International Journal of Engineering Education Vol. 40, No. 4, pp. 948–964, 2024
Printed in Great Britain

0949-149X/91 $3.00+0.00

Analysis of A Systematic Literature Review of Engineering Identity Research (2005–2019)*

SHAWNA FLETCHER
Engineering Academic and Student Affairs, Texas A&M University, College Station, TX, USA. E-mail: fletcher.234@tamu.edu

KRISTI J. SHRYOCK
Department of Multidisciplinary Engineering, Texas A&M University, College Station, TX, USA. E-mail: kshryock@tamu.edu

Since 2005, engineering identity models have emerged within the literature. This publication further examines a systematic literature review conducted to conceptualize engineering identity theory by two independent researchers. The systematic literature review uncovered undergraduate student research, especially underrepresented populations, in higher education between 2005–2019. This analysis explores the origins of engineering identity theory and identity models used in its evolution. This analysis contains an in-depth examination of 43 sources and a detailed explanation of the scope, methods, and categorizations provided in the previous publication. Authors concluded that research on engineering identity can improve by (1) adopting uniformity across terms and factors that are easily identified; (2) recognizing, understanding, and building upon the depth and breadth of research in disciplines other than engineering; (3) correlating engineering identity factors with student success and retention; (4) designing valid measurement instruments specific to engineering identity; and (5) incorporating standards for robust measures, including control or comparison groups. Gaps in literature and future research recommendations are discussed.

Keywords: analysis; systematic literature review; engineering identity; engineering identity research; women in engineering; underrepresented populations; quick reference guide

1. Introduction

A systematic literature review was previously conducted to identify the scope of work for development of engineering identity as a singular concept from 2005–2019. Fletcher and Shryock identified, coded, and categorized 43 studies related to engineering identity theory during this time period [1]. Specific attention was paid to categorize works that included women and underrepresented populations. A detailed account of the systematic review was followed per Borrego, Foster, and Froyd however, several research questions remained [2]. This paper seeks to dive further into an analysis of those 43 specific studies to explore how the theory of engineering identity emerged.

2. Research Questions

To continue the literature review discussion, the following research questions (RQs) emerged:

RQ 1: How did engineering identity theory evolve and was it related to other identity models?
RQ 2: Does engineering identity literature correlate to student success and retention?
RQ 3: Do valid measurement instruments exist and are they specific to engineering identity?
RQ 4: What methods are used in engineering identity studies and are there recommendations for improvement?

3. Methods

Fletcher and Shryock discussed methods for the systematic literature review at length in their previous publication [1]. To summarize, the framework for the review was based upon work by Borrego, Foster, and Froyd. From this framework, the systematic review process was derived from four methodologies including, search (retrieval), selection (apply criteria), coding (quality evaluation), and synthesis (analyze results) to refine results [3]. A team of two researchers applied qualitative content analysis to categorize methods and identify themes. Per Klavans and Boyack, citation searching/indexing was used to identify authors frequently referenced throughout the literature who performed larger, longitudinal studies within engineering education [4]. This process resulted in 43 articles on engineering identity. Table 1 summarizes research questions from the first publication and continuing questions relevant for this analysis. Quick reference guides were created as a result of findings in the first publication [1].

4. Analysis

4.1 Disconnected Models for Engineering Identity

To answer RQ1, identity theory originated within the fields of psychology and education. Early identity style types, such as diffuse-avoidant, normative,

* Accepted 1 June 2024.

Table 1. Summary and comparison of research questions from two publications

Systematic Literature Review Research Questions	**Analysis Research Questions (current publication)**
RQ 1: What studies emerged that conceptualize engineering identity as a singular concept in higher education?	RQ 1: How did engineering identity theory evolve and was it related to other identity models?
RQ 2: What populations have previously been studied in the engineering identity literature during the time period (2005–2019)?	RQ 2: Does engineering identity literature correlate to student success and retention?
RQ 3: What categorizations of research methods were clear in engineering identity literature?	RQ 3: Do valid measurement instruments exist and are they specific to engineering identity?
RQ 4: What were the main identity themes in each publication?	RQ 4: What methods are used in engineering identity studies and are there recommendations for improvement?

and informational [5, 6], prompted researchers to examine student academic success rates in university settings [7, 8]. Though these identity styles are highly recognized and accepted within psychoeducational fields, engineering identity appears to have directly evolved from STEM identity models.

4.1.1 STEM Identity Models

STEM identity models extended from psycho-educational fields are categorized using external and internal components. Through STEM identity models, it is widely accepted that identity relies upon an individual's success in academic subject matter (internal component) and that they are recognized within the larger STEM domain as a member of the community (external component) [9, 10]. As discussed in Fletcher and Shryock, an issue with STEM identity models is that they are over-simplified and exclude relevant levels of detail [1].

Further, ". . . researchers are undecided upon defined characteristics that constitute identity and ways to translate these characteristics into valid identity measurement instruments [11]. Consequently, many studies have linked engineering identity to the development of academic identity, especially an affinity towards core subjects, such as math identity [12, 13] and physics identity [14]. By defining identity solely on the basis of academic competence/performance, interest, and recognition, STEM identity models have often excluded the overarching experience of underrepresented populations, including women and women of color [15] . . ." STEM identity for marginalized populations is complex and must examine multiple intersectional factors. ". . . Models that delineate complexity within each context are necessary [16]." Therefore, fostering intersectional identities in addition to academic and professional identity within underrepresented populations in engineering is a crucial research area.

4.1.2 STEM, Math and Physics Identity

From findings in Fletcher and Shryock, it is evident that engineering identity is not understood as well as psychosocial or STEM educational models [1]. Thus, the body of work surrounding engineering identity has relied heavily on STEM identity definitions, especially physics and/or math identity. For reference, three previous engineering identity literature reviews provide a comprehensive understanding of identity, STEM identity, math identity, and physics identity as the basis for engineering identity theory [17, 18, 19].

Appendix I, Table 2 is modified from Fletcher and Shryock and contains primary author, number of subjects, method (qualitative, quantitative, mixed), instrument used, and identity themes/findings, in chronological order [1]. Main themes are discussed to provide the reader with a conceptual framework for the sequential timeline from which engineering identity evolved as a concept.

Within emergent engineering identity models, survey questions regarding STEM identity, including factors that distinguish science identity from math identity and physics identity, appeared to be prevalent in qualitative studies up until 2011. These factors appeared to be included, interchanged, or separated at random, with the addition of other external traits. For example, two early studies theorized engineering identity consisted of "three types" of personalities: academic, social, and intellectual [16]; another as nerds, academic-achievers, and greeks [20]. Some studies argued that students associate engineering with a professional identity that consists of academic and institutional identities coupled with gendered identities, which are further influenced by positive role-models [21].

Many studies defined engineering identity as either identity through academic success or identity as an affinity towards the engineering profession itself. Though categorization of research for this review was subjective, studies that discussed engineering as a professional endeavor explored the alignment of identity as a gendered experience for men [22] or women and their level of commitment [23, 24], in addition to personal interest and family influence [25]. Few studies at the collegiate level coupled engineering professional identity with participation in service learning [26] or examined how professional identity impacts recruitment, retention, and preparation [27, 28].

To answer RQ2, two publications from Beam and Pierrakos were the only studies that tied recruitment and retention findings to engineering identity data in their study population [27, 28] during this period. This was an area of concern as many of the studies mentioned the importance of recruitment and retention of students without discussing actual impact on recruitment or retention factors within their findings. More about the importance of tying recruitment and retention data to these studies will be discussed in Section 7.

Though disjointed, research from 2005 until 2011 explored the intersectionality of multiple identity factors that may contribute to and influence individual student experience. Until 2012, these factors were viewed as separate. Few studies explored a relational understanding between factors or impact of multiple factors on the student as a whole. For example, qualitative studies in 2011 relied heavily on engineering theory from Gee and explored students' engineering external and internal frame of reference for identity in professional and academic contexts [9, 29–31]. It was evident that after 2007, researchers began to incorporate multiple identity theory [14] and build upon established science identity and physics identity models [15]. This gave researchers comparable models and informed research directions to define identity factors within the engineering community.

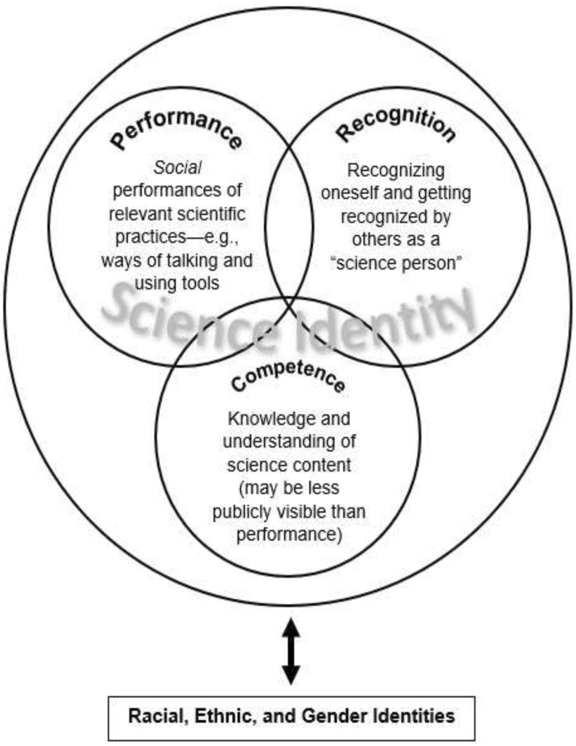

Fig. 1. From Carlone and Johnson, three factors that comprise science identity including, performance, recognition, competence, and their interaction with racial, ethnic, and gender identities [14].

4.2 Basis for Engineering Identity Model Development

Full text review of literature and citation searching/indexing revealed that numerous researchers frequently cited three significant contributions to form a basis for the engineering identity model. Though not included in the literature review, Gee's model for identity factors can be paraphrased as, (1) self-recognition and (2) recognition by others as competent [9]. This idea was not expanded upon significantly until six years later, when a science identity model was discussed for women of color. Carlone and Johnson is widely referenced in engineering identity literature as it may have been the first study to disaggregate data based on gender with ethnicity and examine social factors [14]. In addition, they defined science identity as a professional identity with triangulated traits of performance, competence, and recognition. Carlone and Johnson argued that these three factors interact with other gendered, racial/ethnic identities as a basis for forming science identity [14]. Fig. 1 depicts three factors that comprise science identity and their interaction with multiple identities that are of significance to women of color.

Researchers in physics identity then built upon the science framework by adding interest as a dimension and examined relationships between factors of performance, competence, recognition, and interest [15]. As a sidebar, adding interest to the physics model provided depth to understand STEM identity. However, science identity researchers were apparently unaware of the body of research being developed concurrently in psychology to understand the dimensions of interest in conjunction with engagement and participation. Around that time, a widely known four-phase model of interest development [32] was constructed and to date, has not been integrated into the body of science identity models. This is a shortcoming of science identity research that dimensions of interest (emotional, cognitive, behavioral) and dimensions of engagement (affective, behavioral, cognitive) have not been added to reveal a more comprehensive, in-depth understanding. Also, Hazari's notion of interest is interchangeable with motivation and lacks a clear understanding that these are separate concepts, each with different attributes and definitions. Fig. 2 shows the Hazari model of physics identity with added factor, interest.

From the three notable studies, factors of performance (students' belief in their ability to succeed academically or while completing engineering tasks), competence (students' belief in their ability to understand technical material), recognition (viewed by others as knowledgeable in academic

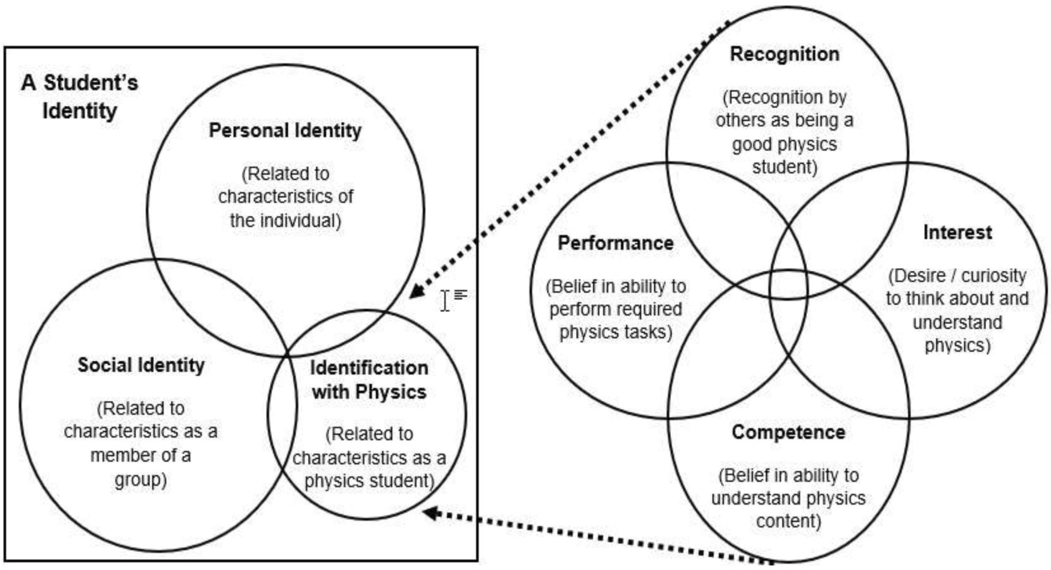

Fig. 2. Hazari's model of physics identity in relation to performance, recognition, competence, and interest [15].

subject matter), and interest (affinity towards engineering tasks, also a defining factor in persistence) were refined [11, 14, 15]. Subsequent works co-authored by Hazari found that performance and competence were theoretically equivalent and began to combine performance/competence into one construct. These factors were further integrated with math identity models to understand engineering career choice [29, 33], academic persistence [34, 35] and to develop structural equation models to inform engineering identity measurement instruments [36].

Finally in 2018, Patrick built upon Hazari's physics identity model to develop an engineering identity model that replaced "physics" with "engineering" to define the three factors of a student's identity as personal, social, and identification with engineering [15, 37]. This study also combined performance/competence into one category as data analysis indicated there was not a significant difference between categories and the factors could be combined. During discovery for the literature review, Patrick was the only study that sought to build upon previous research and provide a new dimension to engineering identity theory [37]. Fig. 3 depicts the Patrick model for engineering identity, based upon Hazari's previous work.

4.3 Evolution of Engineering Identity Factors

Section 4.2 describes the evolution of models that have been used to understand engineering identity in its current state. However, as described in Section

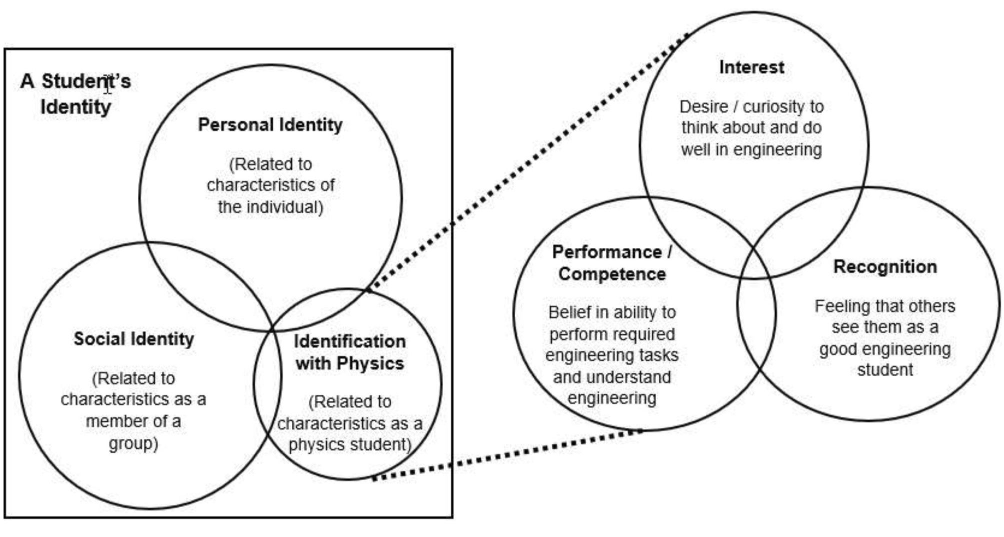

Fig. 3. Patrick's model of engineering identity, which is built on the Hazari model by combining performance and competence into one category and including, recognition, and interest [37].

4.1, the emergence of engineering identity as a singular concept grew from a variety of factors that researchers explored to describe different aspects of identity and its variations. Meyers was a significant study that defined engineering as a professional identity, one where there is both belonging of self and organizational recognition, compounded with factors essential to become an engineer. These factors included making competent design decisions, working with others, and accepting responsibility [38]. Though researchers did not recognize engineering identity theories to date, this study was significant due to its large sample size (n = 701) and the variety of engineering students (freshman through senior) used to quantitatively predict engineering identity by using a linear regression model. As the bulk of previous engineering identity research relied on qualitative methods with small sample size, the use of quantitative methods with larger sample size became a new direction for engineering identity research.

After 2013, it was apparent that researchers began to explore a broader definition of engineering identity. This not only included internal identity with "academics" or "engineering profession"; but included other variables, especially those of interest to supporting underrepresented populations. It seemed that research up until this point was highly scattered and indicated that the engineering educational community did not fully comprehend salient factors that comprise the concept of "engineering identity", nor was there consensus. At this time, studies presented a myriad of experimental conditions used to further understand nuance and complexity of external engineering environments. Studies explored the impact of attending minority serving institutions (MSI's) on underrepresented populations [39]; developing cultural belonging within the profession through 'familia' within Hispanic/Latinx populations [40, 41]; or creating academic and professional identity through access, performance, and retention via participation in targeted programs [42]. A few studies began to explore the impact of gender stereotypes, especially stereotype threat [43], or highly gendered environments on women entering the engineering profession [44]. As each study prescribed different attributes to explain engineering identity, it was apparent throughout the literature that researchers created their own measurement instruments in isolation.

Research after 2015 began to provide a pattern of common understanding and studies began to build upon previous results. Teams developed large-scale quantitative studies to validate instruments developed from physics and math identity models. Factors included in these instruments revisited a combination of internal and external identity variables that appeared to be related to three common themes. With the development of identity instruments, engineering identity research was better examined by dividing data into common factors to explain development of (1) academic identity, (2) professional identity, or (3) holistic self-identity. Instruments are discussed in Section 7.3.

4.3.1 Academic Identity Factors

Though not as prevalent after 2015, studies continued to rely on the definition of engineering identity as solely academic, heavily related to math and physics. Several studies used elements from instruments developed by Hazari to examine factors, such as interest, recognition, performance/competence (math), agency, and physics identity [15, 45, 46]. Though maintaining an overall academic theme, factors such as, attitudes in populations of women [47] or grit in first-generation (FGen) populations [48] may have been added to connect engineering academic identity with other recent developments in the engineering education literature.

4.3.2 Professional Identity Factors

Some research depicts engineering identity as a professional identity; that which is affiliated with a set of workplace skills and hands-on ability. Though engineering educational outcomes are well-established, only one study in the entire literature review tied engineering identity to developing factors associated with ABET educational outcomes a-k. These factors include framing and solving problems, design, project management, analysis, collaboration and tinkering [49]. This study was echoed a few years later to measure similar identity factors [50, 51] and examine these factors within underrepresented populations [52]. Though surprising, only a limited number of studies examined the development of professional identity through hands-on design experiences as professional practice [53, 54] or in maker spaces [55]. It is important to note that studies mentioned concepts, such as tinkering and self-efficacy. However, engineering educational literature does not seem to contain a comprehensive understanding for these longstanding research areas, most prevalent in psychology and education. As noted by one author, performance/competence is akin to self-efficacy in social science literature and these factors are important to understand the development of identity in engineering [37]. Though outdated, research on tinkering could have been utilized to further establish professional identity factors that underlie engineering identity within project-based or hands-on settings as well.

4.3.3 Holistic Self-Identity Factors

Studies that used either academic identity, professional identity, or a combination of both also included expanded factors that encompassed an individual's self-identity within engineering. These factors included design efficacy, creativity, and global agency [56], with growth mindset [57]. As the concept of agency begins to appear within the literature, it is apparent that engineering identity research may include factors that describe the importance of an individual's sense of "purpose" or "ability to act" to connect with engineering and/or become an engineer. Though not referred to as "agency", studies began to couple self-concept identity with personality traits (agreeableness, conscientiousness, extroversion, neuroticism, openness to experience) and authenticity [58]. Self-determination theory was also utilized to establish a sense of developing competence and interpersonal relationships, managing emotions, autonomy towards interdependence, developing purpose, establishing identity, and developing integrity [59, 60]. These self-concepts were further developed through measuring identity through distinctiveness, participation, self-enhancement, visibility of affiliation and citizenship [61].

With interest in measurement instruments, studies holistically used a combination of academic and professional descriptors to better understand affinity towards majors, such as electrical engineering and computing [62]. Academic and professional factors were further enhanced by expansion into social identity construction theories and the impact of communities of practice [63]. Social peer interactions within special populations were observed in Hispanic serving institutions (HSI's) compared with predominantly white institutions (PWI's) [52] and found that underrepresented students develop stronger engineering identity in HSI settings. The impact of social constructs on developing engineering identity has expanded in the last few years with the understanding that environmental settings and social status are salient factors that determine student identity formation. Researchers have begun to understand the importance of belonging [64, 65] and have used belonging as a holistic factor to develop survey instruments [37]. Though the understanding of engineering identity factors has evolved, more work is required to develop reliable and valid survey instruments that can be used in a variety of settings.

5. Measurement Instruments

To answer RQ3, it was observed that some studies borrowed measurement instruments previously developed from other fields. However, most studies were unaware of these identity instruments and failed to utilize instruments already developed. Berzonsky's Identity Style Inventory (ISI3) was one such instrument, only mentioned by one study when citation searching/indexing [5]. The Sustainability and Gender Engineering Survey (SaGE) developed by researchers from Clemson University [66, 67] was used for a number of studies (5/43 = 11.6%) and was most noted by authors that were familiar with the survey and its development [33, 36, 37, 45, 46]. For studies that utilized the SaGE survey, elements from SaGE were later modified to develop a comprehensive measurement instrument specifically for engineering identity [46].

Other notable measurement instruments include the Engineering Identity Factors Survey [38] that examined professional identity and engineering cultural identity however, it does not appear to be widely used. Another emerging instrument specific to engineering identity is the Engineering Student Identity Scale (E-SIS). The E-SIS is constructed from multiple instruments to measure identity and consists of 38 items [60]. Researchers based the instrument heavily on social and identity role theory in the literature. A few studies used a combination of Hazari's physics identity questionnaire, Myers, SaGE, APPLES I or APPLES 2 surveys to construct a comprehensive engineering identity survey [15, 37, 38, 67, 68]. Another instrument was developed to measure affect and identity in professional practice and based survey questions on ABET engineering learning outcome criteria a-k [49]. Finally, a few instruments have been developed since 2018 that seek to predict engineering persistence [37] with overall engineering identity [50] and to validate questions with the use of identity scales [53].

It is notable to mention that other engineering identity instruments exist, such as the Engineering Identity Development Scale (EIDS), for example. However, these instruments are geared more toward understanding identity development in K-12 populations than engineering students in higher education [69].

5.1 Development of Engineering Identity Instruments

As previously mentioned, engineering identity research is disjointed and many of the studies have independently developed their own surveys, tailored to their specific area of interest. However, as mentioned in Section 5, engineering identity instruments that require analysis include use of the Engineering Identity Factors Survey [38], Sustainability and Gender Engineering Survey (SaGE) [33, 36, 37, 45, 46], and Engineering Student Identity Scale (E-SIS) [60]. The first survey that warrants a closer look is the Engineering Identity Factors Survey [38] in Appendix II, Survey 1. This survey examined professional identity and factors that determine engineering cultural identity. As previously noted, this survey has not been widely disseminated or used in the literature. Examples of statements students must indicate they identify with are:

1. Being able to make competent design decisions.
2. Able to teach engineering content to another person.
3. Speaking/communicating using accurate technical terminology.
4. Feeling confident in engineering work without others' confirmation the approach is technically sound.
5. Making moral/ethical decisions considering all factors.

Though these "statements" evoke a sense of identity, the language used throughout the survey warrants improvement. To ensure identity statements are not misleading, wording should be tailored to reflect a sense of active engagement with, or ownership of, rather than passive compliance with, each factor. For example, rewording and replacing, "being able to make competent design decisions" with "I am able to make competent design decisions" or simply, "I make competent design decisions", evokes a stronger sense of awareness and personal reflection within each individual person. Again, this survey has not been widely used in the literature, however, could be used in the future if improvements to the language are explored and validated. The next survey is Sustainability and Gender in Engineering (SaGE) and has been widely used by a team of authors involved in its development [33, 36, 37, 45, 46].

From published works, authors recommend this survey as a valid measurement for science, math, and physics identity, as well as engineering identity. As depicted in Appendix II, Survey 2, excerpts from three questions are listed. Several studies in the literature review indicated this survey was administered to college-level engineering students and they were asked to recount their high school experience in math and physics courses. In addition, this survey asks questions about interactions with high school teachers and their enthusiasm for subject matter as well as parents' level of education and interest in academic subjects.

Reviewing questions on the survey, areas are identified that can relate to interest, recognition, confidence, self-efficacy, performance, and more. However, language in this survey could also be more concise as many of the survey questions may have been indicating one or more results. Since the survey was interested in comparing differences in experience between genders, questions should have been written with gender and bias at the forefront. Again, language could have been more specific to each students' experience to inform researchers of gender differences when data is disaggregated. For example, questions to indicate experience with teachers could have been asked as "treated me with respect" instead of "treated all students with respect". Another question could have asked the gender of the physics or math teacher to indicate a holistic perspective of the environment that could have impacted the student experience. An observation of the types of questions asked, it appears that the SaGE authors compound ideas that may not identify clear concepts in the results. For example, the "teacher was able to, 'handle discipline and manage the classroom'" articulates two separate concepts that could be clarified into "handle discipline" and "manage the classroom".

Finally, the Engineering Student Identity Scale (E-SIS) instrument is based heavily on social and identity role theory. The E-SIS was a hybrid constructed from multiple instruments to measure identity with 38 items [60]. The sole measurement in the study was to gauge identification with being an engineering student. Questions are grouped in sets of three items designed to represent larger themes of distinctiveness, participation, sense of belonging, interest, attitudes, in-group cooperation, and others. Responses for the 38 items were recorded on a 6-point Likert scale from 0 - strongly disagree to 6 – strongly agree. By condensing and grouping factors, researchers were able to identify core value structures that underlie engineering identity. Structural equation modeling also opened the door for other studies to follow suit with simplified versions of questions found to be reliable and validated instruments [45, 46].

6. Discussion

6.1 Constraints

The literature review was performed under significant constraints, such as engineering identity in US higher educational institutions. Specifically, literature was sought that described engineering identity formation from the perspective of women and women of color. Though only a few engineering identity studies exist in this area, historically, the engineering educational community has recognized the disparity of black and Hispanic/Latinx populations' participation in engineering. More work can be done to study underrepresented students and their identity development. Moreover, information on women's participation in specific engineering majors (computer science, electrical engineering, mechanical engineering) was also sought to further identify strategies to build identity in non-traditional, male-dominated disciplines. There were even fewer studies found that tied in majors with identity formation in these populations. Using constraints narrowed the breadth of the literature review and allowed reviewers to identify individual studies dedicated to understanding the experience specifically for women and women of color. The reviewers also recognize that discussing engineering identity in a vacuum, without providing a context for engineering culture and the overall environment in higher education, is deficient. Several studies mentioned "gendered experiences" however, literature included in the review that mentions development of engineering identity in conjunction with the impact of a gendered engineering environment remains sparse.

6.2 Gaps in Literature

There are several gaps that exist in the literature and our understanding of the engineering identity development process, especially in underrepresented populations. Although researchers have assembled multiple factors that describe the engineering experience, engineering identity development is not fully understood itself, nor is it understood within the larger context of higher education. To provide a more robust discussion, engineering identity development in underrepresented populations should contain information on core identity development, intersectionality of multiple identities, and strategies to navigate engineering environmental contexts. The majority discussion regarding engineering identity development is generalized, especially towards an academic or professional identity, and not from a holistic perspective. Therefore, the body of research contains within it a structure of bias, stereotypes, and assumptions that should be disaggregated and addressed.

Scholars should recognize that an individuals' core identity overshadows the formation of their engineering identity. Examination of a baseline for identity in all student subjects is necessary to understand how they will develop over time. Therefore, with engineering identity "factor" questions, researchers should ask for detailed demographic information, coupled with their historical context, to fully assess core identity formation, which few include in their research. Examples include the impact of cultural differences in various regions of the US; influence of family and familial values on core identity formation; and exposure to and acceptance of social norms and values. In addition, student development models should be incorporated that view identity as a longitudinal, ongoing process. Development of engineering identity is dynamic; however, many studies modeled identity as a static endeavor. Within the literature there also was a lack of evidence supporting a correlation of identity formation with retention in engineering. Without connection to student development and retention models, engineering identity research only seeks to understand a singular point in time.

Large-scale, long-term studies were not found therefore, many of the surveys administered in higher education settings were already for students that had (1) self-selected engineering, (2) had been retained at least one semester in engineering, and (3) were currently experiencing the engineering environment that may have had an influence on their opinions. Even when sample sizes were large, the pool of student subjects was found to be narrow. Unless expressly specified, researchers were not examining differences in experience between students from majority vs. underrepresented backgrounds, students with "double-bind" effects, or the impact of gender differences, in general. They also did not examine experience in engineering, coupled with determining factors (e.g., academic success vs. involvement level). The body of literature seemed to pick and choose to examine one or two factors, not fully examining or appreciating the complexity of individuals or engineering identity.

7. Recommendations

To answer RQ4, the following recommendations are further explained to enhance future engineering identity research with emphasis in (1) adopting uniformity across terms and factors that are easily identified; (2) recognizing, understanding and building upon the depth and breadth of research pursued by disciplines other than engineering; (3) correlating engineering identity factors with student success and retention; (4) designing valid measurement instruments specific to engineering identity; and (5) incorporating standards for robust measures, including control or comparison groups, to inform a greater understanding of engineering identity development.

7.1 Cross-Disciplinary Understanding of Engineering Identity

From initial search attempts, it was clear that the field of psychology and education had vast knowledge in the area of identity. However, many of the engineering identity studies failed to recognize, cite, or build from these studies. From an academic identity perspective, Berzonsky was one well-known and prolific researcher in educational psychology that was hardly mentioned within the engineering identity literature. Further, the absence of Berzonsky's Identity Style Inventory (ISI3) as a starting point for engineering identity scale instruments was interesting [5]. Though briefly mentioned in one or two studies, engineering identity research did not correlate known academic identity indicators (diffuse-avoidant, normative, informational identity styles) with retention or "prediction" of maladjustment [7]. Nor did engineering literature indicate how academic identity could be influenced by other factors, such as value orientation [70]. Many of the studies widely accepted the definition provided by Gee in 2001 without realizing the depth of understanding for identity already developed in other fields [9].

In addition, the majority of studies disregarded the body of work available to assist underrepresented populations in engineering and other fields. Due to societal norms, there are a variety of barriers that women and underrepresented minority students face that are distinct from their majority peers. These barriers exacerbate engineering identity construction through marginalization, stereotypes, feeling like an outsider and "code-switching" to navigate various engineering contexts [71]. Interventions recommended by researchers centered on classroom or instructional aids. Only a limited amount of research focused on a holistic student perspective to better inform the impact of minority serving institutions [39], inclusive excellence programs [42], teaming and social interactions [72, 73], or belonging and engineering cultural identity [74]. In addition, there is a large body of research regarding student development of women that could be utilized. For example, one study examined gendered professional identities in industrial engineering context [44] and another belonging in computing for underrepresented students [64]. These studies provide information for the engineering educational community to best serve students. Therefore, the body of scholarly works published on engineering identity should contain a breadth of understanding for cross-disciplinary interventions to develop well-informed theories.

7.2 Student Success and Retention

Though the importance of student success and retention was mentioned in the introduction of several studies, significant results found from the studies did not correlate identity factors with overall student success and retention. To further answer RQ2, one study examined identity and retention but, only from a first-year perspective in freshmen students [27]. Since many of the studies examined first-year students, longitudinal studies to follow-up on surveyed populations could be implemented to better inform whether identity factors truly indicate students will persist or switch from engineering [28]. Longitudinal studies could better inform how preference for individual identity factors change over time.

During analysis, only one study examined the development of engineering identity by participation in a design project to build an electric bicycle for 8th grade students [75]. Another international study found that gendered, problem-based learning environments impacted women [76]. However, these studies were not included within this literature review due to constraints. As previously mentioned, only one study tied results to ABET student learning outcome criteria a–k [37]. Again, more work needs to be done to examine the hands-on aspect of engineering and tie into ABET accreditation student learning outcomes 1–7 (a–k revised in 2019) [77]. For hands-on or project-based learning, observation or portfolio construction have been used as student success evaluation techniques [25]. Though difficult to evaluate, portfolios provide a record of student progress and an opportunity for deep reflection throughout an entire experience; thereby, better informing educational practices to develop identity in engineering students.

7.3 Valid Measurement Instruments

Whether data was presented as qualitative or quantitative, many of the studies consisted of survey instruments or questionnaires that were independently designed by researchers. Because many of the questions were not mentioned in the literature, it is assumed that they varied widely. Within the literature there was little evidence that instruments were developed to ensure reliable or valid measures. In addition, it was apparent that researchers were not necessarily utilizing instruments that were previously developed to determine engineering identity. Therefore, whether significant results were found, it is questionable that researchers' claims are warranted.

Of the studies that used factorial analysis to check validity, further examination of factors indicated that statements were convoluted and contained multiple ideas that should have been disaggregated. Few studies also examined the relationship between factors, strength of factors in identity development, or differences in the pattern of identity factors within majority and underrepresented populations. In many of the studies that used physics identity instruments [15] or SaGE [66, 67], they assumed validity and reliability. Again, there is no consensus for the factors that constitute a well-rounded understanding of engineering identity. Therefore, future work should further develop and refine instruments designed to interpret engineering identity [38, 45, 46, 50, 53, 60].

7.4 Improvements for Experimental Design

Across the literature, significant improvements to experimental design could be made. Experimental design requires a strong understanding of the engineering "system" as a whole to make predictions for engineering identity factors that are specific and testable. Again, many of the studies made assumptions about the engineering educational environment, usually from the viewpoint of a majority perspective [10]. Research questions in most cases were not well defined. In addition, overall study populations were limited to engineering students, without the inclusion of comparison groups in other engineering majors, other majors across the university (non-engineering students), or during different stages in their academic development (first-year vs. graduating senior). Quantitative studies should incorporate larger data sets for comparison across institutions. Again, this would require consensus on instruments used and factors indicated within those instruments. Of the 43 studies reviewed, only six (6/43 = 14.0%) of the studies reviewed utilized a mixed-methods approach to understand student identity development. Future research in engineering education should focus on quasi-experimental design, and incorporate a mixed-methods approach, to ensure a robust understanding and validity of findings.

8. Conclusion

This analysis examined a body of research to better understand the evolution of engineering identity as a concept. First and foremost, engineering identity evolved from psychology and other educational models. Science, math, and physics identity models were tailored to parse out significant factors. This paper highlighted engineering identity factors and exposed the need for reliable and valid survey instruments. Consequently, if the engineering educational community is aware of survey instruments, engineering identity research may become less disjointed.

Further, for the literature to be comprehensive, more needs to be done to craft experimental conditions where students are subject to outside of the classroom. As an engineer, students are required to propose novel ideas, solve grand challenges, and work with teams that are fluid and vertically matrixed. To provide a real-world setting, academia should do more to evaluate identity formation in situations that demand project-based or experiential learning. These include freshmen design projects, capstone design, or competitive project teams that require team-based skills and technical knowledge. These settings, coupled with valid survey instruments, could provide insight to ways engineering identity is formed through active participation in the profession.

Known student success and retention models were not widely incorporated into engineering identity research. A holistic view of how individuals interact with the engineering environment and how the environment impacts their experience is valuable. In addition, other dimensions of understanding are needed to support students from underrepresented or marginalized groups. For example, future scholarship could examine subdisciplines and how underrepresented students develop within these contexts. This could then better inform recruitment and retention efforts, especially for women's participation in non-traditional engineering fields, such as mechanical or electrical engineering. Though it was difficult to determine concrete thematic patterns in the literature overall, it was observed that engineering identity work is in its infancy. Researchers have an opportunity to synthesize knowledge within multiple fields to scale evidence for engineering identity as a singular theoretical concept.

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Appendix I

Systematic Literature Review Research Findings with Survey Instruments

Table 2. Revised from Flether and Shryock, research **s**tudies are listed in chronological order with reference number, population size, method, identity instrument used, and organized into one of six main themes (engineering identity, academic identity, cultural identity, professional identity, gendered identity) and major findings [1].

Primary Author, Year	**Reference**	**Subjects**	**Method**	**Identity Instrument**	**Themes / Findings**
Tate, 2005	[16]	5	Qual	Semi-structured interviews	Engineering identity (EI): academic, social, intellectual
Tonso, 2006	[20]	33	Qual	Observation	Engineering identity (EI): nerds, academic-achievers, greeks
Capobianco, 2006	[21]	24	Qual	Interviews	Professional identity (PI): academic, institutional, gendered, role-models
Rubineau, 2007	[22]	75	Mixed	Observation and surveys	Professional identity (PI): positive peer effects for men, not women
Chachra, 2008	[23]	160	Mixed	Surveys, structured and unstructured interviews, observations	Engineering identity (EI): gender differences in engineering design activities / connect identity and commitment
Dukhan, 2008	[26]	35	Quant	Reflection journal	Engineering identity (EI): identity with service learning
Eliot, 2008	[25]	36	Qual	Professional portfolio / professional statement	Professional identity (PI): purposeful construction of professional identity / internal frame of references / external frame of reference / multiple identities (academic, personal interests, family)
Beam, 2009	[27]	36	Qual	Focus group / interview	Professional identity (PI): identity with recruitment and retention
Foor, 2009	[24]	118	Qual	Semi-structured interviews	Gendered identity (GI): EI perception of field, feminizing disciplines "business" vs. "technical"
Pierrakos, 2009	[28]	8	Qual	Focus group / interview	Professional identity (PI): identity with interest and preparation / recruitment and retention
Cass, 2011	[29]	10,492	Quant	Survey	Academic identity (AI): math constructs predict engineering career choice males/ females
Eliot, 2011	[30]	36	Qual	Survey	Professional identity (PI): external and internal frames of reference
Matusovich, 2011	[31]	20	Qual	Interviews	Engineering identity (EI): men and women, no data disaggregated
Meyers, 2012	[38]	701	Quant	Engineering Identity Factors Survey (EIFS)	Engineering identity (EI): self-identify due to belonging and organizational recognition. Factors to be an engineer: making competent design decisions, working with others, accepting responsibility.
Fleming, 2013	[39]	202	Mixed	Survey and semi-structured interviews	Engineering identity (EI): identity shaped by minority serving institutions (MSI's)
Godwin, 2013	[33]	6,772	Quant	Sustainability and Gender in Engineering (SaGE) survey	Engineering identity (EI): identity coupled with interest, significance for math, physics, science identities

Godwin, 2013	[36]	6,772	Quant	SaGE survey	Engineering identity (EI): significance for math, physics, science identities / personal and global agency
Jones, 2013	[43]	363	Quant	Questionnaire (survey)	Engineering identity (EI): identity with stereotype threat / gender identity
Knight, 2013	[42]	510	Quant	Group identification survey	Engineering identity (EI): access, performance, retention / identity with programs
Cech, 2015	[44]	312	Quant	Survey	Professional identity (PI) / gendered identity (GI): gendered professional identities
Godwin, 2015	[45]	6,772	Quant	SaGE survey	Engineering identity (EI): identity variables are interest, recognition, performance / competence (math) / agency / physics identity
Revelo, 2015	[40]	22	Mixed	Interviews, observations, and surveys	Engineering identity (EI): identity with cultural belonging and "familia" / academic, social, professional identity through SHPE
Godwin, 2016	[46]	3,337	Quant	SaGE survey	Engineering identity (EI): student identity = personal identity (related to individual characteristics), social identity (member of a group), engineering identity (includes interest, performance/ competence, recognition)/ developed from Hazari (2010), physics identity K-12 model
Pierrakos, 2016	[61]	260	Quant	Engineering Student Identity Scale (E-SIS)	Engineering identity (EI): composite unified self-concept, distinctiveness, participation, self-enhancement, visibility of affiliation / citizenship is best
Prybutok, 2016	[56]	563	Quant	Survey	Engineering identity (EI): engineering identity with design efficacy, creativity, global agency as factors
Stoup, 2016	[58]	82	Quant	Survey	Engineering identity (EI): self-concept differentiation (SCD) identity with personality (agreeableness, conscientiousness, extroversion, neuroticism, openness to experience) and authenticity
Tatar, 2016	[59]	915	Quant	Survey	Engineering identity (EI): self-determination theory (SDT), Chickering's seven vectors (competence, interpersonal relationships, manage emotions, autonomy towards interdependence, purpose, identity, develop integrity)
Curtis, 2017	[60]	562	Quant	E-SIS	Engineering identity (EI): measurement instrument development = 38 items/11 factors
Godwin, 2017	[63]	1	Qual	Interview	Engineering identity (EI): subject-related identity / agency with critical engineering identity / social construction of identity / interest, recognition / communities of practice
Henderson, 2017	[57]	397	Quant	Survey	Engineering identity (EI): identity with fixed or growth mindset
Patrick, 2017	[49]	1,288	Quant	Survey	Professional identity (PI): identity measurement instrument aligns w / ABET a-k. Constructs: framing and solving problems, design, project management, analysis, collaboration, tinkering

Borrego, 2018	[53]	1,528	Quant	Survey	Engineering identity (EI): 2 item scale measures professional practice, engineering performance/competence, engineering recognition, engineering interest
Kendall, 2018	[52]	765	Quant	Survey	Engineering identity (EI): professional engineering identity found with HSI Hispanic students / social identity found in PWI Hispanic students
Patrick, 2018	[37]	474	Quant	SaGE Survey	Engineering identity (EI): IPE survey constructed from APPLES, SaGE, Hazari (2010) and Meyers (2012)
Sax, 2018	[64]	1,355	Quant	Building Recruiting and Inclusion Diversity (BRAID) Project Data	Cultural identity (CI): belonging and student climate, underrepresented women and men / yes control group
Verdin, March 2018	[48]	2,916	Quant	Survey Data	Engineering identity (EI): engineering identity with grit in F-Gen students / no effect from performance/competence to identity
Verdin, 2018	[47]	2,916	Quant	Survey	Academic identity (AI): discipline identity with grit, personality, physics identity, math identity, performance/competence (engineering, physics, math)
Choe, 2019	[50]	1,536	Quant	Survey	Engineering identity (EI): framing and problem solving, design, project management, analysis, collaboration, tinkering
Kendall, 2019	[41]	892	Mixed	Survey and interview	Engineering identity (EI): performance/competence, interest, recognition, framing and solving problems, design, project management, analysis, collaboration, tinkering
Kendall, 2019	[51]	184	Quant	Survey	Engineering identity (EI): performance/competence, interest, recognition, framing and solving problems, design, project management, analysis, collaboration, tinkering
Rohde, 2019	[54]	579	Mixed	Survey and interview	Engineering identity (EI): performance/competence, interest, recognition, belonging, academic interest in EE and computing
Taheri, 2019	[65]	1,640	Quant	Survey	Engineering identity (EI): performance/competence, recognition, interest, belonging
Torralba, 2019	[55]	16	Qual	Case Study	Engineering identity (EI): form engineering identity in makerspace

Appendix II

Survey Questionnaires

1. Engineering Identity Factors Survey (Meyers, 2012)

Please read the following statements and indicate whether you feel each is necessary to be considered an engineer:

(1) Being able to make competent design decisions.
(2) Being able to teach engineering content to another person.
(3) Speaking/communicating using accurate technical terminology.
(4) Feeling confident in engineering work without confirmation from others that the approach is technically sound.

(5) Making moral/ethical decisions considering all factors.
(6) Accepting responsibility for the consequences of actions.
(7) Making a long-term commitment to a company.
(8) Making a long-term commitment to a career.
(9) Being able to support a family financially.
(10) Establishing relationships with fellow engineers.
(11) Being able to work with others by sharing ideas.
(12) Committing to engineering as a major.
(13) Committing to the completion of an engineering degree.
(14) Avoiding procrastination on work responsibilities.
(15) Doing your best work – beyond the minimum requirements.
(16) Showing up for class/meetings prepared.
(17) Participating actively in meetings.
(18) Being able to lead a design team/initiative.
(19) Possessing a natural engineering ability.
(20) Excelling in subjects relating to mathematics and science.
(21) Completing the first year of engineering.
(22) Gaining practical engineering experience while still an undergraduate.
(23) Serving as a mentor to another engineering student.
(24) Obtaining full-time employment.
(25) Completing an undergraduate engineering degree.
(26) Completing a graduate engineering degree.
(27) Completing of the 1st stage of professional licensure (FE: Fundamentals of Engineering Examination).
(28) Completing of the 2nd stage of professional licensure (Professional Engineering Examination).
(29) Reaching the age of 22.

2. Sustainability and Gender in Engineering (SaGE) Excerpts

Developed by Researchers at Clemson University: Leidy Klotz (leidyk@clemson.edu), Geoff Potvin (gpotvin@clemson.edu), Zahra Hazari (zahra@clemson.edu).

Question 20. How would you rate your LAST high school PHYSICS teacher on the following characteristics? Likert Scale from 0 (Low) – 6 (High)

Enthusiasm for physics
Treated all students with respect
Explained ideas clearly
Explained problems and answered questions in several different ways
Was able to organize lessons and classroom activities
Was able to handle discipline and manage the classroom
Was available to help students outside of class

Question 27. To what extent do you disagree or agree with the following statements in PHYSICS and MATH. Likert rating in each category 0 (strongly disagree) – 4 (strongly agree)

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

Question 28. In your opinion, to what extent are the following associated with the field of engineering? Rating 0 (not at all) to 4 (very much so)

Creating economic growth	Preserving national security
Improving quality of life	Saving lives
Caring for communities	Protecting the environment

Including women as participants in the field
Including racial and ethnic minorities as participants in the field
Addressing societal concerns
Feeling a moral obligation to other people

Shawna Fletcher, PhD has served as program director in engineering colleges at Texas A&M University, The Ohio State University, and Arizona State University. Her expertise includes developing practical tools to engage underserved students in non-traditional careers and promote strategies to embed inclusive practices within organizations. Academic accomplishments include BS degrees in Microbiology and Physiological Psychology (Neuroscience), with minors in Chemistry and Women's Studies, and an M.S. degree in Bioengineering from Arizona State University; her PhD in Interdisciplinary Engineering was awarded from Texas A&M University. She has been at the forefront of statewide and national efforts for FIRST robotics, the STEM Equity Pipeline Project, TECH CORPS, Project Lead the Way (PLTW), and university-level competitive engineering project teams. Her leadership experience includes serving as President of AZ Promoters of Applied Science in Education (APASE), a non-profit organization and host of the National Underwater Robotics Challenge (NURC); President of Columbus, OH and Brazos Valley, TX Branches for the American Association of University Women (AAUW); and has served on boards for WEPAN (wepan.org), TECH CORPS, and Girl Scouts of NE TX (GSNETX).

Kristi J. Shryock, PhD is the Frank and Jean Raymond Foundation Inc. Endowed Associate Professor in Multidisciplinary Engineering and Affiliated Faculty in Aerospace Engineering in the College of Engineering at Texas A&M University. She also serves as Director of the Craig and Galen Brown Engineering Honors Program and of the NAE Grand Challenges Scholars Program. Her research encompasses helping to form the engineer of the future through a network of transformational strategies she developed that personalizes education using a multifaceted system. These strategies include informing early, addressing preparation for success, increasing diversity of the field, establishing strong identity as an engineer, and enhancing critical and professional skills. The integrated educational toolkit she created allows the educator to understand relationships between and how best to integrate strategies for student success with the objective of preparing the engineer of 2050.