., 2018).

Based on the differences between self-concept and self-efficacy discussed above and the operational and influential definitions of self-concept, this study proposes an extension to the hierarchical model offered by Marsh and Shavelson (1985). The original model offers a clear separation between academic self-concept and non-academic self-concept, but keeps it at a general level by listing english, history, math, and science as the facets of academic self-concept. This work focuses on extending the hierarchical model, but with a focus on engineering education (Figure 3). Extension was performed specifically on engineering-relevant math classes. The other contribution of this study is the hypothetical line drawn across the chart between the math classes and tasks in that class. This line indicates the extent of each of the constructs on perceptions/judgements at different levels. This extension follows the representation in (Marsh, 1990) but differs in the context of target application – school versus engineering education.

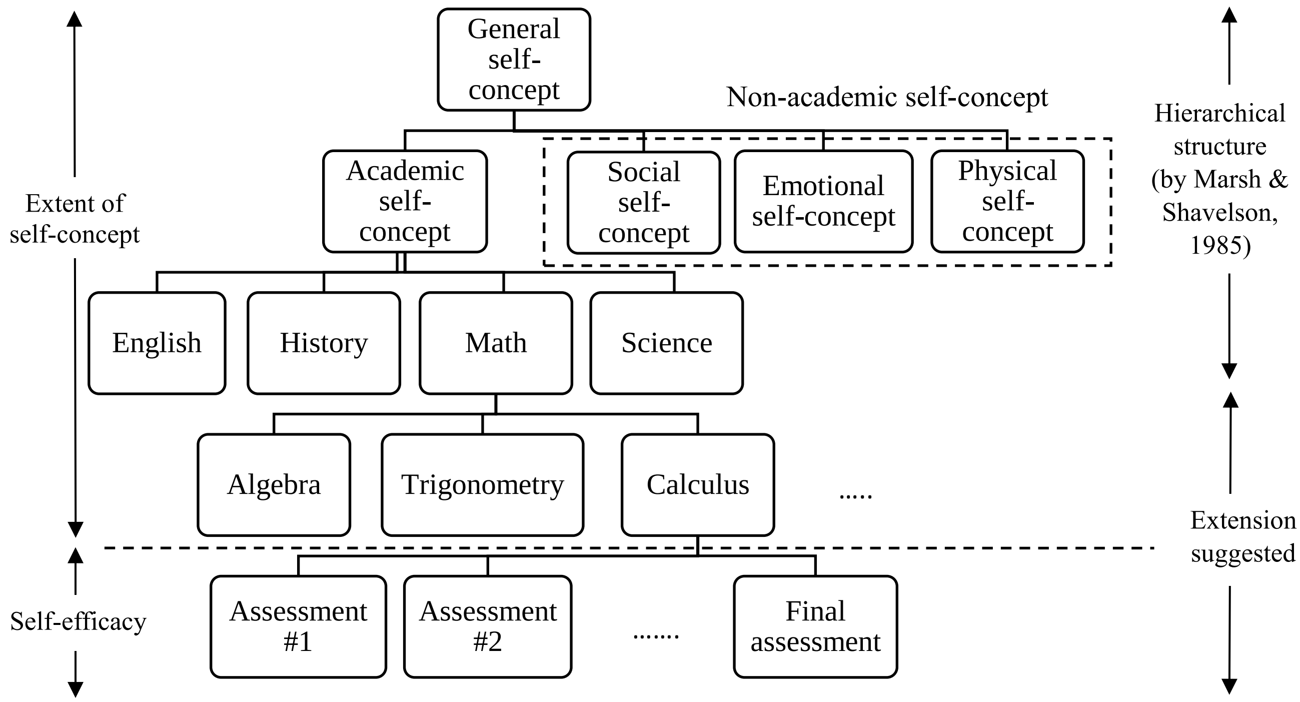


Figure 3: Hierarchical structure of self-concept (adapted from Marsh & Shavelson, 1985) with a coursewise extension to mathematics self-efficacy.

The level below math represents the first level in the proposed extension and includes various domains of math relevant to engineering education (i.e., algebra, trigonometry, and calculus). These domains still lie within the influential range of self-concept, with self-concept driving opinions, perceptions, motivations, and achievements in those domains. The second level extension represents the highest level of specificity in a given domain. This level includes exemplars of tasks (i.e., assignments, tests, or quizzes) relevant to the domain from which it extends. It is at this level where self-efficacy is understood to be driving self-perceptions and eventually performance in those tasks. For instance, self-concept in calculus (i.e., a domain) can be expressed as “I am able to understand and follow along the calculus classes”, and self-efficacy in calculus (i.e., task performance) can be expressed by “I am confident I can score at least a B in the upcoming test”.

The above definitions for both constructs are adapted from previous research and validating or verifying them is not within the scope of this project. This study agrees with previous findings (Marsh, 1992; Frédéric et al., 2003; Marsh & Martin, 2011; Wu et al., 2021), that state self-concept is a prime predictor for favorable academic outcomes and well-being as a student. Self-efficacy, although crucial for an individual’s academic success, is only connected with specific outcomes, i.e., scores/performance in a task. For a well-rounded and ethical education, an individual must identify with what they are learning, see the value in their learning outcomes and acquire significant knowledge. From the perspective of an educator, self-efficacy is a critical construct that helps students progress through the curriculum by passing prerequisite courses, while self-concept drives the student forward towards achievement of a greater goal of graduating as an engineer.

Table 2 consists of the variables condensed from Table 1, but re-categorized into which construct this review has deemed as appropriate. It should be noted that Table 1 had two columns based on interpretations in literature, while Table 2 has three based on the foundational knowledge and distinctions discussed between self-concept and self-efficacy. This re-classification focuses on the variables that are task-specific in regard to the assessment of outcomes essentially. For instance, academic self-description was used to measure self-efficacy in the paper by Qiu et al., (2022). However, because Marsh (1990) used academic self-description questionnaire to assess self-concept, it was adapted and reflected in this review. It was an added advantage that Marsh (1990) had used the academic self-description questionnaire to assess self-concept in the original paper.

Table 2: Re-classification of variables as pertaining to either academic or non-academic self-concept, or self-efficacy.

Academic Self-Concept	Non-Academic Self-Concept	Self-Efficacy
Academic self-description	College persistence	Perceived academic (STEM) performance
STEM intrinsic value	Professional identity (vocational identity)	Academic ability & interest
Perceived academic (STEM) competence	STEM identity	Future goals/intentions
	STEM interest	Expectancy for success
	Sense of belonging	
	Resiliency	
	Self-confidence	
	Self-acceptance	
	Drive to achieve	
	Attainment value	
	Utility value	
	Recognition	

The variables in Table 2 were re-classified based on definitions and descriptions offered in the literature and the synthesis this study completed to clarify and differentiate the terminology. Academic self-concept refers to the broad perceptions or opinions of oneself in academic domains (Shavelson et al., 1976). This study considers that non-academic self-concept refers to ability perceptions in non-academic domains (emotional, social, and physical). Self-efficacy is the expectancy of performance in a particular task (Chemers et al., 2001). The following section discusses those terms that were re-classified.

The first step in the re-classification identified which of the sub-constructs were classified as self-concept but were categorically more fitting under “non-academic self-concept”. Identity in the context of STEM & professional identity is the degree to which an individual identifies themselves with STEM and their current profession as a STEM student. It is associated with the benefits they would reap with continuing in the program (Rüschenpöhler & Markic, 2019). In simple words, it is a perception about how suitable STEM seems to the individual, and how they see themselves fitting in the field. It has social and emotional components – the effect of peers, role models, and educators can be a heavy influence, and hence justified as non-academic self-concept.

Attainment and utility value can be loosely described as the value a student finds in learning a specific derivation or getting that future degree. Attainment value, especially, becomes very apparent when a student weighs the importance and weightage of multiple upcoming deadlines, to decide which one is worth working harder. They possess both emotional and personal components, so an obvious choice for non-academic self-concept.

Academic self-description, which was set under academic self-concept in the re-classification table, can be put in the same terms as is the definition of self-concept. Marsh (1990) described it as the broad perception or description of oneself in a particular domain being inspected, which in this context is academic. It is justified to be re-classified under academic self-concept, having moved it from under self-efficacy in table 1.

STEM intrinsic value is the joy an individual has while performing an activity and the interest one has in a field, specifically academic in STEM (Eccles & Wigfield, 2002). This was listed under self-efficacy in Table 1 based on immediate findings, but this sub-construct is influenced by past-orientation and perceived competence, hence is a good fit for academic self-concept.

Perceived academic (STEM) performance aims at depicting context specific performance, performance in an exam for instance. Previous studies classified it as a sub-construct of self-concept (Bringula et al., 2021), but it is better suitable to be classified as self-efficacy due to its specificity in assessment outcomes.

2.6.2. Sub-constructs for Instrument in Engineering Education

After having examined recent studies and differentiating the suitable variables for self-concept and self-efficacy, this study proceeds towards identifying how these concepts relate to freshman engineering persistence. Although all the identified variables are important for general success, advancement, and persistence of a student, the context of engineering education calls for a modified framework. High schools educate students in math and science, which is important preparation for an engineering curriculum. Students develop perceptions about their ability and standing with respect to their classes, i.e., their domain level self-concept within the school. They carry this academic self-concept when they move on to college, but literature shows that both academic and non-academic self-concept are critical to perform and persist in an engineering institution. The lack of preparation in this direction could be causing the freshman engineering students to experience challenges leading to attrition/diversion (Thiry et al., 2019).

Research in educational psychology found that developing self-concept in K12 students resulted in academic and personal growth (Wu et al., 2021; Rüschenpöhler & Markic, 2019; Marsh & Craven, 2005). The main distinction to observe between this view of self-concept and that for engineering education is academic self-concept in the former is postulated to only have academic facets, but academic self-concept within engineering education is constructed from both academic and non-academic components. It is further proposed that developing engineering self-concept in first-year engineering students could be a critical factor in improving first-year retention in engineering. In the case of K12 education, the model (Figure 3) showed distinct pathways for academic and non-academic self-concepts and held academic performance separate from non-academic perceptions. This study proposes a modified framework for engineering self-concept where the pathways seem to converge (Figure 4). In addition to academic self-concept, non-academic self-concept is critical for commitment to and identifying with the discipline, and both can have positive effects on retention.

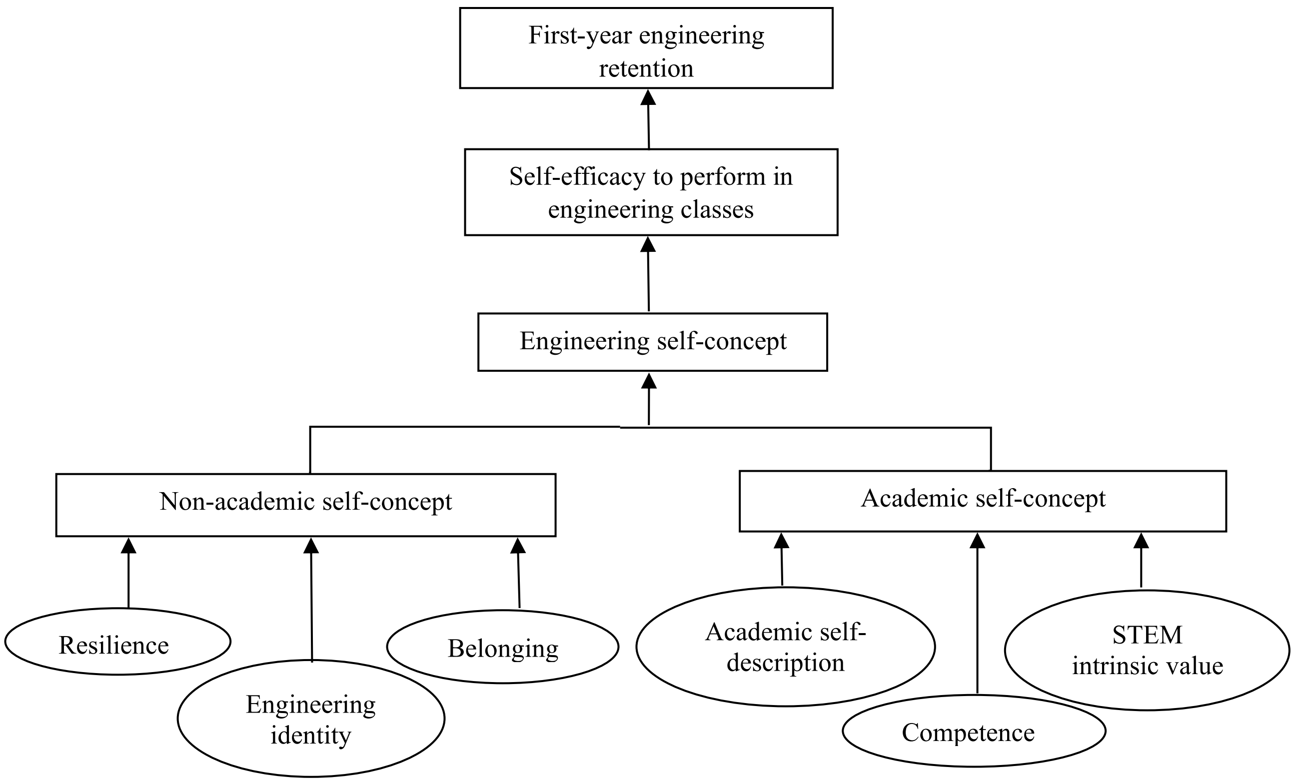


Figure 4: Framework for first-year engineering retention through engineering self-concept and self-efficacy.

This study opines that professional identity (i.e., engineering identity), sense of belonging, and resiliency are key to building non-academic self-concept within engineering. Similarly, academic self-description, competence, and STEM intrinsic value are relevant components for academic self-concept within engineering. These sub-constructs together help build engineering self-concept in an individual, the strength of which is an indicator for self-efficacy to perform in an array of tasks, assignments, and instances in the capacity of an engineering student. This study proposes that this domain specific engineering self-concept and the resultant self-efficacy can have direct effects on first-year retention in engineering with its cognitive and non-cognitive components.

Among all, engineering identity is a dominant sub-construct that could be influencing the other key components mentioned. For instance, the resiliency of a student to stay in engineering can be influenced by the engineering identity they possess. Similarly, one's sense of belonging and fulfilment (i.e., intrinsic value they find in an engineering program) is largely influenced by the engineering identity they hold. However, self-concept in an engineering student can be formed by the combined effects of all the 4 components (i.e., resiliency, sense of belonging, fulfilment, engineering identity). Eventually, the causal relationship between self-concept and self-efficacy as illustrated in Figure 1, might adapt the components of self-concept as long-term influencers for self-efficacy. For instance, when a college student in a math major with high mathematics self-concept enrolls in a trigonometry class and feels confident about performing well in a test, the causality between self-concept perceptions and self-efficacy judgements are observed. The empirical validity of this theory is to be tested in future work.

Implementation of the measurement and improvement of engineering self-concept within the freshman engineering environment has strong potential. Engineering attrition is frequently observed in the freshman and sophomore years (Desai & Stefanek, 2017; Thiry et al., 2019). So, designing a freshman program aimed at improving engineering self-concept is comparable to subduing the issue at its point of origin. Having educators administering such mindful techniques to influence and build engineering self-concept aims for the benefit of students. Improving engineering self-concept among freshmen requires that future engineers are educated to identify with the field, understand why their job is important for humankind, and have the motivation to persist in their career.

Chapter 3 – Classifying Survey Items Related to Engineering Self-Concept for Application in First-Year Engineering

The previous chapter covered a thorough review of the literature and the construction of a theoretical framework for engineering self-concept. The current chapter is the first step in building a survey instrument to measure engineering self-concept, through survey pre-testing. This paper was presented at the American Society for Engineering Education (ASEE) Annual Conference 2024 (Portland, OR), and published in the ASEE 2024 conference proceedings. Minor modifications were made to the original paper to integrate it into this document.

3.1. Introduction

This research paper is a step towards building a survey instrument to measure engineering self-concept. The prior systematic review (Dirisina & Shehab, 2023) identified multiple sub-constructs of engineering self-concept: perceived competence, STEM intrinsic value, belonging, academic self-description, resilience, and engineering identity. This study focuses on identifying survey statements that accurately assess these sub-constructs. The survey statements identified in the systematic review of literature were found to have confounding and ambiguous language/messaging as they described the sub-constructs of engineering self-concept. The language was either unsuited for the context of engineering undergraduates or unclear in referring to the pertaining construct.

A new set of survey statements that represented the constructs in focus were then sampled from other sources in engineering education. To make sure the selected statements were consistently perceived to be interrogating the pertaining constructs, the researchers performed a multi-step validation study. First, 43 survey statements were filtered from some prominent surveys in the field of engineering education. Then 10-subject matter experts (SMEs) performed a card-sorting procedure, where each of the 43 statements was sorted according to the 5 constructs. The SMEs were faculty members who are active in engineering education. Each faculty either holds a doctorate in engineering education or has significant experience teaching and working with first year students. This task was intended to accomplish grouping of the survey statements to the sub-constructs through expert knowledge.

Preliminary analysis revealed confusion between the constructs of perceived competence and self-efficacy given that the survey statements for these constructs appeared to be randomly attributed to each construct. Thus, an abbreviated card sorting task was again conducted. During this step the SMEs were presented with a subset of 11 survey statements from the original collection and asked to group them into either perceived competence or self-efficacy. This paper discusses the card sorting activities and their implications towards building a survey instrument to assess engineering self-concept.

3.2. Literature Review

A systematic review (Dirisina & Shehab, 2023) distinguished between self-concept and self-efficacy and discussed the resultant operating definitions for the two constructs. This review found evidence that the two constructs in focus were often used interchangeably and were considered as the same measure in practice. This created inconsistencies in the understanding of the two constructs. The goal of the review was to understand how self-concept and self-efficacy were different and to establish the underlying constructs of engineering self-concept. The researchers sought to build a survey to assess engineering self-concept through this process. The review revealed 6 different sub-constructs for engineering self-concept – academic self-description, perceived competence, STEM intrinsic value, belonging, engineering identity, and resilience.

One of the sub-constructs identified above, perceived competence, is closely related in theory to self-concept, which is further found in literature to be confounded with self-efficacy. So, to account for and eliminate entanglement of survey statements between perceived competence and self-efficacy, self-efficacy is also included in the sorting task. The current paper identifies definitions for each of these terms and then delves into identifying survey statements that would be appropriate for assessing them (excluding engineering identity and resilience) in first year engineering students.

Self-efficacy refers to the outcome expectations in an upcoming task and the confidence to produce desired behaviors and expected outcomes (Bandura, 1978; Bandura, 1994). It is very task and scenario specific. However, conflicting research is found regarding this argument, that the framing of self-efficacy to be general or task-specific needs to be explicit (Marsh et al., 2019).

Academic self-description is the way an individual perceives and describes themselves in academic contexts (Marsh, 1990). Survey statements to measure this construct should specifically probe to lead the individual to picture a description of themselves with respect to the statement, and rate themselves in that respect.

Perceived competence deals with broad perceptions of self and has the closest relation to self-concept out of all the outlined underlying constructs. It is the context/field specific perceptions of an individual regarding their abilities, standing in that field (Dirisina & Shehab, 2023).

STEM intrinsic value is the innate interest, joy, and value attained by an individual while participating in an activity, in this case, engineering (Eccles & Wigfield, 2002).

Belonging is considered as the degree to which an individual feels that they fit and belong in the program, and the program is a good fit for their future goals.

The review (Dirisina & Shehab, 2023) identified multiple sources where the above sub-constructs were used as part of a larger survey to measure self-concept within engineering students. However, it was challenging to retrieve survey items to build an overall survey specifically for engineering self-concept. This was due to confounded usage of survey items. For instance, the two survey statements “I am interested in the way science and engineering help people”, and “I am interested in reading websites, magazines or books about scientific issues” were used as measures for STEM Identity (Betz et al., 2021). But the linguistic composition is not consistent with the operational understanding of an individual’s identity.

The researchers decided to conduct a new search to find alternative survey statements that could be used to build an instrument to assess the sub-constructs defined for engineering self-concept. Multiple survey instruments identified in the literature review were examined to identify particular statements that aligned with the 6 constructs defined by Dirisina & Shehab, (2023) as important for engineering self-concept. To this end, a new pool of statements was sampled from these widely applied surveys in engineering education.

Prybutok et al., (2016) explored differences in engineering identity between lower and upper-division undergraduate students in engineering. Engineering identity in their paper was based on a model that encompasses performance/competence, interest, recognition (by others and self) and efficacy as the key components of identity. Out of the survey statements used in (Prybutok et al., 2016), one statement was sampled to represent and assess self-efficacy, three for perceived competence, and one for STEM intrinsic value.

A study by Cokely and Patel, (2007) measured the psychometric properties from the scores of the academic Self-Concept Scale (ASCS), a 40-item scale that measures the "perceptions and feelings students have about their academic abilities" developed by Reynolds et al., (1980). From this scale, eight survey statements were sampled to measure academic self-description, four to measure perceived competence, one to measure STEM intrinsic value, and two to measure self-efficacy.

The Longitudinal Assessment of Engineering Self-Efficacy (LAESE) (Rittmayer & Beier, 2009) was designed to identify changes in self-efficacy of engineering undergraduates, by focusing on efficacy and coping strategy in challenging situations, expected outcomes from pursuing engineering, expectations of workload in engineering undergraduate classes, process of choosing an engineering major, extent of career exploration, and influence from role models. From this survey instrument, four statements were sampled to measure perceived competence, three for STEM intrinsic value, four for belonging, and one survey statement for self-efficacy.

The Pittsburg Freshman Engineering Attitudes Survey (PFEAS) was designed to assess and track the abilities and attitudes of engineering freshmen (Besterfield-Sacre et al., 2005). It measures several aspects of students' attitudes including their expectations of the engineering profession. For the purposes of this sorting procedure, 8 survey statements were sampled to assess STEM intrinsic value.

In an evaluation of students' attitudes towards engineering, design, and technology with an introduction to makerspace (Andrews et al., 2021), the researchers analyzed the sense of belonging among students by utilizing an adaptation of a previously validated scale (Hurtado & Carter, 1997). For the sorting procedure, three survey statements were sampled to represent and assess belonging.

3.3. Methods and Results

A total of 43 survey statements were sampled from 5 different sources (described in the previous section) by mapping each statement to the intended construct. Table 3 provides a detailed account of the statements that were extracted from each survey instrument.

Table 3: Survey statements sampled with intended sub-construct.

Intended sub-construct	Statement	Source
Academic self-description	I feel like a failure sometimes.	(Cokely & Patel, 2007)
	I may not do well in my major.	
	I often expect to do poorly on exams.	
	My study habits are poor.	
	I'd like to be a better student.	
	I schedule my study time well.	
	I am a capable student.	
	I feel that I am better than the average college student.	
Perceived competence	It is hard to keep up with classwork,	(Cokely & Patel, 2007)
	If I try, I will get good grades,	
	My academic goals are clear to me.	
	Courses are usually not challenging for me.	
	I am confident that I can understand physics/chemistry/math outside of class.	(Prybutok et al., 2016)
	I can overcome setbacks in physics/chemistry/math.	
	I can understand concepts I have studied in physics/chemistry/math.	
	I can succeed in an engineering curriculum.	(Rittmayer & Beier, 2009)
	I can excel in an engineering major during the current academic year.	
	I can complete any engineering degree at this institution.	
	I can persist in an engineering major during the next year.	
STEM intrinsic value	I expect that engineering will be a rewarding career.	(Besterfield-Sacre et al., 2005)
	I expect that studying engineering will be rewarding.	
	The advantages of studying engineering outweigh the disadvantages.	
	The future benefits of studying engineering are worth the efforts.	
	I don't care for this career.	
	Engineering is an occupation that is respected by other people.	
	I am studying engineering because it will provide me with a lot of money; and I cannot do this in other professions.	
	I am studying engineering because I enjoy figuring out how things work.	
	A degree in engineering will allow me to get a job where I can use my talents and creativity.	(Rittmayer & Beier, 2009)
	A degree in engineering will allow me to obtain a well-paying job.	
	A degree in engineering will allow me to obtain a job that I like.	
	I enjoy learning the concepts I have studied in my engineering classes.	(Prybutok et al., 2016)
	Being an engineering student is rewarding.	(Cokely & Patel, 2007)
Belonging	I can relate to the people around me in my class.	(Rittmayer & Beier, 2009)
	I have a lot in common with the other students in my class.	
	The other students in my classes share my personal interests.	
	Someone like me can succeed in an engineering career.	

	I see myself as a part of the engineering community at my institution.	(Andrews et al., 2021)
	I feel that I am a member of the engineering community at my institution.	
	I feel a sense of belonging to the engineering community at my institution.	
Self-efficacy	I can do well in the physics/mathematics/chemistry exam.	(Prybutok et al., 2016)
	I will succeed in my math/physics/chemistry courses.	(Rittmayer & Beier, 2009)
	Exams are usually not challenging for me.	(Cokely & Patel, 2007)
	I am confident while taking tests.	

To validate the alignment, SMEs were asked to group the statements into various constructs. Each of the 43 statements were printed on individual cards along with the 5 constructs printed on “title” cards. Ten SMEs were instructed to read the statement on each card and group it with the construct they believed to be best described by the statement. Ultimately, each SME sorted all 43 statements to one of 5 constructs. This task took between 7 to 12 minutes to complete. These results were collected and grouped across all experts leaving the respondent anonymous.

This sorting task resulted in clarity on certain constructs, but confusion on others. Survey statements for academic self-description, belonging, and STEM intrinsic value received clear agreement among SMEs, enabling the researchers to identify 5 statements for each of those constructs. Table 4 shows the statements that had high agreement among the SMEs and which sub-construct each statement was mapped into.

Table 4: Results of sorting task for statements with high SME agreement.

Sub-Construct	Survey Statement	Agreement (%)
Academic self -description	My academic goals are clear to me.	100
	My study habits are poor.	90
	I often expect to do poorly on exams.	80
	I schedule my study time well.	70
	Courses are usually not challenging for me.	70
STEM intrinsic value	The future benefits of studying engineering are worth the effort.	100
	I expect that studying engineering will be rewarding.	100
	I expect that engineering will be a rewarding career.	100
	A degree in engineering will allow me to get a job where I can use my talents and creativity.	90

	A degree in engineering will allow me to obtain a job that I like.	90
Belonging	I can relate to the people around me in my class.	100
	I feel that I am a member of the engineering community at my institution.	100
	The other students in my classes share my personal interests.	100
	I see myself as a part of the engineering community at my institution.	100
	I have a lot in common with the other students in my classes.	100

However, SME judgements were overall inconclusive for statements representing perceived competence and self-efficacy. This indicates possible confounded interpretations of the two constructs. Although research exists that differentiate among the two (Bong & Clark, 1999; Bong & Skaalvik, 2003; Ferla et al., 2009; Marsh et al., 2019), the general perceptions of the SMEs regarding the two constructs are indistinct. Table 5 displays the statements in which the SMEs did not agree on the classification into a single construct. The most distinct alignment for perceived competence (statement #1: "I can excel in an engineering major during the current academic year"), still yielded some uncertainty. Specifically, this statement was selected by 7 SMEs to represent perceived competence and by 1 SME to represent self-efficacy (and 2 additional SMEs assigned it to academic self-description). Other statements indicated greater confusion of constructs. For instance, statement #5 ("I can persist in an engineering major during the next year") had an equal number of SMEs align it with each of the two constructs.

Table 5: Results of sorting task for statements with poor SME agreement.

Survey Statement	Perceived Competence	Self-Efficacy
I can excel in an engineering major during the current academic year	7	1
I can succeed in an engineering curriculum	6	3
I can understand concepts I have studied in chemistry/math	5	3
I will succeed in my math/chemistry courses	5	4
I can persist in an engineering major during the next year	5	5
I may not do well in my major	4	1
I can overcome setbacks in chemistry/math	3	7
I am confident that I can understand chemistry/math outside of class	4	6
I can complete any engineering degree at this institution	3	6

If I try, I will get good grades	3	6
I can do well in the chemistry/math exam	3	6

Due to the lack of clarity in the original SME sort task for perceived competence and self-efficacy, a re-sort was conducted with the same SMEs using 11 of the 43 initial statements as listed in Table 5. Adopting the operating definitions from Dirisina & Shehab, (2023), self-efficacy refers to an individual's confidence in producing desired behavior or results in an upcoming task. Perceived competence, on the other hand, is an underlying construct of self-concept and indicates an individual's view of their general standing and abilities in a domain or field. The researcher arranged individual meetings with each of the SMEs to review these operational definitions. SMEs were then instructed to perform a re-sort of the 11 individual statement cards into the two sub-constructs identified on the "title" cards. This process took between 5 to 8 minutes.

The second sorting task revealed a discernible agreement among SMEs for survey statements representing perceived competence (Table 6). However, self-efficacy was not consistently identified through the survey statements included. This meant that the sample of survey statements used for this research are not in consistent alignment with self-efficacy, and that the researchers must look for other sources to sample survey statements for this construct.

Table 6: Results of second sorting task for perceived competence and self-efficacy.

Survey Statement	First Sort		Second Sort	
	Perceived Competence	Self-Efficacy	Perceived Competence	Self-Efficacy
I can excel in an engineering major during the current academic year	7	1	8	2
I can succeed in an engineering curriculum	6	3	7	3
I can understand concepts I have studied in chemistry/math	5	3	6	4
I will succeed in my math/chemistry courses	5	4	4	6
I can persist in an engineering major during the next year	5	5	6	4
I may not do well in my major	4	1	9	1
I can overcome setbacks in chemistry/math	3	7	6	4
I am confident that I can understand chemistry/math outside of class	4	6	6	4
I can complete any engineering degree at this institution	3	6	6	4
If I try, I will get good grades	3	6	6	4
I can do well in the chemistry/math exam	3	6	2	8

3.4. Discussion

Self-concept and self-efficacy are constructs that originated and were established in educational psychology but have been incorporated into the field of engineering education. However, there is a scarcity of research where engineering self-concept has been validated with measures within the field of engineering education. It is likely that when developmental constructs are assessed among individuals of different ages and experiences, so researchers must take initiative to make the instrument suitable for the population. This paper is a step towards creating an instrument to evaluate self-concept within engineering freshmen while also distinguishing it from self-efficacy in practice.

A sorting task was conducted with 43 survey statements and 5 theoretical concepts towards building a survey instrument to assess engineering self-concept among first-year engineering students. Due to the nature of results obtained, the task was conducted twice sequentially. The results obtained from the first sorting task strengthen our reservation that there indeed is a lack of distinction in the way perceived competence and self-efficacy are understood. The second sorting task was conducted after reviewing both constructs with the SMEs and the results were stronger. SMEs had higher agreement for statements aligned with each construct.

This study has yielded robust survey items that can be used to assess engineering self-concept through evaluation of the associated sub-constructs. The resulting items have been demonstrated to be clear and consistently interpreted by SMEs. It was observed that academic self-description, STEM intrinsic value, and belonging got very strong votes with almost a clear choice of survey statements for belonging and STEM intrinsic value. The 3 sub-constructs in focus here have clear boundaries in their theoretical understanding and that is reflected in the resultant votes of the sorting task. But looking at the split of votes between perceived competence and self-efficacy in round #1 of sorting, there was an almost equal split of votes between them, to the extent of one statement "I can persist in an engineering major during the next year" receiving 5 votes each for perceived competence and self-efficacy. This was expected as was evident in the existing literature about self-efficacy (Marsh et al., 2019), and the researchers had included self-efficacy to account for this confounded understanding.

Prior to performing round #2 of the sorting, the operating definitions of perceived competence and self-efficacy were discussed with the SMEs, and 11 statements were presented to sort. This round helped clarify statements aligned with perceived competence and the researchers were able to determine survey statements based on high agreement and by avoiding the ones that highlight task specificity. Only one statement "I can do well in the chemistry/math exam" received a high agreement of its alignment with self-efficacy. Although it fits the task specific elucidation of self-efficacy, overall interpretation of sorting data conveys that further research is required to construct a survey instrument for task-related engineering self-efficacy. The established sample of survey statements post both rounds of sorting are provided in Table 7.

Table 7: Resulting survey statements after two rounds of sorting.

Sub-Construct	Statement
Academic self-description	My academic goals are clear to me
	My study habits are poor
	I often expect to do poorly on exams
	I schedule my study time well
	Courses are usually not challenging for me
STEM intrinsic value	The future benefits of studying engineering are worth the effort
	I expect that studying engineering will be rewarding
	I expect that engineering will be a rewarding career
	A degree in engineering will allow me to get a job where I can use my talents and creativity
	A degree in engineering will allow me to obtain a job that I like
Belonging	I can relate to the people around me in my class
	I feel that I am a member of the engineering community at my institution
	The other students in my classes share my personal interests
	I see myself as a part of the engineering community at my institution
	I have a lot in common with the other students in my classes
Perceived competence	I can excel in an engineering major during the current academic year
	I can succeed in an engineering curriculum
	I can persist in an engineering major during the next year
	I may not do well in my major
	If I try, I will get good grades

This paper is an exploratory step towards implementing survey pre-testing through a sorting task, to promote accurate assessment of behavioral constructs. Research shows that survey pre-testing with SMEs can aid in building clear survey instruments, with the number of SME's ranging from two to over twenty (Ikart, 2019). In the survey pre-testing context, SMEs are individuals with "theoretical knowledge or practical experience" in that domain, making them eligible for evaluating a questionnaire in its development stage (Olson, 2010; Ikart, 2019). Such experts are indicated to be crucial in the process of building strong survey instruments with good questions (Ikart, 2019).

Chapter 4 – Validating the Engineering Self-Concept Survey

The survey instrument constructed through survey pre-testing with SMEs was presented in Chapter 3. The current chapter evaluates the afore constructed survey for statistical significance, to build a robust survey instrument that measures engineering self-concept. This paper is under review for the American Society for Engineering Education (ASEE) Annual Conference 2025 (Montreal, QC).

4.1. Constructing the Survey Instrument

The previous chapter illustrated the partial development of a survey instrument to measure engineering self-concept. Survey statements were established for some sub-constructs of engineering self-concept – academic self-description, STEM intrinsic value, belonging, and perceived competence. To account for the remaining sub-constructs of engineering self-concept theorized by the framework (Dirisina & Shehab, 2023), statements to assess engineering identity and resilience were adopted from more sources.

Personal, social, and institutional contexts of engineering identity were adopted from Fleming et al., (2013), Borrego et al., (2018) and Jensen & Cross, (2021). As a part of self-concept, engineering identity is framed as the importance of "being an engineering student" for an individual, and how closely that identity coincides with their personality and goals. To capture a snapshot of a student's engineering identity, a set of curated statements were adapted from 3 different sources: 2 statements from Jensen & Cross, (2021), 2 statements from Fleming et al., (2013), and 1 statement adapted from Borrego et al., (2018). Moreno-Hernandez and Mondisa, (2021) defined Resilience as "the ability to recover from hardship". Five items from the Resilience, Grit, and Persistence scale (Moreno-Hernandez & Mondisa, 2021) were included within the self-concept survey items to assess a student's resilience.

The inclusion of resilience and engineering identity statements into engineering self-concept provides a comprehensive set of statements to effectively evaluate the proposed facets within the construct. Table 8 lists the survey statements that were intentionally sampled for resilience and engineering identity and the ones that were originally included for belonging, academic self-description, perceived competence, and STEM intrinsic value. The engineering self-concept survey used a 6-point scale (1 – strongly disagree, 2 – disagree, 3 – moderately disagree, 4 – moderately agree, 5 – agree, 6 – strongly agree), to capture student responses.

Table 8: Complete survey instrument used to measure engineering self-concept.

Sub-Construct	Acronym for Reference	Survey Statement
Resilience	r1	I can achieve goals despite obstacles. [a]
	r2	I am able to adapt to change. [a]
	r3	I can deal with whatever comes. [a]
	r4	I think of myself as a strong person. [a]
	r5	I am not easily discouraged by failure. [a]
Engineering identity	eid1	Being good at engineering is an important part of who I am. [b]
	eid2	It matters to me how I do in engineering. [b]
	eid3	Your own sense of who you are (your personal identity) overlaps with your sense of who an engineer is (identity of an engineer). [c]
	eid4	I am fully committed to getting my college degree in engineering. [d]
	eid5	I think that earning a bachelor's degree in engineering is a realistic goal for me. [d]
Belonging	b1	I can relate to the people around me in my class. [e]
	b2	I feel that I am a member of the engineering community at my institution. [f]
	b3	The other students in my classes share my personal interests. [e]
	b4	I see myself as a part of the engineering community at my institution. [f]
	b5	I have a lot in common with the other students in my classes. [e]
Academic self-description	asd1	My academic goals are clear to me. [g]
	asd2	My study habits are poor. [g]
	asd3	I often expect to do poorly on exams. [g]
	asd4	I schedule my study time well. [g]
	asd5	Courses are usually not challenging for me. [g]
Perceived competence	pc1	I can excel in an engineering major during the current academic year. [e]
	pc2	I can succeed in an engineering curriculum. [e]
	pc3	I can persist in an engineering major during the next year. [e]
	pc4	I may not do well in my major. [g]
	pc5	If I try, I will get good grades. [g]
STEM intrinsic value	siv1	The future benefits of studying engineering are worth the effort. [h]
	siv2	I expect that studying engineering will be rewarding. [h]
	siv3	I expect that engineering will be a rewarding career. [h]

	siv4	A degree in engineering will allow me to get a job where I can use my talents and creativity. [e]
	siv5	A degree in engineering will allow me to obtain a job that I like. [e]
(h: Besterfield-Sacre et al., 2005; g: Cokely & Patel, 2007; e: Rittmayer & Beier, 2009; d: Fleming et al., 2013; c: Borrego et al., 2018; f: Andrews et al., 2021; b: Jensen & Cross, 2021; a: Hernandez & Mondisa, 2021)		

4.2. Methods

4.2.1. Data Collection

The engineering self-concept survey was administered among the first-year undergraduate students enrolled in an engineering orientation class in a predominantly white, midwestern institution. Data were collected during weeks 9, 11 and 12 of the first semester (i.e., in the middle of a 16-week semester). Links to the survey were shared through QR codes with all 841 of the students enrolled in the engineering orientation course. Flyers were also posted in their engineering orientation classroom. The number of students that responded to this survey was 113.

4.2.2. Validating Survey Pre-Testing Results

To assess whether the survey items were measuring/interrogating the intended sub-construct, the researchers analyzed correlations between the grouped survey items. This analysis process is useful to establish construct validity by testing whether all statements are measuring the same construct. If high correlations are observed between certain survey statements, we can make inferences about good internal consistency, suggesting that the items are reliably measuring the same construct. If low correlations are identified between any of the survey items, we can group the stronger items and trim out the weak associations to form a more robust measure of engineering self-concept.

Given that the data are ordinal, polychoric correlation analysis was used to evaluate the association among the five survey items for each subconstruct. Polychoric correlations are used under modest violation of normality to evaluate relations among the variables. This method assumes that the observed ordinal variable represents an underlying latent continuous variable that is normally distributed. It boasts numerous applications in social science research and when measuring self-report data (Timofeeva & Khailenko, 2016; Scott, 2018).

To examine whether the survey items measured the same construct, a sequence of paired comparisons were performed.

H_0: No association exists between the two survey items.

H_1: The two survey items are associated with each other.

Each pair of survey items under a particular construct were evaluated with this hypothesis. Since the focus of this test was to evaluate associations between the pairs (and not among all pairs), a familywise error rate does not pertain to this scenario. An alpha of 0.05 was used to evaluate the significance of each pair of survey items.

4.3. Results

The polychoric correlation tests were performed on the survey items listed in Table 8 and results obtained identified the survey items that strongly correlated with each other. Interpretations of significance and effect size are based on Cohen's (1988) seminal work in the field of statistical power analysis. Cohen suggested that correlation coefficients 0.10, 0.30, and 0.50 represent small, medium, and large effect sizes, respectively.

4.3.1. Resilience

The correlation analyses revealed several significant relationships among the survey statements for resilience (Table 9). All correlations, except for r2 & r5 and r3 & r5, revealed statistically significant correlations. The strongest positive correlation was observed between r1 and r4 ($\rho = 0.54$, $p < 0.05$), suggesting a moderate to strong relationship between these two aspects of resilience. Other notable positive correlations included r1 & r2 ($\rho = 0.44$, $p < 0.05$) and r3 & r4 ($\rho = 0.44$, $p < 0.05$), both indicating moderate relationships. Interestingly, r5 showed weak to moderate negative correlations with most other statements, with the strongest negative correlation being with r4 ($\rho = -0.33$, $p < 0.05$). The correlation between r2 and r3 was approaching significance with $p=0.0703$.

Table 9: Correlation strengths among survey items of resilience.

Resilience Statements	**r1**	**r2**	**r3**	**r4**	**r5**
r1	1				
r2	0.44*	1			
r3	0.34*	0.19	1		
r4	0.54*	0.24*	0.44*	1	
r5	-0.22*	-0.15	0.001	-0.33*	1
** Indicates significant correlations*					

4.3.2. Engineering Identity

The correlation analyses to examine the relationships among the five engineering identity statements revealed several statistically significant correlations, with varying degrees of strength (Table 10). The strongest correlation was observed between eid2 and eid3 ($\rho = 0.68$, $p < 0.05$). Moderate positive correlations were found between eid2 and eid4 ($\rho = 0.37$, $p < 0.05$), eid2 and eid5 ($\rho = 0.33$, $p < 0.05$), and eid3 and eid5 ($\rho = 0.38$, $p < 0.05$),. A weak to moderate correlation was observed between eid3 and eid4 ($\rho = 0.30$, $p < 0.05$), and eid4 and eid5 ($\rho = 0.26$, $p < 0.05$). Notably, eid1 did not show any statistically significant correlations with the other statements, with correlation coefficients ranging from 0.09 to 0.17 ($p > 0.05$).

Table 10: Correlation strengths among survey items of engineering identity.

Engineering Identity Statements	eid1	eid2	eid3	eid4	eid5
eid1	1				
eid2	0.17	1			
eid3	0.09	0.68*	1		
eid4	0.17	0.37*	0.30*	1	
eid5	0.12	0.33*	0.38*	0.26*	1
** Indicates significant correlations*					

4.3.3. Belonging

Among the belonging statements, all correlations in the matrix were statistically significant at $p < 0.05$ (Table 11). The strongest correlation was observed between b3 and b5 ($\rho = 0.62$, $p < 0.05$), closely followed by b2 and b4 ($\rho = 0.61$, $p < 0.05$), and b4 and b5 ($\rho = 0.60$, $p < 0.05$), all indicating strong positive relationships. Moderate to strong correlations were found between b3 and b2 ($\rho = 0.40$, $p < 0.05$), b3 and b4 ($\rho = 0.53$, $p < 0.05$), and b1 and b5 ($\rho = 0.45$, $p < 0.05$). The weakest, yet still significant, correlations were observed between b1 and the other variables (ranging from $\rho = 0.28$ to $r = 0.45$, $p < 0.05$).

Table 11: Correlation strengths among survey items of belonging.

Belonging Statements	b1	b2	b3	b4	b5
b1	1				
b2	0.28*	1			
b3	0.31*	0.40*	1		
b4	0.29*	0.61*	0.53*	1	
b5	0.45*	0.38*	0.62*	0.60*	1
** Indicates significant correlations*					

4.3.4. Academic Self-Description

The correlation analyses to examine the relationships among the five survey statements of academic self-description revealed a mix of statistically significant and non-significant correlations, with varying strengths and directions (Table 12). The strongest positive correlation was observed between asd2 and asd4 ($\rho = 0.49$, $p < 0.05$). Other significant positive correlations included asd1 and asd4 ($\rho = 0.37$, $p < 0.05$), asd3 and asd4 ($\rho = 0.32$, $p < 0.05$), and asd2 and asd3 ($\rho = 0.30$, $p < 0.05$). Interestingly, asd3 showed a weak negative correlation with asd5 ($\rho = -0.20$, $p < 0.05$). The correlations between asd5 and the other variables were not statistically significant (ranging from $\rho = -0.10$ to $\rho = 0.02$, $p > 0.05$). The correlation between asd1 and asd2 ($\rho = 0.10$, $p > 0.05$) and asd1 and asd3 ($\rho = 0.16$, $p > 0.05$) were weak and not significant.

Table 12: Correlation strengths among survey items of academic self-description.

Academic self-description statements	asd1**	asd2	asd3	asd4	asd5
asd1**	1				
asd2	0.10	1			
asd3	0.16	0.30*	1		
asd4	0.37*	0.49*	0.32*	1	
asd5	-0.10	0.02	-0.20*	-0.06	1
** Indicates significant correlations*					

4.3.5. Perceived Competence

From the correlation tests of the five survey items of perceived competence (Table 13), the strongest positive correlation was observed between pc3 and pc2 ($\rho = 0.66$, $p < 0.05$). Other significant correlations included pc3 and pc1 ($\rho = 0.59$, $p < 0.05$), and pc2 and pc1 ($\rho = 0.44$, $p < 0.05$. The factor pc4 showed significant but moderate correlations with other variables, ranging from $\rho = 0.21$ to $\rho = 0.37$ ($p < 0.05$). The factor pc5 demonstrated significant correlations with all variables except pc3, but only small effect sizes. Interestingly, the correlation between pc3 and pc5 was not statistically significant ($\rho = 0.09$, $p > 0.05$), suggesting these two aspects of perceived competence may be relatively independent.

Table 13: Correlation strengths among survey items of perceived competence.

Perceived competence statements	**pc1**	**pc2**	**pc3**	**pc4**	**pc5**
pc1	1				
pc2	0.44*	1			
pc3	0.59*	0.66*	1		
pc4	0.37*	0.21*	0.28*	1	
pc5	0.25*	0.27*	0.09	0.34*	1
** Indicates significant correlations*					

4.3.6. STEM Intrinsic Value

The five survey items of STEM intrinsic value revealed statistically significant positive correlations between all items, with correlation coefficients ranging from moderate to strong (Table 14). The strongest correlations were observed between siv4 and siv3 ($\rho = 0.66$, $p < 0.05$), closely followed by siv4 and siv1 ($\rho = 0.64$, $p < 0.05$), and siv4 and siv5 ($\rho = 0.63$, $p < 0.05$). Strong correlations were also found between siv3 and siv5 ($\rho = 0.60$, $p < 0.05$), and siv3 and siv1 ($\rho = 0.57$, $p < 0.05$). Moderate correlations were observed between siv2 and siv3 ($\rho = 0.53$, $p < 0.05$), siv2 and siv1 ($\rho = 0.46$, $p < 0.05$), and siv2 and siv5 ($\rho = 0.45$, $p < 0.05$). The weakest, yet still moderate, correlation was between siv2 and siv4 ($\rho = 0.40$, $p < 0.05$).

Table 14: Correlation strengths among survey items of STEM intrinsic value.

STEM intrinsic value statements	siv1	siv2	siv3	siv4	siv5
siv1	1				
siv2	0.46*	1			
siv3	0.57*	0.53*	1		
siv4	0.64*	0.40*	0.66*	1	
siv5	0.41*	0.45*	0.60*	0.63*	1
** Indicates significant correlations*					

4.4. Discussion

The effect sizes obtained from the polychoric correlation analysis were interpretated as suggested by Cohen (1988) specifically for psychological constructs. The analysis of the underling constructs of engineering self-concept revealed diverse effect sizes.

Resilience demonstrated a positive low to strong effect for items r1, r2, r3, and r4, while r5 indicated a very weak to moderate negative effect size. The moderate to strong positive correlations among r1, r2, r3, and r4 suggest that these statements may be capturing related facets of resilience. The negative correlations and/or insignificant correlations of r5 with other statements, particularly r4, suggest that r5 may be measuring a distinct or even opposing aspect of resilience compared to the other statements.

Engineering identity exhibited moderate to strong effect sizes for eid2, eid3, eid4, and eid5, with eid1 showing very weak effect sizes. The varying strengths of correlations between eid2, eid3, eid4, and eid5 suggest that these items are capturing a multifaceted construct with both interconnected and distinct components. The lack of significant correlations between eid1 and the other statements particularly indicates that eid1 may be measuring a unique construct differing from Engineering Identity.

Belonging consistently displayed moderate to strong effect sizes across all five of its underlying items. The coherence in this construct is evident in the cluster of strong correlations among b1, b2, b3, b4, and b5, which may indicate that a core component of the construct is being measured. Since some correlations were weak to moderate, yet statistically significant, it can be interpreted that they may be capturing a closely related aspect of construct.

Academic self-description presented moderate effect sizes for asd2, asd3, and asd4, whereas asd1 and asd5 showed very weak effect sizes. The significant relationships with moderate effect sizes between asd2, asd3, and asd4 suggest that while these items are measuring related but distinct components of the same construct. The lack of significant correlations between asd1 and asd5 and the other variables supports the notion that it may be capturing a unique construct than academic self-description, and does not exactly align with the other items.

In the case of perceived competence, pc5 had a very weak to moderate effect size, while pc1, pc2, pc3, pc4, and pc5 demonstrated moderate to strong effect sizes. The factor pc5 displayed weaker connections, specifically due to the insignificant connection with pc3. All other items indicated moderate to strong relationships that were statistically significant, suggesting that they are measuring overlapping aspects of a construct.

Notably, STEM intrinsic value exhibited strong effect sizes consistently across all its items (siv1, siv2, siv3, siv4, and siv5). The overall pattern of correlations for STEM intrinsic value items, with all falling in the medium to large effect size range, suggests a coherent structure among these variables. The variations in correlation strengths also indicate that each variable contributes unique information, supporting the multidimensional nature of the construct STEM intrinsic value.

4.5. Refining the Survey Instrument

The polychoric correlation tests helped validate and refine the instrument to assess engineering self-concept among first-year undergraduate students, enhancing its construct validity. Survey statements r5, eid1, asd1, asd5, pc5, were removed due to their weak and insignificant correlations with other items within the construct, ensuring only the strong and moderately strong correlated statements are retained (listed in Table 15). The nuanced correlations among the survey statements of each of the sub-constructs discussed above supported the need to refine the overall instrument. The varying strengths of correlations within and between constructs support the multifaceted nature of engineering self-concept, highlighting the importance of measuring these distinct yet interrelated aspects separately. This refined model provides a strong foundation for the next step, validating the conceptual model of engineering self-concept through confirmatory factor analyses.

Table 15: Refined survey instrument for engineering self-concept.

Sub-Construct	Acronym for Reference	Survey Statement
Resilience	r1	I can achieve goals despite obstacles.
	r2	I am able to adapt to change.
	r3	I can deal with whatever comes.
	r4	I think of myself as a strong person.
Engineering identity	eid2	It matters to me how I do in engineering.
	eid3	Your own sense of who you are (your personal identity) overlaps with your sense of who an engineer is (identity of an engineer).
	eid4	I am fully committed to getting my college degree in engineering.
	eid5	I think that earning a bachelor’s degree in engineering is a realistic goal for me.
Belonging	b1	I can relate to the people around me in my class.
	b2	I feel that I am a member of the engineering community at my institution.
	b3	The other students in my classes share my personal interests.
	b4	I see myself as a part of the engineering community at my institution.
	b5	I have a lot in common with the other students in my classes.
Academic self-description	asd2	My study habits are poor.
	asd3	I often expect to do poorly on exams.
	asd4	I schedule my study time well.
	pc1	I can excel in an engineering major during the current academic year.

Perceived competence	pc2	I can succeed in an engineering curriculum.
	pc3	I can persist in an engineering major during the next year.
	pc4	I may not do well in my major.
STEM intrinsic value	siv1	The future benefits of studying engineering are worth the effort.
	siv2	I expect that studying engineering will be rewarding.
	siv3	I expect that engineering will be a rewarding career.
	siv4	A degree in engineering will allow me to get a job where I can use my talents and creativity.
	siv5	A degree in engineering will allow me to obtain a job that I like.

Chapter 5 – Validating the Theoretical Framework of Engineering Self-Concept

This chapter discusses the validation of the theoretical framework of engineering self-concept developed in the prior chapters. Figure 5 captures the portion of the conceptual model illustrating engineering self-concept and the hypothesized six key constructs. Through an analysis of the pre-existing literature (Chapter 2), survey items were identified to assess each construct, and a comprehensive instrument was developed to assess engineering self-concept (Chapters 3 and 4). This chapter details the statistical validation of the conceptual model based on responses to the engineering self-concept survey.

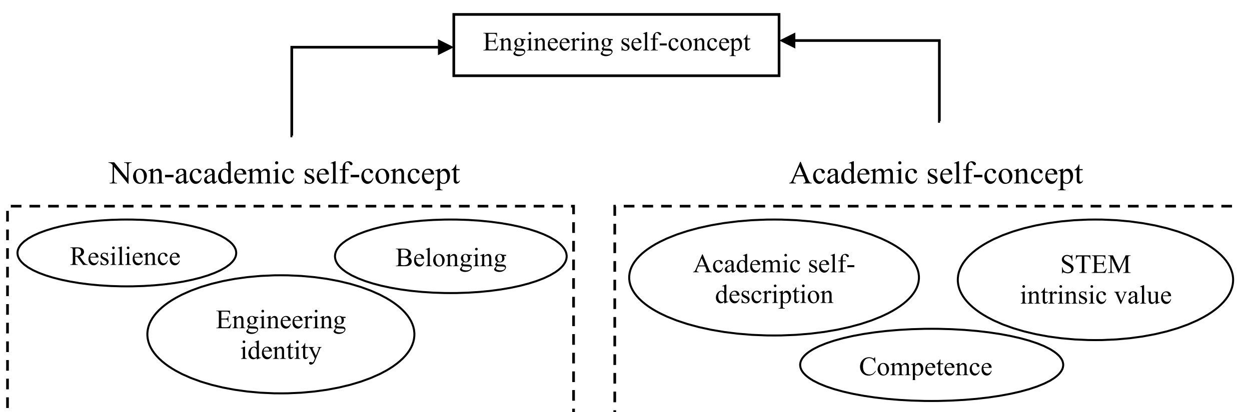


Figure 5: Conceptual model of engineering self-concept.

5.1. Methods

The validation of the theoretical framework relied on the same data set used in Chapter 4 for validation of survey items. Survey data were sampled from the 841 first-year engineering students enrolled in a semester-long engineering orientation class, out of which 113 responses were received. The survey was administered during weeks 9, 10, and 11, which was the middle of a 16-

week semester. Responses were recorded on a 6-point Likert scale (ranging from strongly disagree to strongly agree), yielding ordinal data.

5.1.1. Analysis Approach

Confirmatory Factor Analyses (CFA), a type of structural equation model, was used to examine the validity of the proposed conceptual model. CFA is understood as an iterative procedure (Kline, 2016) to achieve a good model fit as well as strong factor loadings. It is a method that allows modeling of observed and latent factors: Observed factors are those recorded using an instrument, while latent factors are theorized to be predicted and influenced by the observed factors. In this research, the observed factors are the six sub-constructs theorized to influence the latent factor of engineering self-concept.

Intermediary categorization of the sub-constructs into academic and non-academic facets can be represented using a bi-factor modeling structural equation model (Gibbons, 2014). Gibbons (2014) explains that the multidimensionality of certain constructs (e.g., engineering self-concept) is caused because its underlying sub-constructs are sampled from multiple domains (e.g., resilience, belonging, engineering identity) of a broad psychological construct (e.g., non-academic self-concept). The bi-factor model has both observed and latent factors, but considers two different types of latent factors – general and specific (hence, bi-factor). It assumes that the intercorrelations of the observed factors are explained by both the general and specific latent factors, as a "joint association" (Chen et al., 2006; Gibbons, 2014). Figure 6 shows a visual representation of the statistical bi-factor model. The observed factors are the six sub-constructs of engineering self-concept; engineering self-concept is the general factor, while academic and non-academic self-concept are the specific factors.

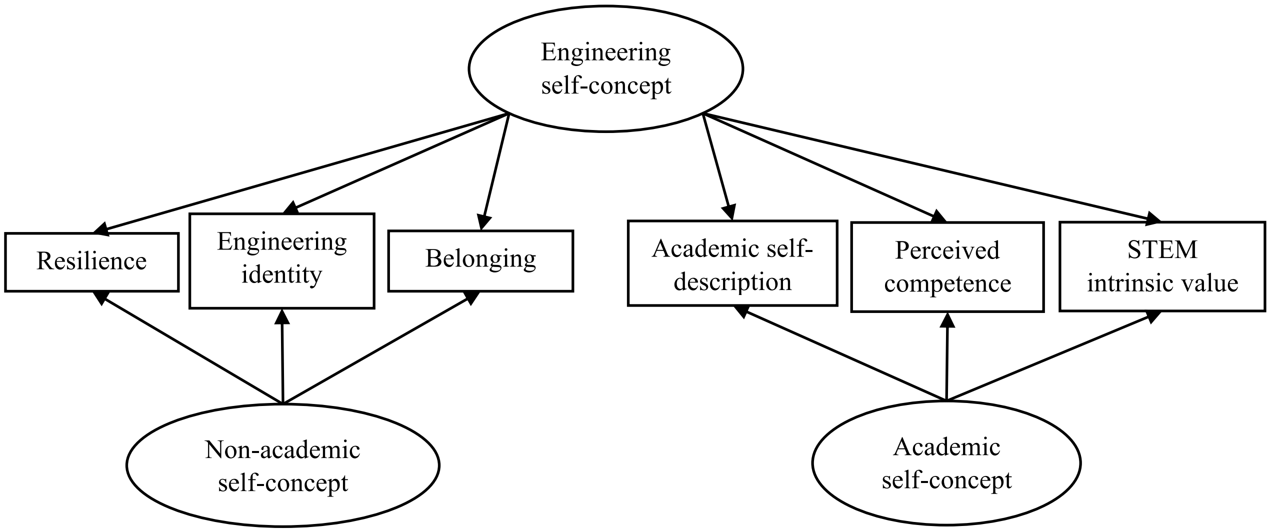


Figure 6: Hypothesized model for engineering self-concept.

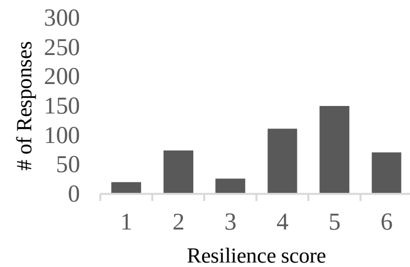
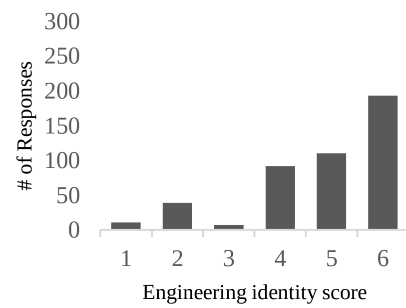
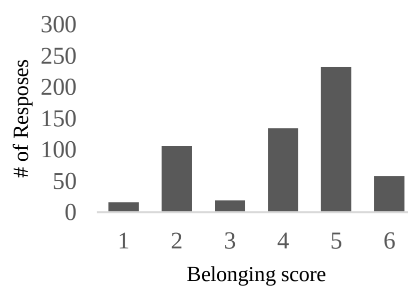
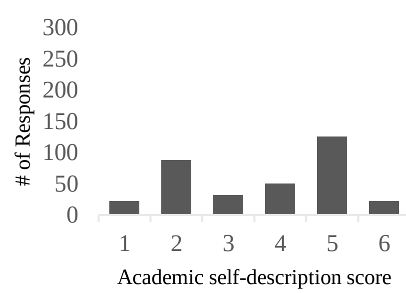
This statistical representation of the hypothesized model has a few distinctions from the conceptual model shown earlier in Figure 5. The shapes that are used to represent all the factors have been altered, consistent with common practice. In the conceptual model, all arrows flowed upwards to represent that engineering self-concept is influenced by the underlying sub-constructs. The intermediary categorization into academic and non-academic facets was indicated by dotted lines so as to simplify the representation. The statistical representation as a Bi-Factor model accounts for both the general factor and the intermediary categorization. It represents the relationship between the variables through joint variance of the general and specific latent factors on the observed factors, shown as arrows pointing towards the observed factors.

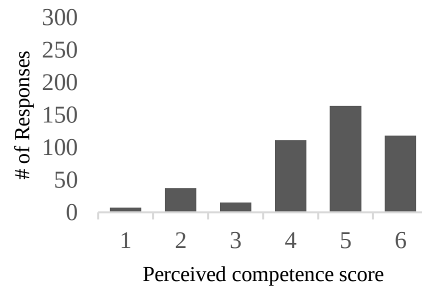
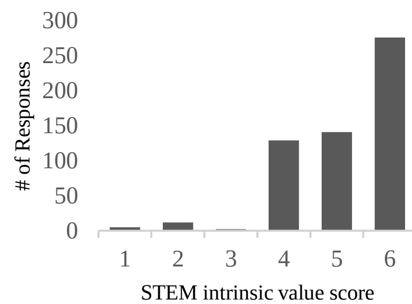
Performing a CFA on ordinal data is not a straightforward process using the traditional maximum likelihood estimation method (Flora & Curran, 2004; Li, 2015). Using CFA is unique to each research scenario, and hence requires some “fit-trials”. Research suggests that different estimation methods should be applied to check which method produces a convergent solution. These “fit-trials” must happen in the order of weighted least squares (WLS), robust weighted least squares (RWLS), and then diagonally weighted least squares (DWLS) estimation methods (Flora & Curran, 2004; Li, 2015). WLS is the most complex and assumption-heavy method among the three, and assumes that the observed variables have a multivariate normality. If WLS fails, moving to RWLS provides a more robust alternative because it is less sensitive to violations of multivariate normality. DWLS is the simplest and most stable of the three methods, and can provide reliable estimates when WLS and RWLS fail, particularly in the presence of skewed data (Flora & Curran, 2004; Li, 2015). By adhering to this sequence of "fit-trials", researchers can ensure they are using the most appropriate estimation method for their data, leading to more reliable and defensible results in structural equation modeling studies.

5.2. Results

The CFA was performed in SAS statistical software suite using the PROC CALIS procedure. Table 16 reports the descriptive statistics computed for the observed factors in this study, with histograms representing response distribution of all survey items within each observed factor. Model fit and factor loadings obtained for the final "fit-trial" using DWLS are illustrated in this section for presentation simplicity. Note that mean ratings were fairly consistent across observed factors with only academic self-description falling below "moderately agree" (i.e., 4.0 rating). STEM intrinsic value was rated highest between "agree" and "strongly agree" while also revealing the lowest variability among raters. The distributions of rating for each observed factor showed lack of normality, thus confirming use of DWLS.

Table 16: Descriptive statistics and plots.

Observed Factors	Mean	Median	Standard Deviation	Distribution
Resilience	4.13	4	1.43	
Engineering identity	4.84	5	1.35	
Belonging	4.12	5	1.36	
Academic self-description	3.69	4	1.5	

Perceived competence	4.64	5	1.22	
STEM intrinsic value	5.15	5	1.02	

Two iterations of analysis were performed, examining the model fit with factor loadings, and eliminating the predictors that did not load strongly on the high-level latent factor. However, it must be noted that although each iteration produced a convergent solution and had a high fit index, the iterations were key in producing stronger factor loadings, and ultimately a more robust model fit. For the current analysis, the suitable fit indices are Goodness of Fit Index (GFI) and Adjusted Goodness of Fit Index (AGFI), because they represent the obtained and implied covariance among the factors (West et al., 2012). The factor loadings were examined in addition to the fit indices to determine the strength of the relation between the sub-constructs (observed variables), the specific factors, and the general factor. A factor loading of 0.3 was established as the threshold for classifying acceptable (strong) versus unacceptable (weak) loadings among the factors. For interpretation, loadings between 0.3 and 0.6 are interpreted to be moderate and strong for a loading above 0.6 (Jennrich & Bentler, 2011).

The first iteration of a DWLS CFA obtained a high (favorable) fit index (*GFI = 0.9521, AGFI = 0.9372*). However, some factor loadings were below the threshold of 0.3 indicating they are poor predictors of the latent variables.

Table 17: Factor loadings between observed and latent variables: Iteration #1.

Acronym	**Non-academic self-concept**	**Academic self-concept**	**Engineering self-concept**
r1	0.2217	0	0.5108
r2	0.2159	0	0.1860
r3	0.2467	0	0.4808
r4	0.2668	0	0.5670
eid2	-0.1984	0	0.7787
eid3	-0.1836	0	0.8074
eid4	0.1544	0	0.4123
eid5	-0.3348	0	0.6413
b1	-0.2765	0	0.4125
b2	-0.6690	0	0.5501
b3	-0.8502	0	0.4025
b4	-0.8092	0	0.6363
b5	-0.7290	0	0.4807
asd2	0	-0.8495	0.3745
asd3	0	-0.6895	0.3717
asd4	0	-0.6961	0.3445
pc1	0	-0.3312	0.6265
pc2	0	-0.1746	0.4452
pc3	0	-0.0876	0.7876
pc4	0	-0.3966	0.4202
siv1	0	0.0635	0.6053
siv2	0	0.1374	0.5222
siv3	0	0.4115	0.5799
siv4	0	0.1249	0.5237
siv5	0	0.1201	0.6316

Interpretations in this iteration are twofold. First, some observed factors (i.e., r1, r3, r4, eid2, eid3, eid4, b1, pc2, pc3, siv1, siv2, siv4, and siv5) were found to load weakly onto the specific factor, while having strong loading with the general factor. All such variables were further formulated to only load onto the general factor, and their relationship with the specific factors was removed from future iterations. Second, the observed variable r2 displayed low factor loadings onto both the specific and general factors. This specific variable was removed entirely from the model as it demonstrated weak connections with both the latent variables in focus.

Iteration #2 was then performed after adjusting the model. This second iteration of the DWLS CFA also resulted in a strong model fit (*GFI = 0.9449, AGFI = 0.9315*). All factor loadings (listed in Table 18) of the observed variables included were found to be above the set threshold.

Table 18: Factor loadings between observed and latent variables: Iteration #2.

Acronym	Non-academic self-concept	Academic self-concept	Engineering self-concept
r1	0	0	0.4586
r3	0	0	0.4373
r4	0	0	0.5125
eid2	0	0	0.8326
eid3	0	0	0.8489
eid4	0	0	0.3914
eid5	0.3630	0	0.6278
b1	0	0	0.4490
b2	0.6770	0	0.5347
b3	0.8538	0	0.3768
b4	0.9125	0	0.5863
b5	0.7267	0	0.4539
asd2	0	0.8663	0.3599
asd3	0	0.6500	0.3594
asd4	0	0.8548	0.3234
pc1	0	0.3010	0.6391
pc2	0	0	0.4521
pc3	0	0	0.8089
pc4	0	0.4070	0.4093
siv1	0	0	0.6215
siv2	0	0	0.5313
siv3	0	-0.3257	0.5721
siv4	0	0	0.5180
siv5	0	0	0.6199

Non-academic self-concept exhibited strong loadings for items b2 through b5, ranging from *0.6770* to *0.9125*. This indicates that these items are robust indicators of non-academic self-concept. Academic self-concept showed strong loadings for items asd2 (*0.8663*), asd3 (*0.6500)*, and asd4 (*0.8548*). Interestingly, pc4 and siv3 showed moderate loadings (*0.4070* and *–0.3257* respectively) on academic self-concept, prompting a deeper investigation is needed of the negatively loading item. Several items loaded onto the specific and general factors, supporting their multi-faceted nature. For instance, eid5 loaded strongly onto engineering self-concept (*0.6278*) and moderately onto non-academic self-concept (*0.3630*). Similarly, b2 through b5 showed moderate loadings on engineering self-concept in addition to their strong loadings on non-academic self-concept.

As predicted with the model, belonging mostly loaded to non-academic self-concept and engineering self-concept. Academic self-description loaded to academic self-concept and engineering self-concept. For other factors, only individual items were found to be meaningful. The model fit indices in both iterations demonstrated strong overall fit. The two iterations of the bi-factor model CFA allowed identification of a model with strong factor loadings, and thus a robust survey instrument to assess engineering self-concept.

This approach aligns with best practices in structural equation modeling, which emphasize the importance of both overall model fit and the strength of individual parameter estimates (Kline, 2016). The refined model is statistically represented in Figure 7, with details of specific survey items and their loadings indicated by the arrow direction. For instance, in Figure 7, variance of only four of the items for belonging is explained by both general and specific latent variables.

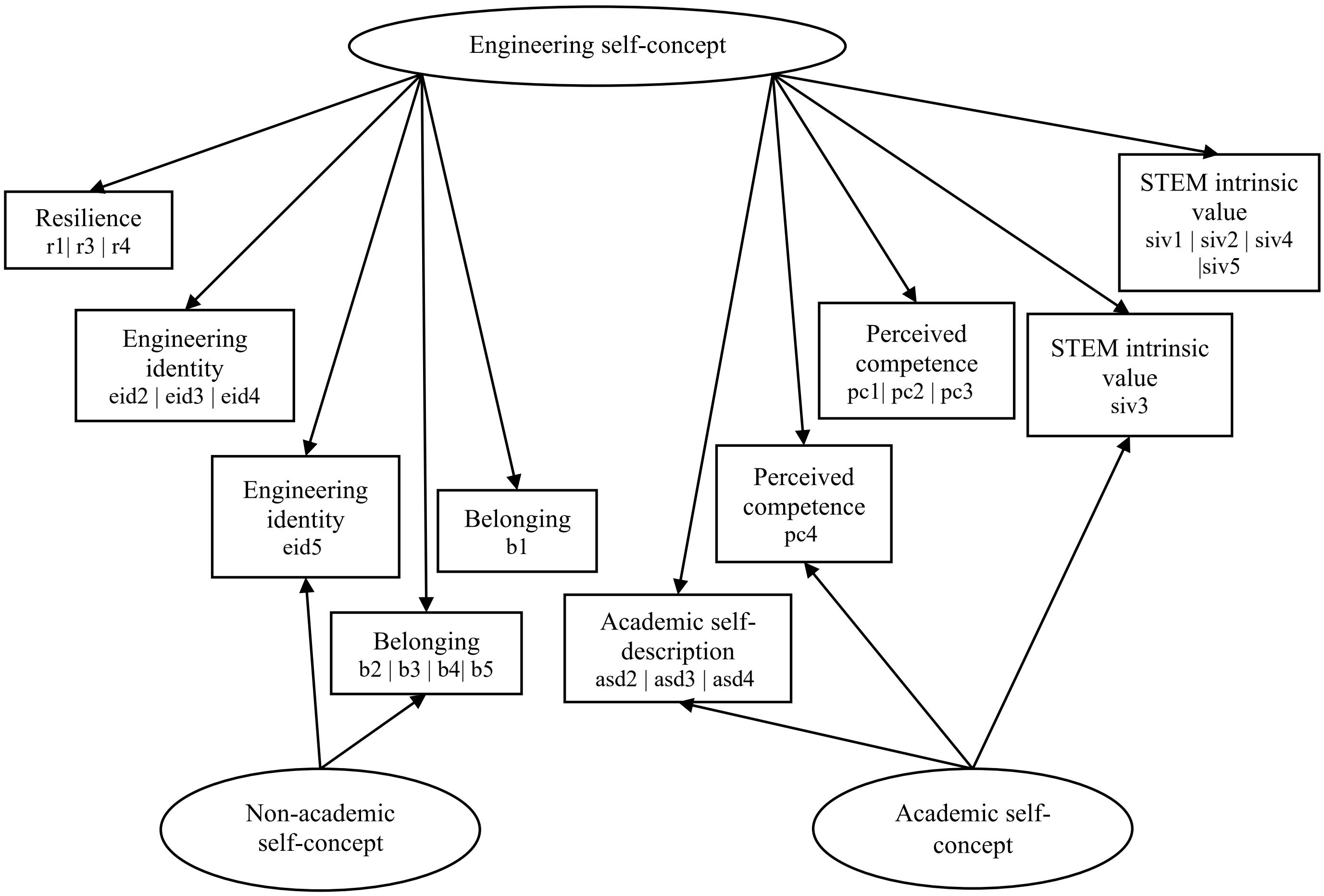


Figure 7: Validated model for engineering self-concept after iteration #2.

While Figure 7 provides a robust framework to assess engineering self-concept, the corresponding survey instrument includes twenty-four statements. Additional iterations were performed seeking to identify a more parsimonious model while retaining the model's explanatory power.

Iteration #3 aimed to further strengthen the survey instrument for practical applications. This iteration was performed by adjusting the factor loading threshold to 0.5 and removing the categorization of specific latent factors, retaining only factors that directly load onto engineering self-concept. The third iteration of the DWLS CFA also resulted in a strong model fit (*GFI* =

0.9591, AGFI = 0.9427). All factor loadings (listed in Table 19) of the observed variables included were found to be above 0.5 except for r4.

Table 19: Factor loadings between observed and latent variables: Iteration #3

Acronym	Engineering self-concept
r4	0.4119
eid2	0.8488
eid3	0.8977
eid5	0.6811
b2	0.6622
b4	0.7287
pc1	0.5866
pc3	0.7199
siv1	0.6593
siv2	0.5613
siv3	0.5736
siv4	0.5408
siv5	0.6170

The final iteration removed the one observed factor (r4) that had a loading less than 0.5 onto the latent factor. The fourth iteration of the DWLS CFA provided the strongest model fit (*GFI = 0.9721, AGFI = 0.9597*), and factor loadings of the observed variables included were found to be above 0.5 (Table 20). The resultant model is presented in Figure 8.

Table 20: Factor loadings between observed and latent variables: Iteration #4

Acronym	Engineering self-concept
eid2	0.8250
eid3	0.8880
eid5	0.6957
b2	0.6760
b4	0.73000
pc1	0.5553
pc3	0.6582
siv1	0.6873
siv2	0.5814
siv3	0.6115
siv4	0.5718
siv5	0.6018

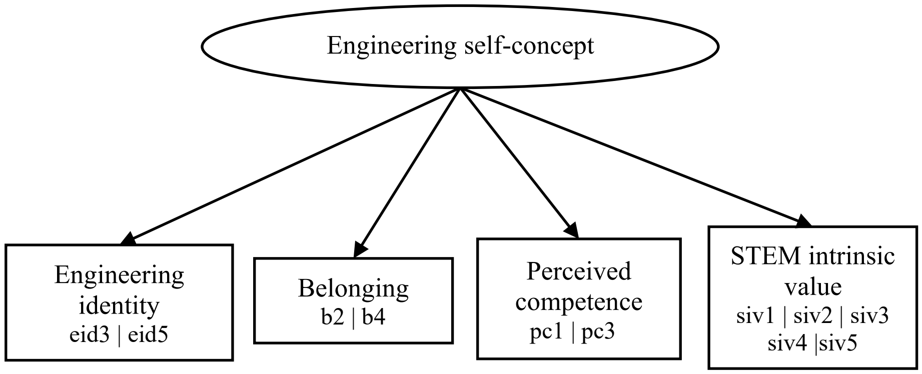


Figure 8: Simplified model of engineering self-concept.

By iteratively refining the model, a balance was achieved between model parsimony and explanatory power, ensuring that each observed variable contributes meaningfully to its respective latent construct while maintaining excellent overall model fit. All models were strong (Table 21) and the reduction in observed factors by iteration #4 provided the best model fit.

Table 21: Model fit indices of the engineering self-concept model for iterations 1 to 4.

Iteration	GFI	AGFI
#1	0.95	0.937
#2	0.94	0.93
#3	0.96	0.94
#4	0.97	0.96

5.3. Discussion

The goal of this research was to build a framework to measure engineering self-concept. Prior studies have measured self-concept by adopting instruments and concepts that were established in the field of educational psychology. Building a framework and an instrument to measure self-concept in engineering offers contextual validity given the multifaceted and multidimensional structure of self-concept.

The iterative confirmatory factor analyses revealed strong fit indices across both iterations, with the final model achieving a GFI of *0.97* and a AGFI of *0.96*. These values exceed the recommended thresholds (Hooper et al., 2008), supporting the validity of the engineering self-concept framework. The iterative refinement process allowed optimization of the model while maintaining a strong model fit, demonstrating the robustness of the underlying construct.

The bi-factor structure provided unique insights into the multidimensional nature of the construct. The modification of allowing items to load on both general and specific factors, was able to disentangle the shared and unique variances associated with the general and specific factors. The analysis suggests a complex factor structure for the framework of engineering self-concept. The general factor, engineering self-concept, showed strong to moderate associations across all of the survey items, and by extension the underlying sub-constructs.

However, the specific factors, academic and non-academic self-concept, have stronger relationships only with some of the observed variables. Not all hypothesized intermediary categorizations found statistical validation. Only belonging and academic self-description, assigned to non-academic and academic self-concept, respectively, were observed to have strong associations with both their general and specific factors. This finding highlights the critical role of belonging in shaping individuals' perceptions of themselves in non-academic contexts, and underscores the interconnectedness of social and academic identities in engineering. In the case of both academic self-description and belonging, the factor loadings strengthen the hypothesized multifaceted relationship with engineering self-concept.

All other observed variables, with a few exceptions (eid5, pc1, pc4 and siv3), were only found to be related to the general factor, engineering self-concept. These anomalies also showed moderate association with the factors. Engineering identity was observed to be loading onto the general factor with strong to moderate loadings, with the exception of eid5. This relationship suggest that engineering identity is a factor that has strong ties with engineering self-concept, and not entirely fit with the bi-factor representation. Factor loadings of perceived competence pc1 and pc4 are the only aspects of perceived competence that are influenced by the specific factor. However, siv3 represents a moderate negative relationship with its specific factor, while having a strong positive relationship with the general factor. Further investigations can be performed in this area to study this negative relationship of siv3. Overall, the framework suggested distinct facets within engineering self-concept, with some limitations. This resultant model, displayed in Figure 7, is theoretically robust and will be used in further evaluations in the following chapters.

On the other hand, the parsimonious model derived from iterations 3 and 4 offers significant advantages in terms of practical application and usability, primarily due to its condensed factor structure. This streamlined approach not only simplifies the assessment process but also enhances the overall reliability of the instrument. The robust factor loadings observed across the twelve survey items effectively blur the boundaries between sub-constructs and intermediary categorizations, resulting in a more cohesive and unified measure of engineering self-concept. Notably, as illustrated in Figure 8, the final model incorporates only four of the six initially proposed sub-constructs, suggesting that the essence of engineering self-concept can be effectively captured with fewer, more comprehensive factors. This refinement not only increases the model's parsimony but also potentially enhances its predictive power.

The findings extend the current theoretical understanding of self-concept by strengthening its validity in the domain of engineering education. Results of CFA align with the distinctions made about the properties and characteristics of self-concept as studied in Chapter 2. It suggests that evaluation of engineering self-concept should consider a broad approach including academic and non-academic factors. The instrument based on this framework (listed in Appendix A) provides comprehensive insights into a student's self-perceptions, with potential applications in early identification of areas that need support. The engineering self-concept framework has practical implications broadly for the field of engineering education.

Chapter 6 – Relating Engineering Self-Concept to Engineering Self-Efficacy

The systematic review of literature conducted in Chapter 2 established self-efficacy as the expectancy to perform in an upcoming task. The literature review also found varied assessments of self-efficacy across disciplines, demonstrating the operational definition of self-efficacy that is based on task specificity.

Task specificity is found to be the key in differentiating self-efficacy from self-concept. Self-concept refers to one's ability and standing in a domain. Its multifaceted nature allows it to extend into different domains based on the individual's involvement and experience. For the current research, engineering self-concept of an undergraduate student is their perceived ability within the domain, and it extends further branches as the student enrolls in various technical or engineering related classes. Overall, the crucial point for this construct is its domain specificity.

The current chapter attempts to establish the hypothesized relationship between engineering self-concept and engineering self-efficacy. The model obtained after iteration #2, shown in Figure 7 is being utilized here due to its theoretical strength, with multifaceted representation of engineering self-concept. It is hypothesized that the domain specific construct, engineering self-concept, influences the task specific construct, engineering self-efficacy. The prior illustration of the framework has now been extended to show the hypothesized relationship between the two constructs (Figure 9). This chapter describes the development and validation of an instrument to test this relationship and the statistical assessment of the model.

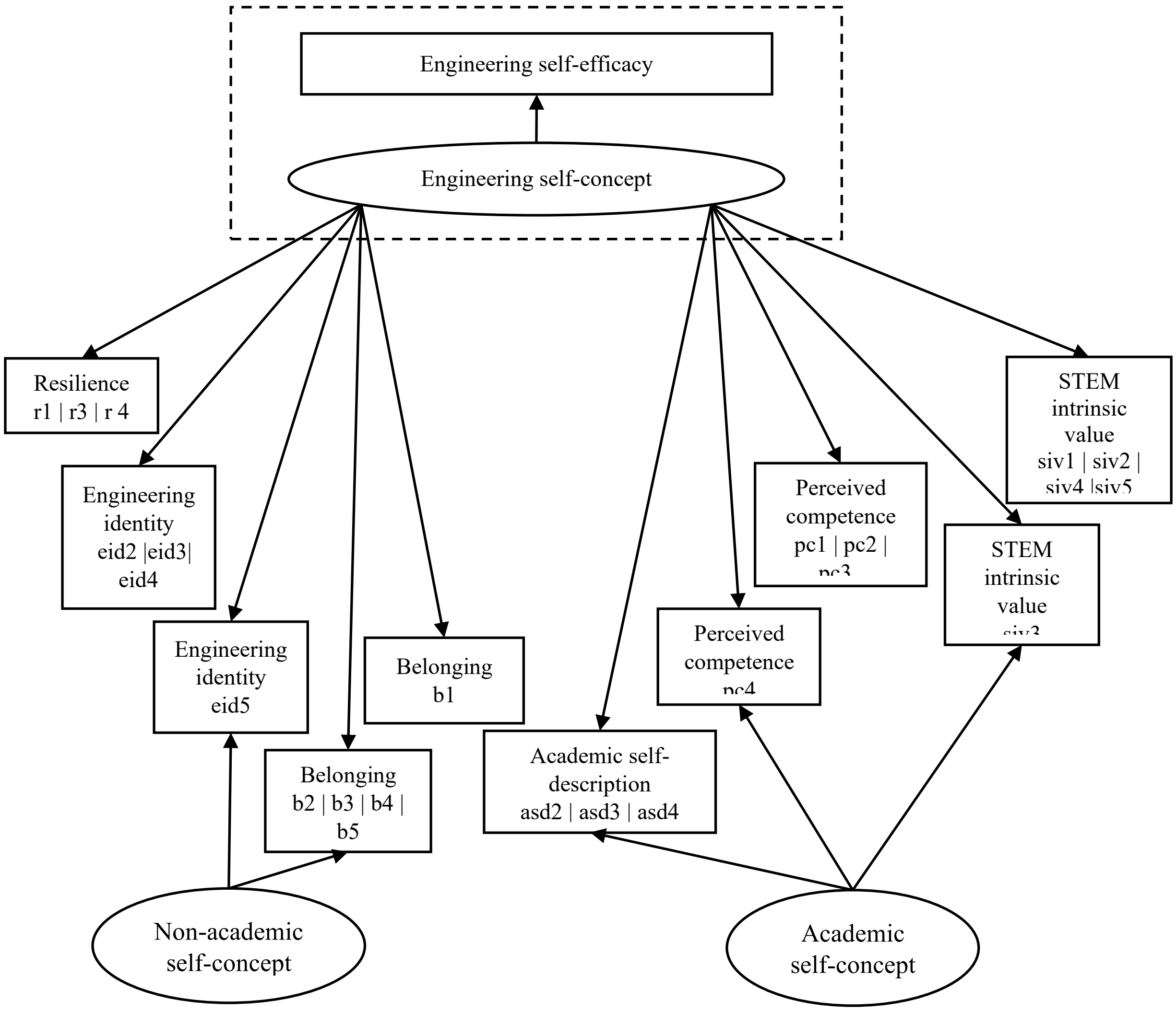


Figure 9: Framework of engineering self-concept with extension to engineering self-efficacy.

6.1. Methods and Results

Data for this analysis were collected during weeks 14 and 15, i.e., the final weeks of a 16-week long semester. The sample population was 841first-year undergraduate students enrolled in an engineering orientation class, at a predominantly white midwestern institution. For this specific test, a within subjects approach was used and the sample was narrowed down to students who responded to both the engineering self-concept and self-efficacy surveys. A total of 77 responses were received, which were used to test the relationship between engineering self-concept and task-related engineering self-efficacy.

6.1.1. Survey Instrument

The self-efficacy survey used in this analysis was adapted from Mamaril, et al. (2016). Mamaril, et al.'s (2016) instrument for self-efficacy presents the construct in two categories: general engineering self-efficacy and engineering skills self-efficacy. The latter was further categorized into experimental, tinkering and design self-efficacy. The survey items validated by Mamaril, et al. (2016) for experimental self-efficacy were sampled and adapted. Adaptation was done so to make the statements align with the learning outcomes of the engineering orientation class (listed in Appendix C). Table 19 shows the original statements by Mamaril, et al. (2016) and the adapted version of each. The adapted survey (Table 22) collects responses on a 6-point scale (1 – strongly disagree, 2 – disagree, 3 – moderately disagree, 4 – moderately agree, 5 – agree, 6 – strongly agree), and was shared through a QR code printed on flyers distributed in the engineering orientation class. Seventy-seven responses were received for this survey.

Table 22: Survey statements adapted for engineering self-efficacy.

Survey Item	Original Statement	Adapted Statement
ese1	I can perform experiments independently	I can perform engineering design projects independently
ese2	I can analyze data resulting from experiments	I can analyze feedback to improve an engineering design project
ese3	I can orally communicate results from experiments	I can orally communicate results of engineering projects
ese4	I can communicate results from experiments in written form	I can communicate results of engineering projects in a written report
ese5	I can solve problems using a computer	I can solve engineering problems ethically

6.1.2. Validating the Instrument

There is a limited body of research that supports the adaptation of survey items by just modifying the action words of the statement, without affecting the validity of the overall instrument (Korb, 2012). However the the adapted survey instrument was evaluated for validity using a correlation analysis since this research is part of a larger framework, and failing to validate each step begins to jeopardize its overall validity. Polychoric correlations (suitable for ordinal data) were examined between each of the survey items in Table 19 to determine whether they are all interrogating the same construct. All correlations in the matrix (Table 23) were statistically significant, as indicated by the asterisks (*). High correlation coefficients (ranging between 0.58 and 0.93) suggest a substantial interrelatedness among the items, which indicate that they measure aspects of the underlying construct, task-related engineering self-efficacy.

Table 23: Correlation strengths among survey items of engineering self-efficacy.

Survey Items	ese1	ese2	ese3	ese4	ese5
ese1	1				
ese2	0.75*	1			
ese3	0.77*	0.59*	1		
ese4	0.72*	0.83*	0.78*	1	
ese5	0.63*	0.79*	0.58*	0.93*	1
** indicates significant correlation*					

The strongest correlation (r = 0.93) was observed between ese4 and ese5, indicating a very strong positive relationship between these two variables and suggesting that these variables may be measuring similar or overlapping aspects of the construct. Ese4 demonstrates strong correlations with all other variables (0.72 to 0.93), further reinforcing its potential importance in the overall construct. Ese1 also shows consistently strong correlations with all other items (ranging from 0.63 to 0.77), suggesting it may be a central or core element of the construct being measured. Even weakest correlation in the matrix, is moderately strong (between ese3 and ese5 (r = 0.58)).

The pattern of strong correlations suggests a high degree of internal consistency among the items used to measure engineering self-efficacy. These results are indicative of a strong construct validity for the instrument.

6.1.3. Analyzing the Relationship

This study used a confirmatory factor analysis with diagonally weighted least squares (DWLS) to understand the relationship between engineering self-concept and engineering self-efficacy. This analysis tool is the most suitable when we are testing for relationships involving observed and latent variables, that are derived from theory. In this case, the literature reviewed in Chapter 2 supports the hypothesized relationship between the domain specific and task specific constructs. Additionally, the DWLS is the most practical choice when dealing with ordinal data as was tested in Chapter 5.

For the current analysis, task-related engineering self-efficacy is the observed variable, and engineering self-concept is the latent variable. This test was performed on the repeated sample that responded to both the engineering self-concept survey (weeks 9, 11, and 12) and the engineering self-efficacy survey (weeks 14 and 15). The sample size of these repeated responses is 77. The timeline for the data collected is supported by research that regards self-concept is stable and self-efficacy as relatively volatile and varies based on preparation for the task in consideration. The results of the analysis are displayed in Table 24. Thus displaying that engineering self-efficacy can partially explained by engineering self-concept.

Table 24: Factor loadings between engineering self-efficacy and engineering self-concept.

Engineering Self-Efficacy (Observed)	Engineering Self-Concept (Latent)
ese1	0.4053
ese2	0.4622
ese3	0.3822
ese4	0.5019
ese5	0.4566

The model fit was found to be strong, with GFI of *0.9831* and AGFI of *0.9367,* and factor loadings obtained for the five survey items assessing engineering self-efficacy ranged between 0.3822 and 0.5019. Based on Cohen's (1988) guidelines for statistical power, these factor loadings indicate a moderate relationship between engineering self-concept and engineering task-related self-efficacy. The moderate relationship means that engineering self-concept and task-related self-efficacy are related constructs, but they are not identical or completely overlapping.

6.2. Discussion

The confirmatory factor analysis suggests a moderate correlation between engineering self-concept and engineering self-efficacy, suggesting that these constructs are related yet distinct. This consistency across items supports the proposed hierarchical relationship between the two (model in Chapter 2, Figure 3). The strength of the relationship implies that as a student develops a stronger engineering self-concept, they are likely to also experience increased confidence in their ability to perform specific engineering tasks.

However, the relationship is not strong enough to suggest that improvements in one construct will automatically lead to substantial improvements in the other. This also supports the distinction made in the proposed model: engineering self-concept is domain specific and engineering self-efficacy is task specific. Engineering self-concept is likely to be more stable and influenced by long-term factors like overall performance in the domain, social influences, and practical experiences in the domain. In contrast, task-related engineering self-efficacy may fluctuate more readily based on recent experiences, perceived stress or difficulty for an upcoming task, and one’s preparation for it.

Chapter 7 – Examining Engineering Identity Status Transitions During the First Semester in an Engineering Program

7.1. Introduction

A large body of research has documented that engineering identity is strongly related to retention and persistence in engineering students (Pierrakos et al., 2009; Bergerson et al., 2014; Perez et al., 2014; Patrick et al., 2018; Hughes et al., 2019; Burleson et al., 2021; Doran & Swenson, 2022). For the sake of interpretation in this paper, retention and persistence are considered analogous to each other. Engineering identity plays a key role in addressing the retention of engineering students, by building an individual's interest and intention to commit to engineering, and the motivation to apply engineering in their professional life. A systematic review of literature conducted on engineering identity (Morelock, 2017) documented the construct in diverse ways, such as professional identity and technical identity, highlighting its multidimensionality. Engineering and professional identity have been linked to prolonged participation (Ross et al., 2021), predicting the career choice (Godwin et al., 2016), and the grit of students (Verdin et al., 2018), within engineering.

Gathering from the research, it was found that identity is a developmental construct that is also multidimensional, i.e., it can be measured with multiple underlying factors. It is a trait that can be developed systematically through various stages. Marcia (1966) introduced an ego identity development model as a multi-avenue framework that considers identity development within avenues such as occupation, religion, and politics. With the evolution of identity development status research over the years, new avenues were introduced (Bennion & Adams, 1986), and hence philosophical life-style, sex roles, friendship, recreation, and dating, emerged as additional avenues of identity status. Marcia (1966) postulated that the proposed avenues operate independently, e.g., an individual could have performed a thorough exploration regarding a lifestyle choice and made a commitment about the way they want to live, while at the same time the individual may not have done extensive exploration about occupational choice and is on the fence about committing to an occupation. Identity in each of these avenues was found to be developed through the exploration and commitment processes. Based on where one is in those processes, identity development can be classified as one of 4 statuses: achieved, foreclosed, moratorium, and diffused.

Table 25 visually represents Marcia's (1966) framework. An individual is said to have an *achieved* identity within an avenue if they have undergone a period of exploration and made informed commitments within that avenue. A *foreclosed* identity manifests when a commitment is imposed on the individual by a near peer(s) or person(s) of authority who claims to know the individual, and hence knows what is suitable for them. This status implies that the individual has done little to no exploration regarding the available options, but has committed to the suggestion of their peers. *Moratorium* identity status refers to the process of ongoing exploration and seeking out available opportunities. It implies that an individual has not made a firm commitment, and this status is often a precursor to achieved identity. *Diffused* identity status refers to a status of apathy and indifference, where an individual is neither interested in making a commitment nor in exploring any available prospects.

Table 25: Identity statuses according to Marcia's (1966) model.

<table>
<tr><th colspan="3">Identity Status Quadrant</th></tr>
<tr><th rowspan="2">Exploration</th><th colspan="2">Commitment</th></tr>
<tr><th>Yes</th><th>No</th></tr>
<tr><th>Yes</th><td>Achieved</td><td>Moratorium</td></tr>
<tr><th>No</th><td>Foreclosed</td><td>Diffused</td></tr>
</table>

In this research, engineering identity development of first-year engineering undergraduate students is studied through the lens of the occupation avenue. Transitions of identity development are examined among students who are enrolled in an engineering orientation course., by evaluating changes in the self-reported identity status at the start and end of the semester.

7.2. Methods

This study applies a repeated measures approach to understand transitions in the identity development of first-year engineering students at a pre-dominantly white, midwestern institution. The survey to assess identity status was adopted from the Extended Objective Measure of Ego Identity Status (EOM-EIS) (Bennion & Adams, 1986). It consists of multiple questions categorized according to avenue. For each avenue, the survey includes eight items, with two questions to assess each of the 4 identity development statuses. Responses to these eight items were made using a 6-point scale, consisting of the options “strongly disagree”, “disagree”, “moderately disagree”, “moderately agree”, “agree”, and “strongly agree”. For the purposes of this study, only the occupation-based items were used to create the current instrument (Table 26).

Table 26: Survey instrument to assess engineering identity status.

Representing Status	Statement
Achieved	It took me a while to figure it out, but now I really know what I want for a career.
	It took me a long time to decide but now I know for sure what direction to move in for a career.
Foreclosed	I might have thought about a lot of different jobs, but there’s never really any question since my parents said what they wanted.
	My parents decided a long time ago what I should go into for employment and I’m following through their plans.
Moratorium	I just can’t decide what to do for an occupation. There are so many that have possibilities.
	I am still trying to decide how capable I am as a person and what jobs will be right for me.
Diffused	I’m really not interested in finding the right job, any job will do. I just seem to flow with what is available.
	I haven’t chosen the major I really want to get into, and I’m just going with whatever is available until something better comes along.

The survey was administered using a repeated measures design administered to engineering students in weeks 1 and 2 (pre-measure) and during weeks 15 and 16 (post-measure) of a 16-week semester. The survey was administered in a college of engineering first-year engineering orientation course, using the Qualtrics online platform and made accessible through a unique QR code. Students in the classroom were informed about the voluntary nature of the survey and were invited to participate by scanning the QR code using their personal devices. Students who chose to participate were able to submit their responses anonymously through their devices. This method of data collection was chosen for its efficiency, accessibility, and ability to quickly gather responses from a large group of individuals, which in this case is 841 students.

7.3. Preliminary Observations

The pre-measure sample recorded 162 responses while only 47 of those students provided post measure responses. Thus, 47 responses were available for the repeated measures analysis. A sum of the ratings received for the two survey questions in each status was used as the score for each status, and hence the data had a range of 2 – 12.

The data were examined for patterns, but no discernible patterns or categories emerged among the participant data. Responses were grouped to reduce the noise in the data. Identity scores: greater than and equal to (≥) 10 were "high" scores; "medium" scores were $5 \leq \text{score} \geq 9$; "low" scores were less than or equal to (≤) 4. Figure 10 displays histograms of pre and post-scores of each identity status type, as reported by the 47 students. The high, low, and medium categories are indicated with dotted lines and the medians of all the measures are represented by asterisks. The data plots did show some inherent patterns. Students moved to higher achieved and moratorium identity scores across the time of the semester. At the same time, student foreclosed and diffused identity scores notably decreased across the semester.

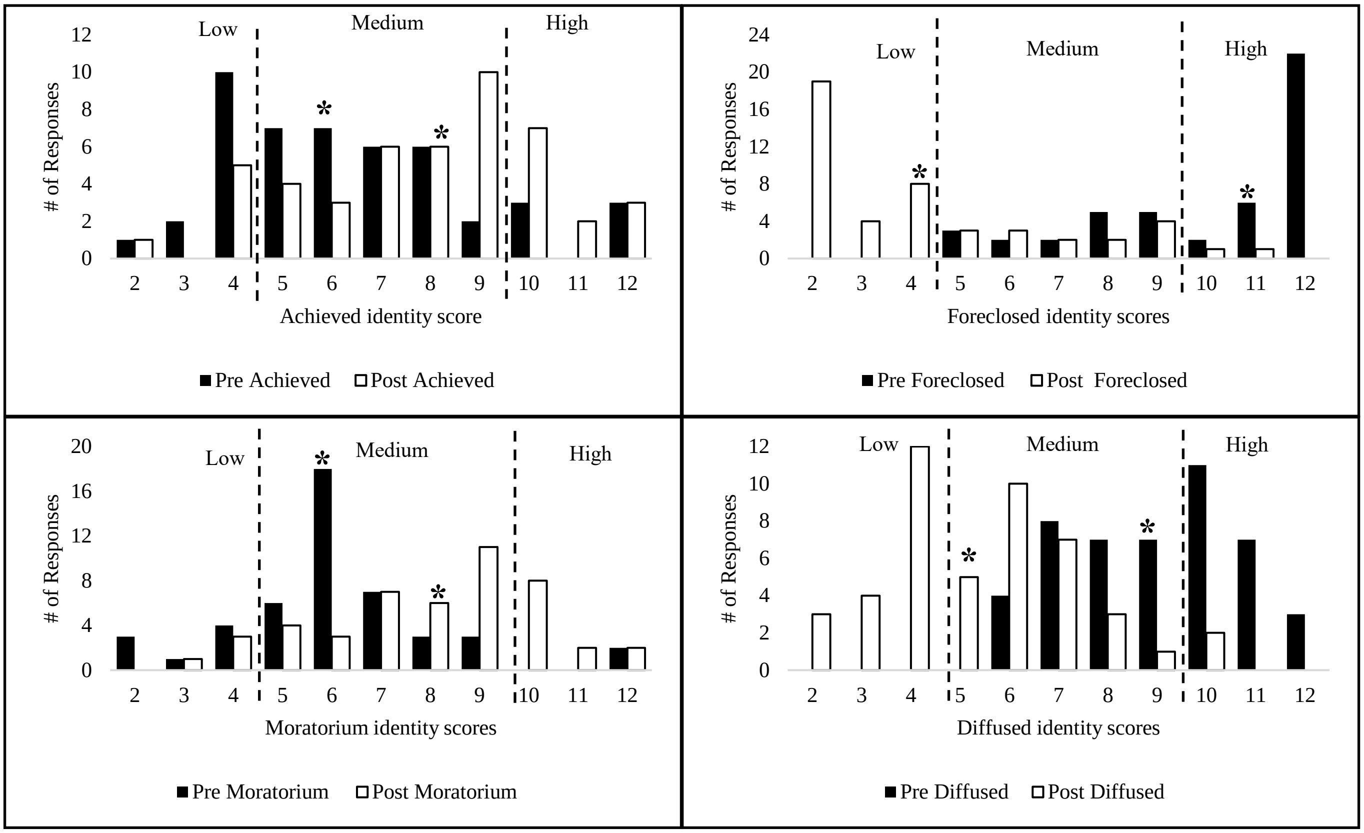


Figure 10: Pre and post scores of the 4 identity statuses (* indicates median).

Further descriptive analysis visually examined the transitions within various score categories for each identity status. Figure 11 shows the 30 individuals that rated themselves high (10 or above) in foreclosed identity at the beginning of the semester. The figure shows how this group transitioned related to achieved identity status during the first semester. As can be seen, even within a specific score category for a given identity status, changes in identity status are seemingly particular to the individual. While interesting, the transition diagrams were not helpful in describing meaningful patterns.

To better understand the data related to the students' identity statuses, they were clustered into high and low scores based on their pre-scores for each identity status, yielding eight categories. The number of students in each cluster is shown in Table 27. It is interesting to note that only a

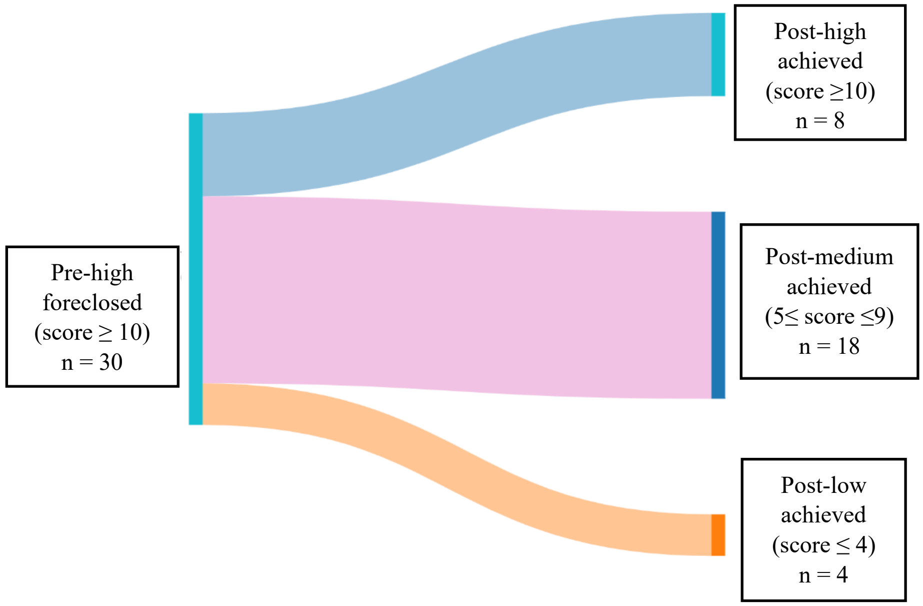


Figure 11: Achieved identity transitions of pre-high foreclosed students.

few students showed high achieved identity when they started college, while a higher number of students started with a high score of foreclosed and diffused identities. This juxtaposition reflects what we would expect to see with the information we have about each of these statuses. Both foreclosed and diffused identities imply no or low exploration from the students. Also, scores of moratorium do not suggest any considerable exploration at the start of the program.

Table 27: Categorization of pre-scores.

Category	**Sample Size**	
	High score	**Low score**
Pre-Achieved	6	13
Pre-Foreclosed	30	0
Pre-Moratorium	2	8
Pre-Diffused	21	0

7.4. Analysis

The eight categories are the lens through which the identity status of an incoming first-year engineering student's identity transitions across the first semester were observed. Statistical tests were performed to identify transitions in identity status within each of the eight categories. For instance, for students in the pre-high achieved category, pre and post scores were compared for each of achieved, foreclosed, moratorium, and diffused identity scores. This allowed inferences about identity transitions of students based on their initial identity status at the start of their engineering degree.

7.5. Statistical Test

A Wilcoxon rank sum test was used to test for significant differences between the identity status scores of the students at the beginning and the end of their first semester. The test was performed in SAS statistical software suite using the PROC UNIVARIATE procedure for Wilcoxon signed rank test for paired data. The general hypothesis used across the tests examines if students experience a significant transition in identity during their first semester of the engineering program. This test was performed using a between subjects approach and with an alpha of 0.05.

Statistical hypotheses were:

H_0: there is no significant difference between the pre and post measures of identity transition.

H_1: a significant difference is found between the pre and post measures of identity transition.

7.5.1. Pre-High Achieved

Six students started the semester with a high score in achieved status. The analyses for this group is shown in Figure 12. This group showed a significant decrease in their mean value of achieved status across the semester (*mean = 11 vs 5.5*; *p=0.031*). Of note are the foreclosed identity scores, which appear disparate in the box-plot representation, yet their means are not in fact statistically different at alpha = 0.05 (*mean = 10.5 vs 3.67*; *p=0.063*). Diffused identity scores showed a similar decreasing trend (*mean = 8.83 vs 4.83; p=0.095*). Moratorium status, on the other hand, had a nonsignificant increase (*mean = 5 vs 8.5; p=0.25*).

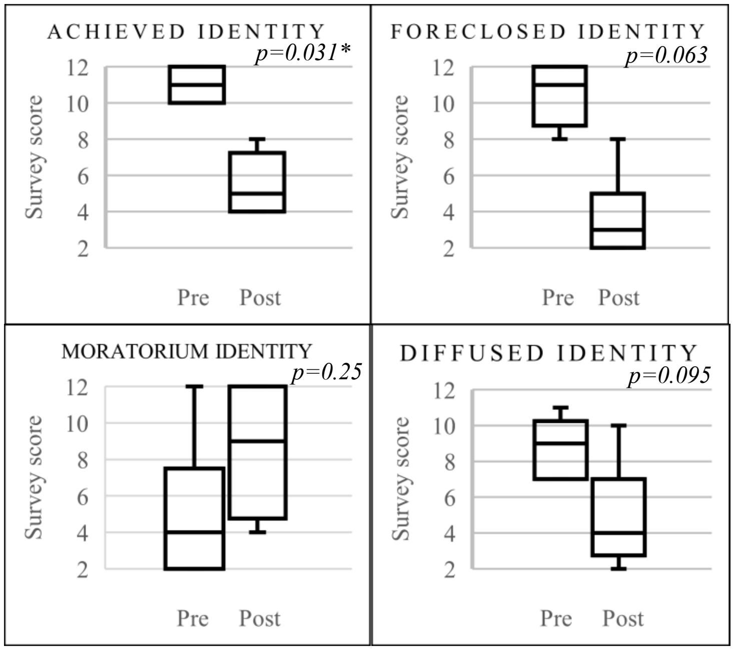


Figure 12: Identity transitions within the pre-high achieved (≥ 10) group (n = 6, score range = 2 to 12).

Students in this group entered the engineering program with a high achieved, foreclosed, and diffused identity. However, after spending one semester in a first-year engineering curriculum, they saw a significant drop in their achieved identity. Similarly, this cluster of students demonstrated a slight decrease in foreclosed and diffused identities. A slight increase in moratorium identity was also observed (although not significant).

7.5.2. Pre-Low Achieved

The thirteen students that entered the engineering program with a low achieved identity score saw a significant rise in their score after spending one semester in the program (*mean = 3.69 vs 8.85; p=0.0005*). Their foreclosed scores saw a significant decrease during the semester (*mean = 10.84 vs 3.54; p=0.0005*). This same cluster, however, seemed to have a relatively stable moratorium score, but displayed statistical significance (*mean = 7 vs 6.77; p=0.04*). Their diffused status scores were observed to be significantly lower at the end of the semester (*mean = 9.31 vs 3.92; p=0.0002*). Plots for this cluster are presented in Figure 13.

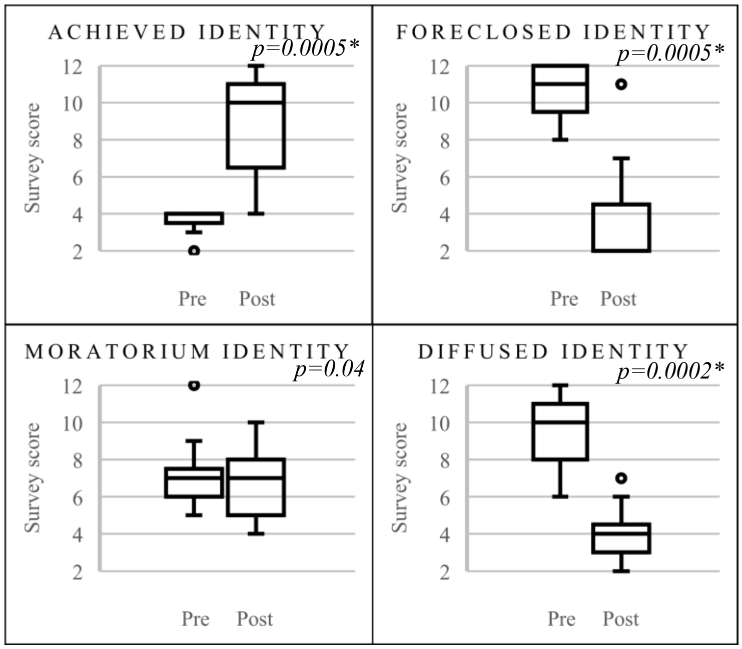


Figure 13: Identity transitions within the pre-low achieved (≤ 4) group (n = 13, score range = 2 to 12).

When starting in an undergraduate program, this group of individuals held an unstable commitment (low achieved and medium moratorium) to the engineering program without adequate exploration (high diffused), displayed a high level of possessing an imposed engineering identity (high foreclosed). This cluster experienced significant decreases in their foreclosed and diffused identity as they progressed through their first semester, showing they built their interest for studying engineering as their major and future occupation, and the significantly higher post achieved status score indicated that they made an informed commitment towards their educational program.

7.5.3. Pre-High Foreclosed

A relatively large sample of thirty students reported high foreclosed status at the start of the semester, and plots for this cluster are displayed in Figure 14. This cohort had a significant decrease in the measures of foreclosed (*mean = 11.67 vs 3.33;* $p<0.0001$) and diffused (*mean = 9.13 vs 4.97;* $p<0.0001$) identity scores. Their achieved (*mean = 6.2 and 7.63;* $p=0.0743$) and moratorium (*mean = 6.47 vs 7.7;* $p=0.0736$) scores only increased slightly over the course of the semester.

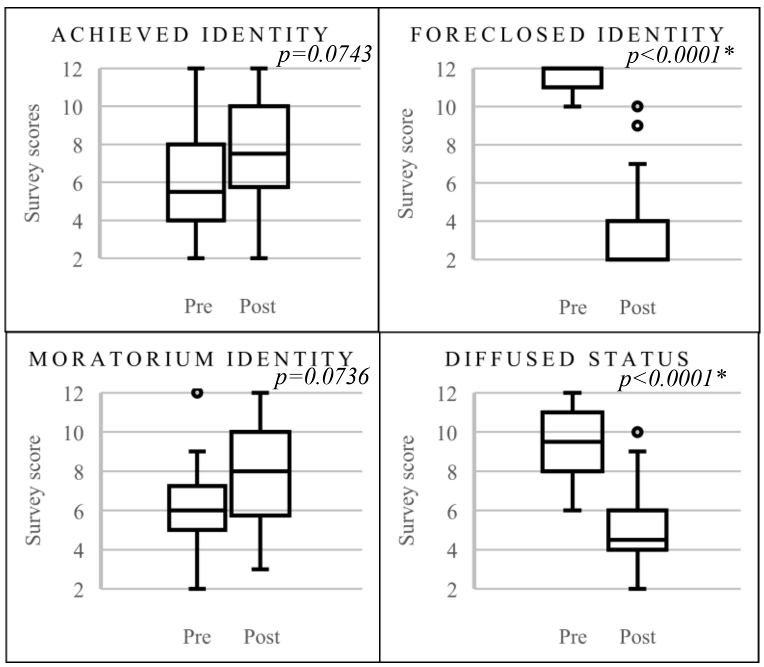


Figure 14: Identity transitions within the pre-high foreclosed (≥ 10) group (n = 30, score range = 2 to 12).

This group of students reported lower scores in their moratorium and achieved identity statuses upon entering their engineering program. This suggests feelings of indifference, and a disinterest to explore, which was paired with a very strong, yet imposed, commitment to engineering i.e., high foreclosed identity. However, as the semester progressed, their high diffused identity status significantly dropped and so did their foreclosed identity status. This finding aligns with expectations that as students are exposed to classes informing them about engineering as a discipline and career, they will start to explore, developing preferences and identities of their own. The attributes of moratorium and achieved identity statuses, although not significant, are observed to be rising.

7.5.4. Pre-High Moratorium

Only two individuals began the engineering program with a high moratorium identity. The students also showed high possession of an imposed commitment of engineering, i.e., a foreclosed identity. They also showed initial signs of being disinterested in their career choice (i.e., high diffused). Yet, the individuals had notably different achieved identity scores. After their first semester, these students reported the lowest possible scores for their foreclosed and diffused identities. Their moratorium scores, however, decreased slightly, while achieved scores also shifted slightly, increasing for one of them and decreasing for the other. Table 25 shows the scores for this group.

Table 28: All identity status measures of 2 students with pre-high moratorium score.

	Achieved		**Foreclosed**		**Moratorium**		**Diffused**	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
S1	2	4	12	2	12	7	12	2
S2	12	7	12	2	12	5	11	2

7.5.5. Pre-Low Moratorium

The eight students that had initially low moratorium scores (see Figure 15) saw a significant rise in moratorium identity scores by the end of the semester (*mean = 3.13 vs 9.13; p=0.016*). Similarly, this cluster reported a significant decrease in their foreclosed (*mean = 10.38 vs 3.5; p=0.016*) and diffused (*mean = 8.5 vs 5.75; p=0.039*) identity scores. As a contrast, their achieved identity scores started high and experienced a notable but insignificant decrease, over the semester (*mean = 8.75 vs 5.63; and p=0.055*).

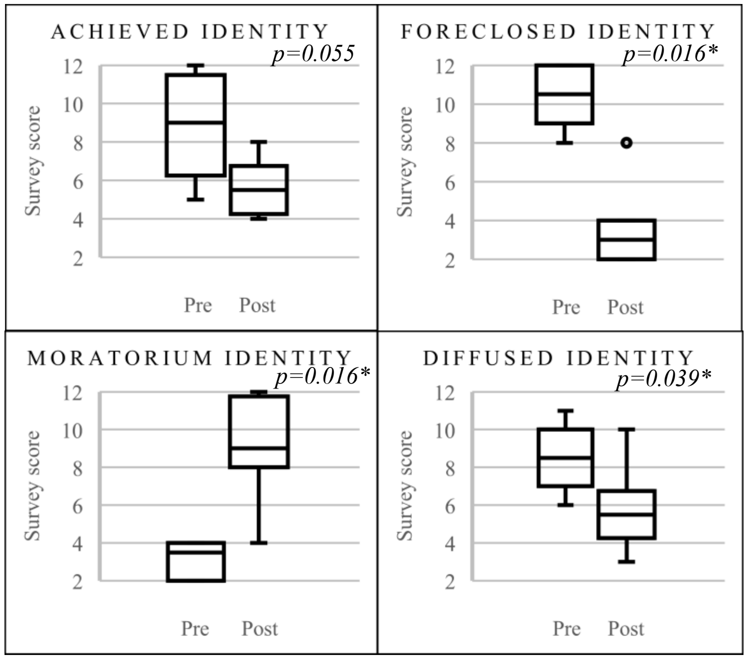


Figure 15: Identity transitions within the pre-low moratorium (≤ 4) group (n = 8, score range = 2 to 12).

The pre-scores of this cluster report a high score in all statuses except moratorium, making it challenging to draw conclusions. This relatively smaller cluster of students started the program with limited exploration (i.e., low moratorium), and reported to have both informed (high achieved status) and imposed decision (high foreclosed status) about their chosen disciplines They also reported being indifferent regarding their choices. But the post-scores show a significant increase in their exploration, a significant drop in the imposed commitment and indifference regarding the major, along with a large but insignificant drop in their informed commitment scores. This may be interpreted that exposure to classes in the engineering program effectively influenced the students to explore their options and believe less in the commitment made to engineering prior to starting the program.

7.5.6. Pre-High Diffused

Twenty one students showed a high diffused identity score at the start of the semester and their transitions are shown in Figure 16. Across the semester they experienced a significant decrease in their diffused (*mean = 10.62 vs 5; p<0.0001*) and foreclosed (*mean = 10.57 vs 4.62; p<0.0001*) identity scores. The cohort's achieved (*mean = 6.29 vs 7.9; p=0.1119*) and moratorium (*mean = 6.86 vs 7.71; and p=0.294*) identity scores remained mostly stable, does not seem notably high.

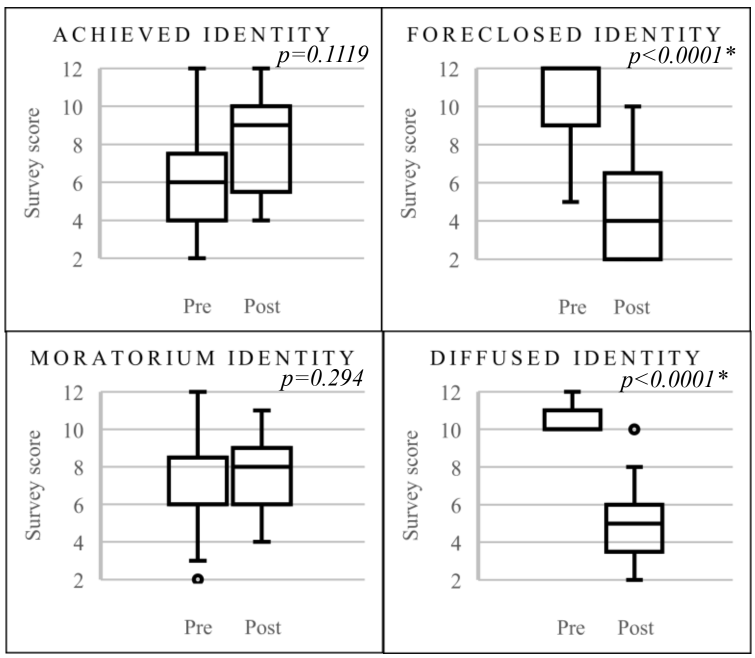


Figure 16: Identity transitions within the pre-high diffused (≥ 10) group (n = 21, score range = 2 to 12).

With pre-high diffused and pre-high foreclosed statuses, the significant decreases suggest a journey away from an imposed commitment to engineering and towards increasing interest in the field. After the semester-long exposure to college and engineering classes, it was observed that these students moved away from the imposed idea of engineering towards high achieved identity. The transition observed within diffused identity is also indicative of students moving away from indifference. A small increase in achieved identity scores showed a rise in informed commitment, perhaps consistent with the reduced foreclosed identity. These results suggest that the engineering program may have led students towards exploring what engineering entails deciding about their future in this discipline.

7.5.7. Special Cases

The sample size was zero in the categories of pre-low foreclosed and pre-low diffused. No reports of pre-low foreclosed means that all students started the program with some notion of what an engineering career would mean for them, either self-attained or imposed by an authority figure. The absence of pre-low diffused scores is intriguing since it shows all the students have at least a little interest in the chosen discipline. This could be reflection of the transitional nature of the first semester in college as students may be exposed to some pre-college information during high school.

In summation, significant differences were found for students clustered by pre-identity status, in five of the eight categories, listed in Table 29.

Table 29: Significant differences in identity transitions for students clustered according to pre identity status.

Cluster	Status	Direction
Pre-high achieved	Achieved	Decrease ↓
Pre-low achieved	Achieved	Increase ↑
	Foreclosed	Decrease ↓
	Diffused	Decrease ↓
Pre-high foreclosed	Foreclosed	Decrease ↓
	Diffused	Decrease ↓
Pre-low moratorium	Foreclosed	Decrease ↓
	Moratorium	Increase ↑
	Diffused	Decrease ↓
Pre-high diffused	Foreclosed	Decrease ↓
	Diffused	Increase ↑

7.6. Discussion

Based on the documentation of identity development by Marcia (1966) and later studies that helped evolve the theory (Kroger & Marcia, 2011; Perez et al., 2014), this study operates on the understanding that the goal of higher education as a system is to promote students towards achieved identity status. This is facilitated by conscious exploration leading to an informed commitment to a field of study, with exploration playing a prominent role. Improving performance and instilling interest are all viewed as a product of exploration that builds engineering identity. Educators, along with the institution, should strive to provide as many exploratory opportunities as possible, while also offering mentorship to help the students evaluate and understand what is best suitable for them. Thus, the transitions observed in the eight categories above were interpreted with the consideration that the goal for these students is to develop a high achieved identity. Other statuses and the scores reported in them are viewed as the pathway for them to reach that goal.

Students that entered the engineering program with a high achieved identity reported to have slightly deviated from their commitment towards engineering by the end of their first semester. This sample of students started college believing they had sufficiently explored and contemplated their engineering major. During the first semester, they were introduced to more information about engineering as a field of practice and took major-related classes. In short, they were offered opportunities to explore, and the lower levels of achieved identity at the end of the semester indicate that their commitment to being an engineering student decreased. This result is consistent with the educational goal of guiding students towards exploration in developing career identity.

On the other hand, students that initially had lower achieved identity reported a rise in that status. The students were given opportunities to self-evaluate and make their own decisions about their major. Overall, it was observed that the engineering educational environment instilled an interest to explore in this sample of students. In addition, some students experienced a subtler push towards the intent to explore, as understood through their reports of decreased diffused and foreclosed identities.

The clustering of scores in the medium range observed in the non-significant transitions, indicating a non-committal status, provides valuable insights into the identity development process of first-year engineering students. This pattern suggests that a single-semester engineering orientation course coupled with other first-year engineering coursework may be insufficient to fully support students' identity exploration and commitment processes. This finding aligns with research on the developmental challenges faced by first-year engineering students. The transition to college represents a critical period for identity formation, as students encounter new academic and social environments that challenge their preexisting beliefs and commitments (Danielak et al., 2014). A single semester may not provide sufficient time or structured opportunities for students to fully explore their interests, values, and career aspirations within engineering. Extending the introductory program to a full academic year could offer prolonged exploration, identity reflection, and potentially leading to stronger commitment.

7.7. Limitations

A primary limitation of this study is the sensitivity of the instrument used to assess the identity statuses. With only two survey items per identity status the instrument may not capture the full complexity of Marcia's identity development framework (1966). This limited number of items to measure each status could potentially lead to oversimplification of the nuanced processes involved in identity formation and may not adequately differentiate between subtle variations in identity statuses. In addition, the statements refer to discipline choice in general without specifying engineering.

The reliance on self-report survey data presents another significant limitation. Self-report measures are subject to various biases, including social desirability bias, where participants may respond in ways they perceive as more socially acceptable rather than providing entirely accurate representations of their experiences. Additionally, self-report data depends on participants' self-awareness and ability to accurately assess and report their own standing, which may vary among individuals. Such limitations of self-report data may affect the accuracy and reliability of the data to some extent.

Given the scope and timeline of this study, the identity statuses at only two specific time frames in the first semester were assessed. Since identity development is a dynamic process, this design limits the ability to capture the more nuanced progression and fluctuations in identity statuses over a prolonged period. A longitudinal research design could potentially uncover deeper interpretations of this phenomenon.

Chapter 8 – Capturing the Essence of Student Experiences that Led to Identity Status Transitions

8.1. Introduction

The transition from high school to college represents a critical period in identity development, particularly for students entering demanding majors, such as engineering. Experiences during this transition often influence how a student performs and develops in college. Transition experiences are an important focus for study because the success of that transition ultimately influences student retention. This chapter explores the identity transitions of first-year engineering students through the lens of Marcia's (1966) ego identity status model. As described in Chapter 7, Marcia's framework identifies four identity statuses: achieved, foreclosed, moratorium, and diffused, based on the presence or absence of exploration of opportunities and choices and commitment to one of the explored options (in this case major choice).

Engineering education research has long recognized the importance of identity formation in student persistence and success (Marra et al., 2013; Godwin et al., 2016). However, less attention has been paid to the specific identity transitions that occur during the crucial first year of college. The quantitative analysis of identity status transitions in Chapter 7 showed that transitions can happen in several directions, but with limited significance. To further examine those transitions, a qualitative analysis examined student experiences during the first semester, their expectations for their major, reasons for such expectations, what were the changes they experienced, and why. This view helps us identify, through introspective qualitative methods, what factors helped students to build towards a goal and what led them to drift away from it.

8.2. Methods

To understand engineering students' identity transitions, clusters were formed with students who responded to both the pre and post identity status surveys. As achieved identity is understood to be critical to student performance and retention, five clusters were identified that narratively related to achieved identity (Table 30). Clusters 1, 2, 3, and 5 encompass students that showed gains in achieved identity during the first semester. Cluster 4 categorizes students that showed a drop in their achieved identity during the semester. Since the goal is to promote students towards a high achieved identity, students within the clusters 1, 2, 3, and 5 were invited for interviews.

Table 30: Clusters defined related to achieved identity.

#	Cluster title
1	Pre-high foreclosed to post-high achieved
2	Pre-high moratorium to post-high achieved
3	Pre-high diffused to post-high achieved
4	Pre-high achieved to post-low achieved
5	Pre-low achieved to post-high achieved

8.2.1. Participants

Twelve students were identified within the clusters 1, 2, 3, and 5 and were sent an interview invitation via multiple emails. Responses to the interview invitations were limited and only two out of the twelve volunteered to participate in this phase of the study. The chosen pseudonyms were: Taylor and Jordan. Taylor was a mechanical engineering major and was present in clusters 1, 3, and 5. Jordan was an architectural engineering major and was found in clusters 1 and 5.

8.2.3. Data Collection

Semi-structured interviews with fifteen predetermined questions were conducted with each participant. Interviews were formulated with prompts to encourage expansion and depth of responses. Both participants were interviewed in the second semester of their undergraduate program, in weeks 10 and 12, respectively. For a duration of 50 – 60 minutes the interviews focused on students' backgrounds, reasons for choosing engineering, experiences during the first semester, and any changes in their perceptions of engineering. The questions used for the interviews are listed in Appendix C.

8.3. Results

The interview analysis focused on identifying shifts in exploration and commitment, as well as factors contributing to these changes. The analysis process was inspired from the thematic analysis strategy followed by Wolcott, (1994) as found in Creswell & Poth (2016, p.252). Initial coding was conducted to identify key items of focus. Proposed codes: “Exploration” and “Commitment” were based on identity development and transition, in relation to Marcia's (1966) ego identity statuses. In addition, some emergent codes were identified from the interview data. These codes, which were not initially a part of the predetermined codebook, surfaced as recurring themes across both participant responses. The three prominent codes extracted were: “identity crisis”, “external influences” and “future orientation”. Proposed codes and their related aspects identified in the data are provided in Table 31.

Extraction of these emergent codes involved an iterative process of open coding where the interview transcripts were reviewed, recurring concepts were identified, and then consolidated into the final set of emergent codes. This inductive approach allowed for capturing unanticipated yet significant themes that were prevalent in students’ responses.

Table 31: Codebook for participant responses.

Code	Included aspects
Exploration	• Active information seeking • Consideration of alternatives • Self-reflection
Commitment	• Decision certainty • Value alignment • Goal persistence
Identity crisis	• Uncertainty • Internal conflict • Reevaluation of choices
External influences	• Familial or Important adult impositions • Peer pressure
Future orientation	• Career planning • Long-term goal setting • Adaptability

Participant responses that were identified during coding are summarized in Table 32. This comprehensive process involved a thorough review of all participant data, carefully identifying statements and responses that aligned with the predefined and emergent codes. This systematic approach allowed the distillation of complex interview data into manageable, categorized information, facilitating a more structured analysis. The identified statements were critically analyzed to serve as a foundational basis for drawing in-depth analyses and understanding the multifaceted factors that led to identity status transitions among first-year engineering students.

Table 32: Coded statements.

Code	Taylor	Jordan
Exploration	i. "I've realized mechanical engineering involves more design and planning than expected." ii. "Learning about other types of engineering has made me appreciate mechanical even more, but also see how they all connect."	i. "I switched from environmental because I didn't like chemistry as much as I thought I would." ii. "After taking Chem one, I realized that I do not think I would not have the most enjoyment if I had to do as much chemistry as would be required."

	iii. "I'm starting to see how the math and physics we're learning applies to actual engineering problems."	iii. "I can't wait to get done with my gen ed classes so I can start taking more engineering-focused classes."
Commitment	i. "I still want to work in renewable energy, just like my dad." ii. "Mechanical engineering is definitely the right choice for me." iii. "I'm excited to learn more about how mechanical systems can be applied to renewable energy projects."	i. "I wanted to be able to say I helped make this." (in relation to performing in a job)
Identity crisis	N/A	i. "I was pretty set on environmental engineering, but now I'm not so sure." ii. "It's been a bit overwhelming trying to figure out which engineering field is the best fit for me." iii. "I'm glad I realized early on that environmental wasn't for me, but it's also scary to change paths so soon."
External influences	i. "My dad's work in renewable energy has always been a big inspiration for me." ii. "I still talk to my dad a lot about my classes and what I'm learning. He helps me see how it connects to his work in renewable energy." iii. "Seeing how my classmates approach problems differently has been really interesting."	i. "My parents have always been very clear that what I do in college is what I want." ii. "My older brother studied engineering here, so I knew a bit about what to expect." iii. "Talking to other students in different engineering majors has really opened my eyes to the possibilities."
Future orientation	i. "I'm already thinking about which classes will be most useful for a career in renewable energy." ii. "I want to make sure I'm prepared for the rapid changes happening in the energy sector." iii. "I'm considering joining some engineering clubs to get more practical experience outside of class."	i. "I'm looking forward to the design classes in architectural engineering." ii. "I hope to get an internship in my junior or senior year to get some hands-on experience." iii. "I'm excited about the possibility of working on sustainable building projects in the future."

8.4. Discussion

This qualitative study provides rich insights into identity development of two first-year engineering students, Taylor and Jordan, through the lens of Marcia's (1966) ego identity status model. The findings reveal a complex and dynamic process of identity formation, highlighting the potential for significant transitions within the timeframe of a single semester.

Jordan:

Thematic findings placed Jordan at foreclosed status for pre-identity status placement and at moratorium with indications for approaching achieved identity as post-identity status. In terms of coding, Jordan demonstrated high levels of exploration, indicative of a transition from foreclosed to moratorium. However, their commitment appeared to be rising, characteristic of achieved identity. Jordan also showed signs of an identity crisis, a key feature of moratorium as their external influences supported exploration. They demonstrated future orientation with a focus aligned with moratorium and achieved identity.

Taylor:

Based on thematic findings, Taylor reported his pre-identity status placement as foreclosed and post-identity status placement as moratorium with emerging achieved identity. In the line of coding, Taylor showed limited but emerging exploration within their foreclosed status, and maintained a strong commitment, which is typical of moratorium. They did not express clear indicators of an identity crisis, consistent with their pre-foreclosed status. Their external influences reinforced their foreclosed status and they demonstrated future orientation with a focus that aligned with achieved identity.

The analysis of interview transcripts from Jordan and Taylor revealed patterns of identity development aligned with Marcia's (1966) identity status framework.

8.4.1. Identity Status Transitions

Both Taylor and Jordan entered college with foreclosed identity statuses, characterized by strong commitments to their chosen engineering fields without evidence of significant prior exploration. This aligns with previous research suggesting that many students enter STEM fields with foreclosed identities, often influenced by family backgrounds or limited exposure to alternatives (Perez et al., 2014). However, their experiences during the first semester led to varied paths in identity development, illustrating the individualized nature of identity development.

Jordan's responses are indicative of a possible transition from foreclosed status to moratorium. This change is consistent with Waterman and Waterman's (1971) findings that the college environment can prompt identity exploration. Jordan's statement, *"I switched from environmental (engineering) because I didn't like chemistry as much as I thought I would,"* emphasizes the active questioning characteristic of moratorium. Their experience aligns with Marcia’s (1966) description of moratorium as a period of exploration accompanied by a lack of firm commitments.

In contrast, Taylor's identity development followed a more nuanced trajectory. While initially foreclosed, Taylor showed signs of emerging exploration without fully moving away from their foreclosed identity. Their statement, *"I've realized mechanical engineering involves more design and planning than expected,"* indicates an evolving understanding of their chosen field without fundamentally challenging their commitment. This partial transition suggests that identity development occurs on a continuum, supporting more recent interpretations of Marcia's theory that propose a more fluid conceptualization of identity statuses (Meeus et al., 2010).

8.4.2. Exploration and commitment

The interplay between exploration and commitment, central to Marcia's theory, was evident in both students but manifested differently and at varying intensities. Jordan's high level of exploration, coupled with fluctuating commitment, is typical of the moratorium status*: "I switched from environmental because I didn't like chemistry as much as I thought I would"* and *"After taking Chem-1, I realized that I do not think I would not have the most enjoyment if I had to do as much chemistry as would be required"*. Their eagerness to explore different engineering disciplines demonstrates the active search for alternatives characteristic of this status: *"I can't wait to get done with my gen-ed classes so I can start taking more engineering-focused classes"*.

Taylor, on the other hand, maintained a strong commitment to mechanical engineering while engaging in some exploration: *"Learning about other types of engineering has made me appreciate mechanical even more, but also see how they all connect"*. Taylor's exploration is strengthening their commitment to mechanical engineering, suggesting a gradual evolution from foreclosed towards achieved identity, rather than a full transition to moratorium. This case illustrates that identity development can occur without abandoning initial commitments, challenging the notion that identity statuses are discrete and mutually exclusive.

8.4.3. Identity Crisis

The presence or absence of an identity crisis is a key distinction between the two students. Jordan's statements, like *"It's been a bit overwhelming trying to figure out which engineering field* *is the best fit for me,"* indicate an identity crisis, an indication of having moratorium status. This crisis serves as a catalyst for exploration (Marcia, 1966).

The absence of crisis indicators in Taylor's responses is noteworthy. It suggests that identity development can occur through a process of gradual refinement and expansion of understanding, rather than always requiring a dramatic crisis. This finding supports a more nuanced view of identity development that acknowledges various pathways to identity achievement.

8.4.4. External Influences

The role of external influences, particularly influential adults, emerged as a critical factor in shaping foreclosed identity. Taylor's ongoing reliance on parental guidance seemed to reinforce elements of their foreclosed status. This is evident by their statement *"I still talk to my dad a lot about my classes and what I'm learning. He helps me see how it connects to his work in renewable energy"*. This statement by Jordan suggests a contrasting scenario, *"My parents have always been very clear that what I do in college is what I want"*. Jordan's family's encouragement of independent decision-making appears to have facilitated their transition to moratorium.

These findings highlight the complex role of family influence in identity development, supporting Marcia's (1966) assertion that the quality of an individual's relationships plays a crucial role in foreclosed identity formation as well as moratorium identity. They also suggest that supportive family environments can foster identity exploration without necessarily requiring a full-blown identity crisis.

8.4.5. Future Orientation

Both participants demonstrated strong future orientation, with characteristics aligned with their respective identity statuses. Jordan's future plans were more exploratory and open-ended, consistent with moratorium status, evident by this statement *"I hope to get an internship in my junior or senior year to get some hands-on experience"*. Taylor's future orientation was more focused and aligned with their existing commitments, yet showed signs of exploring to understand broader possibilities within their chosen field. Two statements indicate this characteristic: *"I'm already thinking about which classes will be most useful for a career in renewable energy"* and *"I want to make sure I'm prepared for the rapid changes happening in the energy sector"*. This difference in future orientation reflects the varying degrees of commitment and exploration characteristic in foreclosed and moratorium, respectively, with emerging exploration.

8.5. Implications for Engineering Education

These findings have several important implications for first-year engineering education. First, it highlights the importance of early exploration opportunities. Providing structured opportunities for students to explore different engineering disciplines early in their college careers could facilitate more informed major choices and stronger engineering identities. The findings also emphasize the support for various identity statuses. Recognizing that students may enter and progress through college with different identity statuses, engineering programs should provide support tailored to students at various stages of exploration and commitment. Being able to understand identity transitions can help the educators tailor their approaches to better support a student towards exploration.

Transitions between the statuses for some students did not vary much (or show significance) within the first semester. It can be more evidently observed in the concentration of scores in the medium range of scores indicating ongoing change. These findings show that identity development happens gradually. The case of Taylor suggests that identity development can occur gradually. Engineering programs should create environments that allow for ongoing refinement of professional identities without necessarily requiring dramatic crises or major changes. The interview analyses indicate positive influence of family on development of achieved identity, through encouragement for exploration. Educational institutions should consider ways to engage families in supporting students' identity development while encouraging independence. The importance of a familial and cultural support system for student persistence was also underscored by Foor et al. (2007). Lastly, integrating opportunities for reflection on personal interests, values, and future goals within first-year engineering curricula could support ongoing identity development and major fit assessment.

8.6. Limitations

A significant limitation of this study is the discrepancy between the quantitative pre-post identity status scores for the two students and the qualitative findings derived from the interview analysis. For Taylor, the quantitative measures indicated a transition from pre-high foreclosed identity to post-high achieved identity. However, the qualitative analysis of his interview responses suggested a more nuanced transition, from pre-high foreclosed status to a post-high moratorium status, along with emerging signs of achieved identity. Similarly, in Jordan's case, the pre-post scores of the quantitative test suggested a direct transition from pre-high foreclosed status to post-high achieved identity status. The interview results revealed a more complex path: from pre-high foreclosed to a post-high moratorium status, with indications of having approached post-high achieved identity. This slight mismatch emphasizes the limitations of relying solely on quantitative measures to capture the nuanced and often non-linear nature of identity development. Further, this highlights the potential oversimplification in quantitative measures of identity status, in which two survey questions were used for each identity status. This may not capture the subtle, ongoing processes of exploration and commitment that characterize identity development.

Additional opportunities to develop deeper understanding of identity status development should examine long-term persistence in engineering majors and careers. A longitudinal examination throughout a 4 or 5 year program could offer better insights into understanding prominent patters and the associated timeline of identity transitions. A more holistic evaluation of other factors that can potentially influence identity development could also be informative. Factors that are currently under practice are exploration and commitment. Other factors not discussed in this scope of literature such as external influences (including peer influences), extracurricular activities, and internship experiences in shaping engineering identities could provide a more comprehensive understanding of additional models that can promote identity development.

Chapter 9 – Relating Identity Status to Engineering Self-Concept

9.1. Introduction

This chapter delves into the integration of two pivotal frameworks that form the cornerstone of our research: engineering self-concept and identity development. These frameworks, while distinct in their origins, offer complementary perspectives on how individuals perceive themselves within the engineering field and how their professional identities evolve over time. The engineering self-concept framework provides insights into how students view their capabilities, interests, and fit as an engineering student. The identity status development framework offers a lens through which we can examine the stages of commitment and exploration that individuals undergo as they establish their engineering identities. By synthesizing these two approaches, we aim to examine the relationship between engineering self-concept and identity development.

9.2. Methods

This analysis phase faced limitations in sample size and data completeness. Only 11 students completed all sets of observations, including engineering self-concept scores and both pre and post identity development scores. However, based on the survey responses received, 22 observations paired engineering self-concept with pre-identity development scores, and 37 observations paired engineering self-concept with post-identity development scores, and these data formed the basis for our analysis.

As in the earlier analysis of identity transitions in Chapter 7, identity development scores ranging from 2 – 12 were coded to High (≥ 10), Medium ($9 \leq$ score ≥ 5), and Low ($4 \leq$). The combined score for engineering self-concept lay between the range 23 to 138. Scatter plots were built to juxtapose engineering self-concept scores with the achieved, foreclosed, moratorium, and diffused identity scores.

Figure 16 shows the identity scores measured in weeks 1 – 2 (i.e., pre score) and Figure 17 shows the identity scores measured in weeks 14 – 15 (i.e., post score). Both scatter plots reveal interesting patterns in the relationship between identity statuses and engineering self-concept. Higher engineering self-concept scores tend to cluster similarly for achieved and moratorium identity scores and foreclosed and diffused identity scores have a similar pattern but with lower engineering self-concept scores.

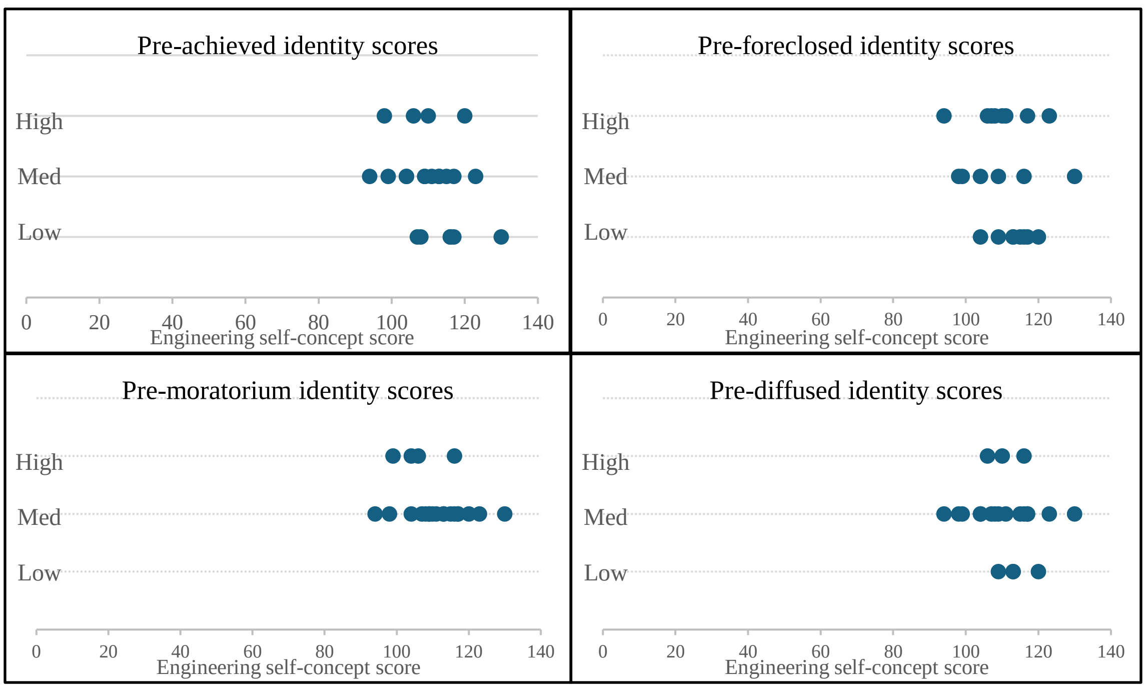


Figure 17: Pre identity status score across engineering self-concept scores.

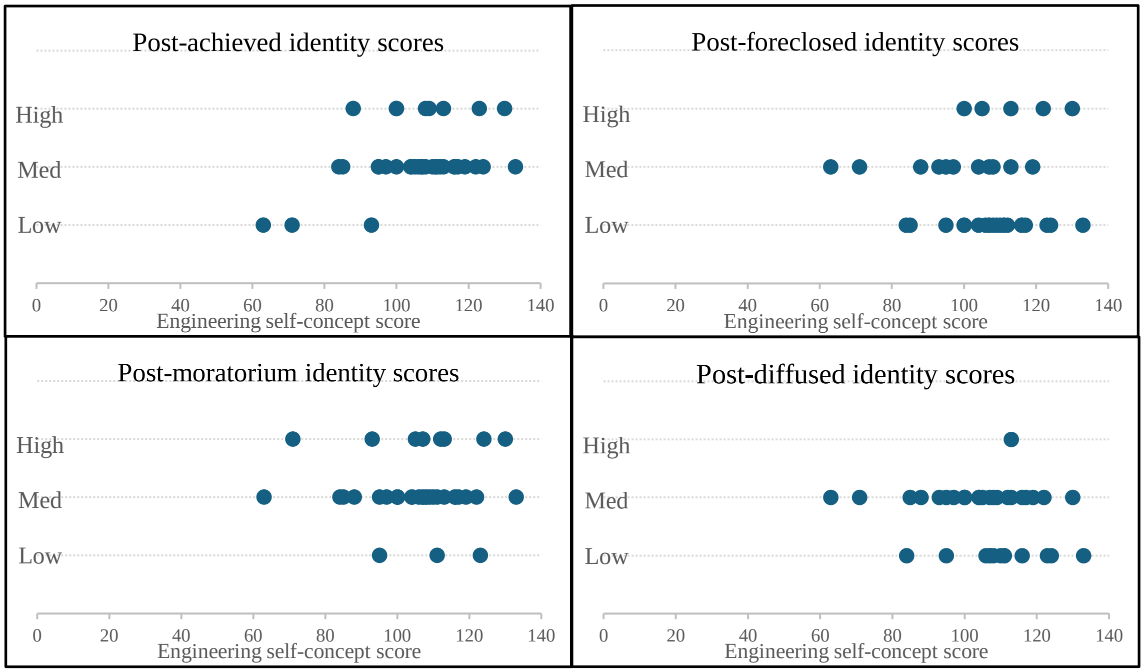


Figure 18: Post identity status score across engineering self-concept scores

For pre and post-measures of achieved and moratorium identity statuses, which share the common element of active exploration, engineering self-concept scores were observed to be clustering around high and medium identity scores. This observation aligns with theoretical expectations, as exploration involves questioning, seeking information, and considering alternatives - processes that may contribute to a more robust self-concept in engineering. Conversely, for both pre and post-measures of foreclosed and diffused identity, engineering self-concept scores were observed to be clustering close to their low and medium categories, and their medians do not seem to be that different.

9.2.1. Analysis

A statistical analysis was used to determine if the observed trends in identity status were meaningfully related to engineering self-concept. Knowing statistical power is influenced by sample size, the first step was to look for ways to aggregate samples. Only 11 individuals answered all three surveys, 22 provided pre-identity status and engineering self-concept responses, and 37 responded to the post-identity status survey along with the engineering self-concept survey. If the pre and post identity status scores were not significantly different, all the observations could be aggregated, to obtain better power.

A Wilcoxon rank sum test was performed for each identity status with the following hypotheses:

H_0: there is no significant difference between the pre and post measures of identity status.

H_1: there is a significant difference between the pre and post measures of identity status.

This test is performed to examine significant differences between the pre and post measures of identity status within the subjects, i.e., within the aforementioned sample of 11 students. The test performed in Chapter 7 to examine significant differences was performed between subjects who individually responded to the pre and post identity status measures. As seen in Table 33, three out of four status results were found to be significant. In other words, achieved, foreclosed, and diffused statuses were significantly different for the pre and post measures. These results also support that significant transitions were observed in all identity statuses except in moratorium status. Thus, the paired samples from participants who completed pre-identity survey with engineering self-concept and post-identity survey with engineering self-concept could not be aggregated.

Table 33: Results of Wilcoxon rank sum test on identity status (N=11).

Identity Status	**Mean**		**p-value (* indicates significance)**
	Pre	**Post**	
Achieved	6.18	8.36	0.0200*
Foreclosed	10.36	3.82	< 0.0001*
Moratorium	6.45	6.91	0.2402
Diffused	8.82	4.55	< 0.0001*

Statistical tests were performed on the pre and post samples separately to assess which identity status is strongly related to engineering self-concept. Multiple linear regression was used twice, once on the 22 observations pairing engineering self-concept with pre-identity development scores, and again on the 37 observations pairing engineering self-concept with post-identity development scores. The four identity status types were the explanatory variables (i.e., independent variables), and engineering self-concept score was the response variable (i.e., dependent variable). The mathematical model was:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \epsilon$$

Where,

Y: Self-concept score

β_0: *Intercept of the model*

X_{1-4}: *Identity status (Achieved, Foreclosed, Moratorium, Diffusion)*

β_{1-4}: *Coefficients of effect size*

ϵ: *Error term*

The multiple regression hypotheses evaluate the significance of the model coefficients. When the coefficients are significant, it is interpreted that the explanatory variable is linearly related to the response variable.

9.3. Results

Inferential results from the statistical tests did not entirely align with the descriptive observations. The scatter plots were of limited use in identifying a particular identity type that is related to engineering self-concept, and suggested that each identity status type has a certain unique relationship with the construct. The regression analyses added a little understanding regarding these relationships.

The regression analysis for pre identity status scores (Table 31) revealed no statistically significant relationships with engineering self-concept. These results suggest that at the initial stage of joining the undergraduate program, none of the identity statuses were predictive of a student's engineering self-concept (Table 34). The regression analysis for post identity status scores (Table 35) showed slightly different results. Importantly, achieved identity status emerged as a significant predictor of engineering self-concept (*β=0.12231; p=0.0067*). The positive regression coefficient indicates that students who reported higher levels of achieved identity status towards the end of the first semester also tended to have higher engineering self-concept scores.

Table 34: Regression analysis for pre identity status scores and engineering self-concept (N=22; R^2=0.1589).

Identity Status	**Regression Coefficient (β)**	**Standard Error**	**p-value**
Achieved	– 1.34	0.82778	0.1252
Foreclosed	– 0.13	0.80350	0.8688
Moratorium	0	1.18069	1.0000
Diffused	– 0.24	1.27771	0.8520

Table 35: Regression analysis for post identity status scores and engineering self-concept (N=37; R^2=0.2271).

Identity Status	**Regression coefficient (β)**	**Standard Error**	**p-value**
Achieved	3.43	1.18263	0.0067*
Foreclosed	– 1.5	1.19327	0.2192
Moratorium	0.12	1.32543	0.9271
Diffused	1.51	1.67558	0.3727

9.4. Discussion

The different results between the pre and post-measurement analyses highlight the dynamics of identity development and its relation to engineering self-concept. The emergence of achieved identity as a significant predictor in the post-identity scores aligns with Marcia's (1966) theory, which posits that individuals with achieved identity have undergone a period of exploration and have made firm commitments towards their chosen path. Engineering self-concept also, by definition, is the state that one develops after having worked towards building their skills and abilities in the domain of engineering, to the extent of their level of exposure and achievement. It is assumed that by the end of the first semester, students had experienced exploration and had started to develop confidence about their achieved identity.

The lack of significant predictions in the pre identity scores, particularly for the achieved identity status, is noteworthy. This might be explained by an observation made in Chapter 7, where some students who initially reported high levels of achieved identity showed a decrease in this status during the post scores. This phenomenon could account for why the pre-achieved identity status does not significantly relate to engineering self-concept, while post-achieved identity status does. Several factors might contribute to this anomaly. Students entering engineering programs might initially perceive themselves as having an achieved identity based on their decision to pursue engineering. However, as they progress through their studies and encounter the realities and challenges of the program, some may re-enter a period of exploration or questioning, temporarily moving away from the achieved status. This process of re-evaluation and potential identity reconstruction could explain why only the post-achieved identity status has a significant predictive relationship with engineering self-concept.

The small, but positive predictive relationship between post-achieved identity status and engineering self-concept suggests that students who have solidified their identity as engineers through exploration and commitment demonstrate a stronger and more positive perception of themselves as an engineer. The non-significant results for other identity statuses in both pre and post measurements suggest that these statuses may not play a crucial role in shaping engineering self-concept. However, the larger research results of this study support the idea that these statuses may be a pathway towards achieved identity. In conclusion, these results support that achieved identity status is most strongly related to engineering self-concept, but only when the individual is given ample opportunity to explore opportunities and make an informed commitment

These findings have important implications for engineering education and student support. Educators and institutions might consider implementing strategies that facilitate identity exploration and commitment among engineering students, potentially leading to more students achieving a stable engineering identity and, consequently, a stronger engineering self-concept. This could involve providing diverse experiences, mentorship opportunities, and reflective practices that encourage students to explore and commit to their engineering identities.

Chapter 10 – Final Integration

This chapter assimilates all the research presented in the previous chapters to provide clear interpretations related to the research questions. The main foci of this study were the novel framework developed to assess engineering self-concept, and the exploration of identity transitions among first-year engineering students. By integrating findings from both quantitative and qualitative analyses, this study provides insights into how these students perceive themselves and navigate their identities during the critical adaptation period in the first year of college.

In doing so, key insights and implications that can inform educational support systems are highlighted. This final chapter will summarize the findings, discuss their significance and discuss limitations and future research in this area.

10.1. Research Question 1: How does engineering self-concept relate to task-related engineering self-efficacy?

To answer this question, a review was performed to differentiate between self-concept and self-efficacy, followed by building and validating survey instruments for both constructs within the context of first-year engineering education. Those results informed the analysis of the relationship between engineering self-concept and engineering self-efficacy. The confirmatory factor analysis performed indicated a moderate relationship between engineering self-concept and engineering self-efficacy. The variance of engineering self-efficacy was only partially explained by engineering self-concept suggesting that while engineering self-concept can influence engineering self-efficacy, it cannot entirely determine the latter. The variance of task-related engineering self-efficacy that is not explained by engineering self-concept, may be impacted by personal factors of the individual, like difficulty of a task, mastery and/or preparation for the task under consideration, and emotional and psychological state of an individual. Such factors paired with engineering self-concept could be crucial in shaping engineering self-efficacy.

This understanding can inform more targeted and effective pedagogical approaches, recognizing that while both these constructs are important for a student's success, they represent distinct aspects of student experiences in an educational program. Higher education and researchers should consider this distinction when designing programs and tasks to support students' development in engineering.

10.2. Research Question 2: How does identity status change in a first semester engineering experience course?

The study provided evidence that identity status can indeed change and/or strengthen during a first-semester engineering experience course. The changes in foreclosed suggest that the support provided by the engineering program is effective in challenging a student's preconceived and imposed notions about engineering. The change observed in diffused and moratorium statuses indicates that the program was able to promote active exploration, ultimately supporting the professional growth of a student. These findings demonstrate that a first-semester engineering orientation course, as a part of college curriculum, can have an impact on students' identity development. In practice, it has important implications for curriculum design and student support in engineering education, emphasizing the need for early, structured experiences that promote exploration and informed commitment to the field.

10.3. Research Question 3: How is identity status related to self-concept of a first-year engineering student?

The analysis that was conducted to integrate the frameworks of engineering self-concept and identity development addresses this research question. It was found that post-achieved identity status demonstrates a strong predictive relationship with an individual's engineering self-concept. This finding suggests that those students who have successfully navigated the exploration process and arrived at a well-defined sense of identity in their role as an engineering student are more likely to possess a robust and positive engineering self-concept. The relationship between these two frameworks highlights the interconnected nature of identity formation and self-concept within the field of engineering education. While these results are interesting, it's important to note that this is an initial finding and further research would be beneficial to understand why post-achieved identity status was found to be predictive of engineering self-concept, while pre-achieved identity was not.

10.4 Conclusive Discussion

The preceding sections have explored two crucial aspects of engineering undergraduate student experiences: engineering self-concept and identity development. While each construct provides valuable insights independently, integrating them provides a more holistic understanding of how undergraduate experiences can be shaped, from an educator's perspective, to improve overall student performance.

10.4.1. Theoretical Integration

Engineering self-concept is a multidimensional and multifaceted construct encompassing an individual's beliefs about their abilities in both non-academic and academic aspects. The relationship between engineering self-concept and identity development can be understood through the lens of reciprocal determinism (Bandura, 1986). It was posited that human behavior is a result of complex interplay between personal, environmental, and behavioral factors. According to Bandura, these three factors are interconnected and mutually influence each other in a continuous cycle. For example, an individual's personality (i.e., personal factor) might influence how they interact with their environment (i.e., environmental factor), which in turn can shape their behavior. Simultaneously, their behavior can influence their environment, their personal beliefs and attitudes. This dynamic interaction can be viewed in the context of this study. A student's personal beliefs about their engineering abilities (engineering self-concept) likely shape their behavioral exploration and commitment to engineering, leading to developing an identity status, while their identity development process influences how they perceive their abilities. Illustrative cases for the four identity statuses are discussed below:

a. Achieved status and stability in engineering self-concept:

   Students who have explored and committed to their engineering identity, i.e., possessing achieved status, may have a more stable self-concept, as their sense of self is more firmly established.

b. Moratorium and fluctuation in engineering self-concept:

   Those in moratorium status, actively exploring their engineering identity, might experience greater fluctuations in self-concept as they encounter new experiences and challenges.

c. Foreclosed and uncertainty in engineering self-concept:

   Students in foreclosed status might have a high overall engineering self-concept due to their commitment to the major, but potentially lower self-concept in more funneled domains, within engineering, they haven't explored (refer to Chapter 2)

d. Diffusion and low Engineering Self-Concept:

Those in diffused status may struggle to develop a strong engineering self-concept due to lack of both exploration and commitment.

10.5. Limitations

A prominent limitation of this study is the potential for response fatigue among participants due to the repeated measures design implemented across the semester. As students were asked to complete multiple surveys at three different time points throughout the semester, there was a risk that their engagement and the quality of their responses may have diminished over time. The fatigue effect could have manifested in several ways, like decreased attention to survey questions, increased likelihood of selecting neutral responses, or even complete disengagement from the study.

It should be noted that this entire research relied on students having access to smartphones or tablets capable of scanning QR codes and a stable internet connection. While this method provided a convenient and rapid means of data collection, it's important to acknowledge potential limitations, such as the possibility of selection bias (as only students with compatible devices could participate) and the inability to control for potential discussions among students while completing the survey.

This research suffered with limitations with lower-than-expected response rate, which resulted in smaller sample sizes across all phases of the study. This constraint had far-reaching implications for our analytical approach and interpretation of results. To address this limitation, this research exercised caution in selecting analysis tools, model fit indices, and factor loading criteria. Parsimonious models were deliberately opted for and employed more tolerant statistical criteria to accommodate the smaller sample sizes while still maintaining analytical rigor. This approach was particularly evident in Chapter 5, where a threshold of 0.3 was adopted for factor loadings, a more lenient criterion compared to conventional standards. While this decision allowed this research to retain potentially important factors in the analysis, it also necessitated a more cautious interpretation of the findings. The smaller sample sizes may have limited statistical power, potentially affecting the generalizability of our results. Furthermore, this limitation highlights the need for future research confirming and replicability of these findings with larger sample sizes.

The theoretical framework constructed in Chapter 2 (Figure 4) presents a comprehensive model that extends to first-year student retention, exploring its relationships with engineering self-concept and engineering self-efficacy. This framework was proposed to provide a holistic understanding of the factors influencing student persistence in engineering undergraduate programs. However, I acknowledge that the inability to draw conclusions with the comprehensive framework is a significant limitation in our research process. I experienced some restrictions in utilizing this student directory information for interpretative purposes. The final step with this framework was to relate engineering self-concept and engineering self-efficacy to first-year engineering retention, which was not explored due to the limitation in accessing the student directory information regarding major choice.

10.6. Future Directions

Connecting the two frameworks examined in this research – identity development statuses and engineering self-concept through engineering identity – presents a promising direction for future investigations. This research indicates that engineering identity is a strong predictor of engineering self-concept, highlighting its importance in students' academic and professional development. The identity development statuses, with their distinct developmental characteristics, offer a complementary perspective on how individuals progress towards establishing a robust identity. Future research could explore how students in different identity statuses (achieved, foreclosed, moratorium, and diffused) score on measures of engineering identity strength. This could provide insights into whether certain statuses are more closely associated with stronger engineering identities.

Additionally, longitudinal studies could track how students move through identity statuses over time and how these transitions correlate with changes in engineering identity and/or engineering self-concept measures. Such research could examine if the results observed in one semester are persistent throughout and also illuminate developmental pathways that lead to a strong engineering self-concept. It may also reveal critical periods or experiences that facilitate positive identity development in engineering students.

Another avenue for future research is examining how educational interventions might differentially impact students in developing engineering identity. For example, students in a diffused status might benefit from different types of support or experiences compared to those in moratorium or foreclosed statuses. Understanding these nuances could inform more targeted and effective strategies for fostering engineering identity development across diverse student populations.

Further research into the application and testing of the validated engineering self-concept framework presents a valuable opportunity to advance our understanding of this construct. By extending the scope of investigation to diverse populations, educational settings, and cultural contexts, researchers can rigorously assess the framework's generalizability and robustness. Such studies could involve longitudinal designs to track the development and stability of engineering self-concept over time, or cross-sectional comparisons across different engineering disciplines and career stages.

Expanding the assessment tool for identity status represents a crucial avenue for enhancing the findings from the identity development phases of this study. As specified in the limitations, the current tool with two survey items assessing each status can have limited generalizability. To address this limitation, future research should focus on developing a more comprehensive instrument. By incorporating a broader range of survey items, researchers can capture a more holistic picture of identity status development and transitions. A more robust assessment could potentially uncover subtle variations and patterns in identity development that may have been overlooked with the current limited approach.

Lastly, future studies could explore how the integration of these frameworks might improve important educational outcomes, such as retention in engineering programs, academic performance, and career choices. By combining the developmental perspective of identity statuses with the domain-specific focus of engineering identity, researchers may develop more comprehensive models of student success in engineering education.

10.7. Acknowledgement

This research aimed to expand upon the surveys and sub-constructs that had been meticulously documented in prior studies. By integrating these existing findings, the goal was to develop a comprehensive and consolidated framework for understanding engineering self-concept. This approach was not intended to challenge or defy the previous research, but rather to build upon it, ensuring a cohesive foundation for future investigations in the field of engineering education.

References

Andrews, M. E., Borrego, M., & Boklage, A. (2021). Self-efficacy and belonging: the impact of a university makerspace. *International Journal of STEM Education, 8*, 1-18.

Bandura, A. (1978). Reflections on self-efficacy. *Advances in Behavior Research and Therapy*, 237-269.

Bandura, A. (1986). *Social Foundations of Thought and Action: A Social Cognitive Theory.* Prentice-Hall, Inc.

Bandura, A. (1994). Social Cognitive Theory and Exercise of Control over HIV Infection. In R. J. DiClemente, & J. L. Peterson, *Preventing AIDS: Theories and Methods of Behavioral Interventions* (pp. 25–59). Boston, MA: Springer.

Bandura, A. (1997). *Self Efficacy: The exercise of control.* New York: Freeman.

Bennion, L. D., & Adams, G. R. (1986). A Revision of the Extended Version of the Objective Measure of Ego Identity Status: An Identity Instrument for Use with Late Adolescents. *Journal of Adolescent Research , 1*(2), 183-197.

Bergerson, A. A., Hotchkins, B. K., & Furse, C. (2014). Outreach and Identity Development: New Perspectives on College Student Persistence. *Journal of College Student Retention: Research, Theory & Practice, 16*(2), 165-185.

Besterfield-Sacre, M., Shuman, L. J., Hoare, R., & Wolfe, H. (2005). University of Pittsburgh School of Engineering student assessment system. *University of Pittsburgh*.

Betz, A. R., King, B., Grauer, B., Montelone, B., Wiley, Z., & Thurston, L. (2021). Improving Academic Self-Concept and STEM Identity Through a Research Immersion: Pathways to STEM Summer Program. *Frontiers in Education, 6*.

Bong, M., & Clark, R. E. (1999). Comparison between self-concept and self-efficacy in academic motivation research. *Educational Psychologist*, 139-153.

Bong, M., & Skaalvik, E. M. (2003). Academic Self-Concept and Self-Efficacy: How Different Are They Really? *Educational Psychology Review, 15*, 1-40.

Borrego, M., Patrick, A., Martins, L., & Kendall, M. (2018). A New Scale for Measuring Engineering Identity in Undergraduates. *ASEE Gulf-Southwest Section Annual Conference.*

Bradford, B., Beier, M., McSpedon, M., & Wolf, M. (2020). Examining STEM Diagnostic Exam Scores and Self-efficacy as Predictors of Three-year STEM Psychological and Career Outcomes. *American Society for Engineering Education.*

Bringula, R., Reguyal, J. J., Tan, D. D., & Ulfa, S. (2021). Mathematics self-concept and challenges of learners in an online learning environment during COVID-19 pandemic. *Smart Learning Environments*.

Burleson, S., Major, D. A., Hu, X., & Shryock, K. J. (2021). Linking undergraduate professional identity development in engineering to major embeddedness and persistence. *Journal of Vocational Behavior, 128*, 103590.

Byrne, B. M. (1990). Methodological Approaches to the Validation of Academic Self-Concept: The Construct and Its Measures. *Applied Measurement in Education*, 185-207.

Carroll, L., Finelli, C. J., & DessSJardins, S. L. (2022). Academic Success of College Students with ADHD: The First Year of College. *Collaborative Network for Engineering and Computing Diversity.* New Orleans, LA.

Chemers, M. M., Hu, L.-t., & Garcia, B. F. (2001). Academic self-efficacy and first year college student performance and adjustment. *Journal of Educational Psychology, 93*(1), 55–64.

Chen, F. F., West, S. G., & Sousa, K. H. (2006). A Comparison of Bifactor and Second-Order Models of Quality of Life. *MULTIVARIATE BEHAVIORAL RESEARCH, 41*(2), 189-225.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences.* https://doi.org/https://doi.org/10.4324/9780203771587

Cokely, K., & Patel, N. (2007). A Psychometric Investigation of the Academic Self-Concept of Asian American College Students. *Educational and Psychological Measurement, 67*(1), 88-99.

Creswell, J. W., & Poth, C. N. (2016). *Qualitative Inquiry and Research Design: Choosing among five approaches.* Sage Publications.

Danielak, B. A., Gupta, A., & Elby, A. (2014). Marginalized Identities of Sense-Makers: Reframing Engineering Student Retention. *Journal of Engineering Education, 103*(1), 8-44.

Desai, N. H., & Stefanek, G. (2017). An Introductory Overview of Strategies used to Reduce Attrition in Engineering Programs. *American Society of Engineering Education.*

Dirisina, J., & Shehab, R. L. (2023). A Systematic Review of Academic Self-Concept Measures in First-year Engineering Education. *ASEE Annual Conference and Exposition.*

Doran, K., & Swenson, J. (2022). 'Do I Belong Here?': Persistence and Retention Implications of Engineering Belongingness and Identity in Academically At-Risk Populations. *IEEE Frontiers in Education Conference.* Uppsala, Sweden.

Eccles, J. S., & Wigfield, A. (2002). Motivational Beliefs, Values, and Goals. *Annual Review of Psychology, 53*, 109-132.

Ferla, J., Valcke, M., & Cai, Y. (2009). Academic self-efficacy and academic self-concept: Reconsidering structural relationships. *Learning and Individual Differences, 19*(4), 499-505.

Fleming, L. N., Smith, K., & Williams, D. (2013). Engineering Identity of Black and Hispanic Undergraduates: The Impact of Minority Serving Institutions. *ASEE Annual Conference & Exposition.*

Flora, D. B., & Curran, P. J. (2004). An Empirical Evaluation of Alternative Methods of Estimation for Confirmatory Factor Analysis With Ordinal Data. *Psychological Methods, 9*(4), 466–491.

Foor, C. E., Walden, S. E., & Trytten, D. A. (2007). "I Wish that I Belonged More in this Whole Engineering Group:" Achieving Individual Diversity. *Jornal of Engineering Education, 96*(2), 103-115.

Frédéric, G., Marsh, H. W., & Michel, B. (2003). Academic self-concept and academic achievement: Developmental perspectives on their causal ordering. *Journal of Educational Psychology, 95*(1), 124–136.

Gibbons, R. (2014). Bi-Factor Analysis. In A. C. Michalos, *Encyclopedia of quality of life and well-being research* (pp. 1-10). Springer, Dordrecht.

Godwin, A., Potvin, G., Hazari, Z., & Lock, R. (2016). Identity, Critical Agency, and Engineering: An Affective Model for Predicting Engineering as a Career Choice. *Journal of Engineering Education, 105*(2), 312-340.

Gulati, S. (2022). Work in Progress: An Integrative Learning-Centered Advising Experience for First Year Students. *ASEE Annual Conference & Exposition.*

Hofer, S. I., Reinhold, F., Loch, F., & Vogel-Heuser, B. (2020). Engineering Students' Thinking About Technical Systems: An Ontological Categories Approach. *Frontiers in Education, 5*, 66.

Hooper, D., Coughlan, J., & Mullen, M. R. (2008). Structural Equation Modelling: Guidelines for Determining Model Fit. *Electronic Journal of Business Research Methods, 6*(1).

Hu, L.-t., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal, 6*(1), 1-55.

Hughes, B. E., Schell, W. J., Annand, E., Beigel, R., Kwapisz, M. B., & Tallman, B. (2019). Do I Think I'm an Engineer? Understanding the Impact of Engineering Identity on Retention. *American Society for Engineering Education.*

Hurtado, S., & Carter, D. F. (1997). Effects of College Transition and Perceptions of the Campus Racial Climate on Latino College Students' Sense of Belonging. *Sociology of Education,, 70*(4), 324-345.

Ifenthaler, D., Siddique, Z., & Mistree, F. (2015). Designing for Open Innovation: Change of Attitudes, Self-Concept, and Team Dynamics in Engineering Education. *Emerging Technologies for STEM Education*, 201–215.

Ikart, E. M. (2019). Survey Questionnaire Survey Pretesting Method: An Evaluation of Survey Questionnaire via Expert Reviews Technique. *Asian Journal of Social Science Studies, 4*(2).

Jennrich, R. I., & Bentler, P. M. (2011). Exploratory Bi-Factor Analysis. *Psychometrika: A Journal of Quantitative Psychology, 76*, 537–549.

Jensen, K. J., & Cross, K. J. (2021). Engineering stress culture: Relationships among mental health, engineering identity, and sense of inclusion. *Journal of Engineering Education, 110*(2), 371-392.

Jin, S., Seok-Jean, J., & Rhee, B. S. (2020). Does "Women Friendliness" Matter in STEM Education?: Differential Effects of High-Impact Practices on Career Aspiration of STEM College Students by Gender. *Journal of Engineering Education Research, 23*(4), 37-51.

Kline, R. B. (2016). *Principles and practice of structural equation modeling, (4th ed.).* Guilford Press.

Korb, K. A. (2012). *Conducting Educational Research- Adopting or Adapting an Instrument*. Retrieved from korbedpsych.com: http://korbedpsych.com/R09aAdopt.html

Kroger, J., & Marcia, J. E. (2011). The Identity Statuses: Origins, Meanings, and Interpretations. In S. J. Schwartz, K. Luyckx, & V. L. Vignoles, *Handbook of Identity Theory and Research* (pp. 31 - 53).

Li, C.-H. (2015). Confirmatory factor analysis with ordinal data: Comparing robust maximum likelihood and diagonally weighted least squares. *Behavior Research Methods , 48*, 936–949. https://doi.org/https://doi-org.ezproxy.lib.ou.edu/10.3758/s13428-015-0619-7

Mahadeo, J., Hazari, Z., & Potvin, G. (2020). Developing a Computing Identity Framework: Understanding Computer Science and Information Technology Career Choice. *ACM Transactions on Computing Education, 20*(1), 1-14.

Mamaril, N. A., Usher, E. L., Li, C. R., Economy, R. D., & Kennedy, M. S. (2016). Measuring Undergraduate Students' Engineering Self-Efficacy: AValidation Study. *Journal of Engineering Education, 105*(2), 366–395.

Marcia, J. E. (1966). Development and validation of ego-identity status. *Journal of Personality and Social Psychology, 3*(5), 551–558.

Marra, R. M., Rodgers, K. A., & Shen, D. B. (2013). Leaving Engineering: A Multi-Year Single Institution Study. *Journal of Engineering Education, 101*(1), 6-27.

Marsh, H. W. (1986). Verbal and Math Self-Concepts: An Internal/External Frame of Reference Model. *American Educdational Research Journal, 23*(1).

Marsh, H. W. (1987). The Hierarchical Structure of Self-Concept and the Application of Hierarchical Confirmatory Factor Analysis. *Journal of Educational Measurement*, 17-39.

Marsh, H. W. (1990). A multidimensional, hierarchical model of self-concept: Theoretical and empirical justification. *Educational Psychology Review*, 77–172.

Marsh, H. W. (1990). The structure of academic self-concept: The Marsh/Shavelson model. *Journal of Educational Psychology, 82*(4), 623-636.

Marsh, H. W. (1992). Content specificity of relations between academic achievement and academic self-concept. *Journal of Educational Psychology, 84*(1), 35-42.

Marsh, H. W. (1993). Academic Self-Concept: Theory, Measurement, and Research. *Psychological Perspective on the Self, 4*, 40.

Marsh, H. W., & Craven, R. (2005). A reciprocal effects model of the causal ordering of self-concept and achievement : new support for the benefits of enhancing self-concept. *New Frontiers for SELF Research*, 17-51.

Marsh, H. W., & Martin, A. J. (2011). Academic self-concept and academic achievement: Relations and causal ordering. *British Journal of Educational Psychology, 81*(1), 59-77.

Marsh, H. W., & Shavelson, R. J. (1985). Self-Concept: Its Multifaceted, Hierarchical Structure. *Educational Psychologist*, 107-123.

Marsh, H. W., Byrne, B. M., & Shavelson, R. J. (1988). A multifaceted academic self-concept: Its hierarchical structure and its relation to academic achievement. *Journal of Educational Psychology*, 366–380.

Marsh, H. W., Pekrun, R., Murayama, K., Arens, A. K., Parker, P. D., Guo, J., & Dicke, T. (2018). An integrated model of academic self-concept development: Academic self-concept, grades, test scores, and tracking over 6 years. *Developmental Psychology, 54*(2), 263-280.

Marsh, H. W., Reinhard, P., Parker, P. D., Murayama, K., Guo, J., Dicke, T., & Arens, A. K. (2019). The murky distinction between self-concept and self-efficacy: Beware of lurking jingle-jangle fallacies. *Journal of Educational Psychology, 111*(2), 331-353.

Marsh, H. W., Walker, R., & Debus, R. (1991). Subject-specific components of academic self-concept and self-efficacy. *Contemporary Educational Psychology, 16*(4), 331-345.

Mattingly, B. A., & Lewandowski Jr, G. W. (2013). An Expanded Self is a More Capable Self: The Association between Self-concept Size and Self-efficacy. *Self and Identity, 12*(6), 621-634 .

McKoy, T., Beane, C. D., Oyeteju, M. O., Hammond, M. S., & Hargrove, K. (2020). Persistence of African American Females in Engineering: The Mathematics Identity Factor. *Urban Education Research and Policy Annuals , 7*(1).

Meeus, W., Van De Schoot, R., Keijsers, L., Schwartz, S. J., & Branje, S. (2010). On the Progression and Stability of Adolescent Identity Formation: A Five-Wave Longitudinal Study in Early-to-Middle and Middle-to-Late Adolescence. *Child Development, 81*(5), 1565-1581.

Miller, J. W., Coombs, W. T., & Fuqua, D. R. (1999). An examination of psychometric properties of Bandura's multidimensional scales of perceived self-efficacy. *Measurement and Evaluation in Counselling and Development*, 186.

Möller, J., & Marsh, H. W. (2013). Dimensional comparison theory. *Psychological Review, 120*(3), 544-560.

Morelock, J. R. (2017). A systematic literature review of engineering identity: definitions, factors, and interventions affecting development, and means of measurement. *European Journal of Engineering Education, 42*(6), 1240-1262.

Moreno-Hernandez, A. D., & Mondisa, J.-L. (2021). Differences in the Self-Perceptions of Resilience, Grit, and Persistence amongFirst-YearEngineeringUndergraduates. *International Journal of Engineering Education, 37*(3), 701–711.

Olson, K. (2010). An Examination of Questionnaire Evaluation by Expert Reviewers. *Field Methods, 22*(4), 295-318.

Patrick, A. D., Borrego, M., & Prybutok, A. N. (2018). Predicting Persistence in Engineering through an Engineering Identity Scale. *International Journal of Engineering Education, 34*(2a).

Pawlecki, J. (2022). Factors Influencing Female Engineering Students' Social Self-Confidence. *Doctoral dissertation, University of Toledo*.

Perez, T., Cromley, J. G., & Avi, K. (2014). The role of identity development, values, and costs in college STEM retention. *Journal of Educational Psychology, 106*(1), 315-329.

Pierrakos, O., Beam, T. K., Constantz, J., Johri, A., & Anderson, R. (2009). On the development of a professional identity: engineering persisters vs engineering switchers. *IEEE Frontiers in Education Conference.*

Prybutok, A., Patrick, A. D., Borrego, M., Seepersad, C. C., & Kirisits, M. J. (2016). Cross-sectional Survey Study of Undergraduate Engineering Identity. *ASEE Annual Conference and Exposition.*

Qiu, S., Okundaye, O., Natarajarathinam, M., Chu, S. L., Kuttolamadom, M., Li, Q., & Quek, F. (2022). ‘All Together Now’-Integrating Horizontal Skills in CareerTechnical Education Classes with Making and Micro-manufacturing. *ASEE Annual Conference & Exposition.*

Reynolds, W. M., Ramirez, M. P., & Allen, J. E. (1980). Initial Development and Validation of the Academic Self-Concept Scale. *Educational and Psychological Measurement, 40*(4), 1013-1016.

Rittmayer, A. D., & Beier, M. E. (2009). Overview: Self-Efficacy in STEM. *Applying Research to Practice (ARP) Resources*, 12.

Ross, M. S., Huff, J. L., & Godwin, A. (2021). Resilient engineering identity development critical to prolonged engagement of Black women in engineering. *Journal of Engineering Education, 110*(1), 92-113.

Rüschenpöhler, L., & Markic, S. (2019). Self-concept research in science and technology education – theoretical foundation, measurement instruments, and main findings. *Studies in Science Education*, 37-68.

Sadia, S. (2022). Factors influencing female intention to participate in science technology engineering mathematics (STEM) education in Pakistan. *Master Dissertation, UTAR*.

Salgado, L. (2020). Motivations of Low-income Engineering Transfer Students Influencing Choice and Pursuit of Baccalaureate Degree Attainment. *Universit of California, Irvine*.

Scott, M. (2018). Contributions to Estimation of Polychoric Correlations. *Multivariate Behavioral Research, 53*(2), 247-266.

Shavelson, R. J., Hubner, J. J., & Stanton, G. C. (1976). Self-Concept: Validation of Construct Interpretations. *Review of Educational Research* , 407-441.

Thiry, H., Weston, T. J., Harper, R. P., Holland, D. G., Koch, A. K., Drake, B. M., Hunter, A.-B., & Seymour, E. (2019). *Talking about Leaving Revisited: Persistence, Relocation, and Loss in Undergraduate STEM Education.* Springer.

Timofeeva, A. Y., & Khailenko, E. A. (2016). Generalizations of the polychoric correlation approach for analyzing survey data. *2016 11th International Forum on Strategic Technology (IFOST).* Novosibirsk, Russia.

Verdin, D., Godwin, A., Kirn, A., Benson, L., & Potvin, G. (2018). Understanding How Engineering Identity and Belongingness Predict Grit for First-Generation College Students. *ASEE CoNECD.* Crystal City, Virginia.

Waterman, A. S., & Waterman, C. K. (1971). A longitudinal study of changes in ego identity status during the freshman year at college. *Developmental Psychology, 5*(1), 167–173.

West, S. G., Taylor, A. B., & Wu, W. (2012). Model Fit and Modle Selection in Structural Equatin Modeling. In R. H. Hoyle, *Handbook of Structural Equation Modeling.* Guilford press.

Wille, E., Stoll, G., Gfrörer, T., Cambria, J., Nagengast, B., & Trautwein, U. (2020). It Takes Two: Expectancy-Value Constructs and Vocational Interests Jointly Predict STEM Major Choices. *Contemporary Educational Psychology, 61*.

Wolcott, H. F. (1994). *Transforming Qualitative Data: Description, Analysis, and Interpretation.* Thousand Oaks.

Wu, H., Guo, Y., Yang, Y., Zhao, L., & Guo, C. (2021). A Meta-analysis of the Longitudinal Relationship Between Academic Self-Concept and Academic Achievement. *Educational Psychology Review*, 1749–1778.

Yullyaningsih, R. M., Wahyuni, S., & Sulistiyanti, R. (2022). CONTRIBUTING TO THE INTENTION FACTORS OF CHEATING BEHAVIOR IN STUDENTS OF SMA NEGERI 2 JAKARTA . *European Journal of Psychological Research , 9*(1), 38.

Appendices

Appendix A: Simplified Survey for Engineering Self-Concept.

Sub-Construct	Survey Statement
Engineering identity	It matters to me how I do in engineering. [a]
	Your own sense of who you are (your personal identity) overlaps with your sense of who an engineer is (identity of an engineer). [b]
	I think that earning a bachelor's degree in engineering is a realistic goal for me. [c]
Belonging	I feel that I am a member of the engineering community at my institution. [b]
	I see myself as a part of the engineering community at my institution. [b]
Perceived competence	I can excel in an engineering major during the current academic year. [d]
	I can persist in an engineering major during the next year. [d]
STEM intrinsic value	The future benefits of studying engineering are worth the effort. [e]
	I expect that studying engineering will be rewarding. [e]
	I expect that engineering will be a rewarding career. [e]
	A degree in engineering will allow me to get a job where I can use my talents and creativity. [d]
	A degree in engineering will allow me to obtain a job that I like. [d]
(e: Besterfield-Sacre et al., 2005; d: Rittmayer & Beier, 2009; c: Fleming et al., 2013; b: Borrego et al., 2018; a: Jensen & Cross, 2021)	

Appendix B: Learning Outcomes of the Introductory Engineering Orientation Class.

1. **Explain** what an engineer does and distinguish between various engineering disciplines.
2. **Describe** opportunities for and impacts of engineering in meeting societal challenges.
3. **Apply** the engineering design process, including stakeholder and ethical considerations.
4. **Design** a prototype under specified criteria and constraints.
5. **Communicate** engineering design process through report, oral presentation, and poster presentation.
6. **Identify** potential ethical impacts of proposed engineering solutions on society.
7. **Demonstrate** effective teamwork practices.
8. **Apply** academic success strategies.
9. **Develop** personal connections to OU engineering community.
10. **Cultivate** intrinsic motivations in engineering.

Appendix C: Qualitative Interview Questions.

Introductory questions

1. What is your name?
2. Where are you from?
3. Where you did you go to high school?
4. Who are your important adults?
    a. Did they go to school / college?
        i. What did they major in?
    b. What do they do now?

Exploring the pre-status

5. What are you majoring in?
    a. How did you choose the major?
    b. Who / What influenced the choice?
        i. How?
    c. When did you decide about your major?
        i. Explain the pathway you took to arrive at this decision?
        ii. Are your adults part of this process?

Exploring the changes

6. Have you switched majors after joining college?
7. Did you ever change your choice of major?
    a. What prompted the switch?
        i. Why?
        ii. Who/What influenced this? (Teachers / important adults?)
        iii. How so?
8. Who are the important adults in your life now, after having experienced the first semester of college?
    a. Who do you reach out to for college related questions or help?
    b. Ask about important adults if they don't mention it.
9. What is the reaction of your important adults that (when you entered school) were a part of this process?

Exploring the post-status

10. Talk to me about what / how you are thinking about engineering now?
    a. What are your thoughts about your chosen major
11. Have your beliefs about engineering changed since you joined college?
    a. How so?
    b. What/who prompted it?
12. Has your outlook about college changed since you joined college?
    a. How so?
    b. What / Who prompted it?

13. What do you see as your future pathway with this major during college and after?

14. How do you reach out to your important adults?
    a. Why do you reach out to each of these people?
    b. Would you say it changed since you joined college?
    c. How so?
    d. What prompted this change?
    e. What does this change mean to you?
15. Is there anything you want to tell me about being an engineer? About being in your major?