Engineering Identity in Pre-College Students: A Literature Review

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Engineering Identity in Pre-College Students: A Literature Review (Other)

Abstract

In response to increasing demands for engineers, engineering has become a more prominent feature of K-12 education. Additionally, engineering and engineering related topics have become part of many state's standards, further encouraging this growth. Over the last two decades, programs such as Project Lead the Way, Engineering is Elementary, and others have allowed many K-12 schools to incorporate engineering into their offerings. At the same time, many universities, corporations and other youth organizations have offered opportunities for students to learn about engineering outside of the classroom in informal settings. These programs include camps, after school programs, mentoring programs and other programmatic offerings.

If the effect of these experiences on engineering identity are better understood, this understanding will allow engineering identity development to be actively fostered in pre-college students. Engineering identity is one factor tied to recruitment and retention of engineering students, so fostering an engineering identity in pre-college students may help meet the growing demand for engineers. In order to understand the current state of research, a literature review was conducted focused on pre-college engineering identity. This literature review identified existing literature from engineering education and STEM education. The findings from this literature review are used to propose new directions for research.

Background

Engineering has historically been limited to the realm of higher education; however, due to the increasing demand for engineers, recently engineering has been moving into the pre-college environment. Though there were some efforts to introduce engineering to pre-college students in the 1990s, such as Project Lead the Way, which was founded in 1997 [1], there was little in the way of a formalized push to introduce engineering to K-12 students until the late 1900s. In 1998, the Massachusetts Board of Education began developing engineering standards for their K-12 students, which were adopted in 2000 [2]. This is often seen as a turning point for pre-college engineering education with engineering becoming a more common component of K-12 standards in the years that followed. By the end of 2010, engineering was present in the standards of 41 states, though the strength of those standards varied widely from state to state. While some states, such as Massachusetts and Connecticut, had specific engineering standards, others, including Nebraska, Arizona, and West Virginia, only mention engineering in the context of technology design or only mention components of engineering [3]. When reviewing only the science standards for each state, Moore, Tank, Glancy, Kersten and Ntow [4] found that only 13 states referred to engineering explicitly. Other states either referred to engineering implicitly, or their state's science standards made no reference to engineering. With the 2013 release and spreading adoption of the Next Generation Science Standards (NGSS) [5], which includes both engineering design and scientific inquiry, engineering has become a more prevalent part of the K-12 curriculum.

Additionally, engineering has become a more prominent fixture outside of the classroom as well. Organizations such as the Girl Scouts, Boy Scouts and 4-H have all added or reinvigorated

engineering programming in order to introduce more students to engineering [6]–[8] and many universities and companies offer engineering camps or other outreaches to their local communities (e.g. [9]–[11]). Many toys that seek to build STEM skills are available for purchase (e.g. [12], [13]), and STEM-focused children's television shows are available on major networks [14]. As engineering and other STEM disciplines become more a part of day-to-day life for children and teens, it is important to understand how these interactions affect children's views of the engineering field and their place in it.

One way to investigate pre-college students' views of engineering and their place in the engineering field is through the construct of identity. Identity has many definitions, but is often framed around the question "Who are you?" [15], or "the 'kind of person' one is seeking to be and enact in the here and now"[16]. However, since pre-college students are still in the process of making career decisions, it may be more appropriate to look at identity as who students see themselves becoming, such as through the framework of possible future selves [17] or future time perspective [18]. A student's identity has been tied to recruitment and retention in the engineering field (e.g. [19]–[21]), so understanding how identity develops in pre-college students may help meet the growing demand for engineers.

Methods and Scope

The goal of this paper is to investigate the state of the literature regarding engineering identity development in pre-college students. This literature review will serve as an initial overview of the existing literature in preparation for a possible future systematic literature review and will seek to answer the question: *What kind of research has been done regarding engineering identity in pre-college students*? This will be answered by reviewing the literature from 2010 to the present. This range was chosen in order to incorporate the timeframe immediately before the development of the Next Generation Science Standards (NGSS) which began in 2011. The material for review was identified using the databases ERIC and Scopus, in attempts to access both education focused literature and engineering focused literature. The search terms "Engineering Identity" and "STEM Identity" were used in combination with "K-12", "Primary School", "Secondary School", "Elementary School", "Middle School", "High School", "Outreach" and "Camp" to identify articles for review. "Outreach" and "Camp" were chosen to try to identify articles about engineering identity in spaces outside of the K-12 classroom, whereas with "K-12", "Primary School", "Secondary School", "Elementary School", "Middle School", "High School" were chosen to identify engineering identity within the K-12 classroom. The abstracts of each paper were reviewed and used to determine if the paper was appropriate for this literature review. In order to be included in this literature review, the paper needed to be published between 2010 and the present and needed to focus on engineering identity development in pre-college students.

Through this literature review, fifteen articles focused on engineering identity development in pre-college students were identified. These articles are drawn from a variety of journals and conferences, including *Journal of Engineering Education, Science Education, International Journal of Engineering Education,* and the proceedings of the American Society for Engineering Education Conference. The articles were published from 2012 to 2018 and cover a range of settings, including classrooms, camps and other outreach programs.

Limitations

Because of the search terms and sources used, all articles regarding engineering identity in K-12 students may not have been identified. Though both Scopus and ERIC index a wide range of journals and conference proceedings, additional resources, such as additional conference proceedings or journals; may have been identified had another search term or database been used. Additionally, because this literature review focused on academic journals and conferences, information regarding pre-college engineering programs and their effect on students' identity development that may have been published in other venues, such as press releases, books or news stories, may not be included. These include reports such as *Girls, STEM & Careers: Decoding Girls' Future in an Age of Social Media* [22] written by independent organizations.

Results

Table 1, which can be found in the appendix, provides a brief summary for each of the articles identified for this literature review.

Engineering Identity in Middle and High School

The articles that were identified investigate engineering identity from a variety of perspectives, such as gendered perspectives, program effect on engineering identity and retrospective examination of college students' background factors. Articles focused on middle and high school are evaluated together as only one article focusing exclusively on middle school students' identity was identified during the literature review. Programs that introduce students to engineering topics, such as engineering design and the engineering field, were shown to have a positive effect on students' engineering identity (e.g. [22], [23]). These studies varied greatly in length from a set of narrative based engineering lessons over the course of a whole school year [24] to a single encounter with ambassadors from a local university [23]. These studies suggested that their interventions were effective at improving students' engineering identity with the narrative-based lessons being especially effective for students who had poor initial opinions of engineering, and for girls [24].

Additional studies examined engineering identity in female students. These studies seek to shed light on factors which may support identity development in middle school and high school students, in order to improve gender parity in STEM fields (e.g. [25], [26]). Buontempo, Riegle-Crumb and Patrick [25] investigated the factors which influence the gender differences in engineering identity in male and female high school students. They concluded that the primary factors are lower self-efficacy and interest in female students, though this could be mitigated by focusing on improving female students' attainment value, defined as the importance students put on engineering and engineering tasks relative to other fields, for the field of engineering. Kim, Sinatra and Seyranian [26] investigated the impacts of social factors, and concluded that in order to improve women's representation in STEM fields, it is necessary to both support female pre-college students in their STEM identity development and to work to change the larger perception of who pursues a STEM degree. Both studies investigated the importance of relationships,

including peer, family and mentor relationships, on female students' engineering identity, though they came to differing conclusion, as Kim et. al [26] concluded that relationships are key to young women interested in STEM and Buontempo et al. [25] found that relationships have only a moderate effect. Both studies found that young women's belief in their ability to succeed, or their self-efficacy, is a major limiting factor for identity development [25], [26].

Unique in the research around middle and high school engineering identity is an investigation of the background factors that predict engineering students' engineering identity and success factors within an aerospace engineering program [27]. This study examined 98 aerospace engineering students' backgrounds through both qualitative and quantitative measures. Both the qualitative and quantitative data indicated the importance of pre-college engineering experiences on the development of an engineering identity. The authors stated that "we found that taking engineering classes in high school or middle school significantly increases the development of an engineering identity" [27, p. 115]. This study, in combination with the other studies regarding middle and high school engineering identity, shows the importance of this timeframe on engineering identity development.

Engineering Identity in Elementary School

Interestingly, despite the fact that the literature review by Hynes et al. [28] identified comparatively fewer research article in elementary grades, more articles on engineering identity development in elementary grades were identified as part of this review than middle and high school. The topics covered by these articles are similar to those address in the research regarding engineering identity in middle and high school, including examining the impact of various programs, gender differences and factors affecting engineering identity development. Additionally, differences in engineering identity development based on student age and research regarding the facilitation of identity work were discussed in the identified articles.

Most of the articles identified for review focus on the impact of various programs on engineering identity development (e.g. [23], [29], [30], [31]). Many of the studies use the Engineering Identity Development Scale (EIDS), developed by Capobianco, French and Diefes-Dux [32], to quantify this development. The studies which employed EIDS all investigated the implementation of hands-on engineering coursework in the elementary school classroom on the engineering identity of the students. Universally, these studies showed that the hands-on engineering activities in the elementary school classroom improved engineering student identities across genders [29]–[31] and ethnic backgrounds [29]. Additionally, elementary students' engineering identity was also studied after participating in a single-day experience where elementary school students were given the opportunity to participate in a roller-coaster design challenge by a local university's engineering ambassadors [23], which, like the middle and high school students, was found to positively impact elementary school students' identity formation.

Differences in engineering identity development based on student age and gender were also investigated [29]–[31]. These studies which used EIDS [32] to investigate students' engineering identity development, found that male and female students had similar engineering identities both before and after exposure to the hands-on engineering activities. When comparing students

of different grade levels, Capobianco, Yu and French [31] found that the hands-on engineering coursework were found to be more impactful for younger children's engineering identity than their older counterparts. This comparison was done between first through fifth grade students.

In another study, Capobianco, Deemer and Lin [33] sought to determine how engineering identity development occurred over the course of the school year and if this development occurred differently in students of different ages or genders. This study uses EIDS [34] to compare students in third through sixth grade at the beginning, middle and end of the school year, with the engineering interventions occurring between the between the beginning and the middle of the school year and between the middle and end of the school year. Consistent with earlier studies, there were no differences between male and female students, and the younger students (third grade in this study) were most impacted by the engineering interventions. The improvement in engineering identity on the EIDS scale was seen between the beginning and the middle of the school year, across grade levels.

The examination of student and teacher discourse and its influence on engineering identity development was investigated by Kelly, Cunningham and Ricketts [35]. This was done by observing two classrooms of elementary school students completing an engineering unit, and analyzing the discourse between students and teachers. One of these classrooms was a fourth-grade classroom and the other was a second-grade classroom. After analyzing the classroom discourse, the authors identified seven practices as supportive of engineering identity, including addressing students as engineers, using the engineering design process, and celebrating engineering successes. These authors posit that these kinds of discourse processes can help support identity development for minority students who are underrepresented in various STEM fields.

Engineering Identity in Informal Settings

Several articles were identified regarding engineering identity development outside of the classroom (e.g. [9], [36], [37], [38]). STEM camps are the most common experience discussed, but after-school STEM clubs or programs and STEM hobbies are also discussed in the literature. Like the research on engineering identity in K-12 classrooms, these articles focus on the impact of these camps and clubs on engineering identity, as well as specifically investigating these camps and clubs as a way to support underrepresented students in identity development.

STEM or engineering specific camps have become a common way for the STEM community to introduce engineering to students in their communities. These camps are the focus of two of the identified articles (e.g. [9], [37]). Additionally, other articles included informal programs, like camps, as a factor in identity development (e.g. [36], [38]). Hughes, Nzekwe and Molyneaux [9] investigated two camps offered by a national laboratory for middle school students, one co-educational and one all-girl camp, focusing on the effect of these camps on girls' identity development. This work was further extended by Hughes to investigate the longitudinal impact of the all-girls camp [37]. These studies concluded that both of the camps had a positive impact on girls' STEM identity immediately after the camp but that the impact of the all-girls camp does not necessarily translate to girls choosing STEM disciplines in college. The longitudinal study followed eleven girls who participated in the all-girls camp during middle school until the

participants were in college. Six of them ultimately chose a STEM major and five did not. The students who did not choose a STEM major often attributed this to experiences during high school. Additionally, work by Kang, Calabrese Barton, Tan, Simpkins, Rhee and Turner [38] investigated the factors that influence middle school girls of color engineering identity, and identified out-of-school and home experiences as an important influence on engineering identity development for girls of color. Finally, from a survey of approximately 15,000 college freshman (including both engineering students and non-engineering students), participation in STEM clubs, camps, and groups was found to significantly predict a students' perception of themselves as an engineer at the time but that does not necessarily translate to their future perception [36].

Several of these studies also investigated how STEM hobbies and other out of school experiences impacted students' engineering identity. From the survey of college freshmen discussed above, hobbies such as mechanical and electrical tinkering, participation in STEM competitions, and computer programming were determined to be positive influences on feeling like an engineering in the moment and in the future [36]. Kang et al. [38] included STEM-related home experiences as a factor contributing to identity development of middle school girls of color. Additionally, the study of aerospace engineering students' backgrounds, which was discussed earlier, indicated that previous positive STEM experiences, including hobbies and camps, were found to be beneficial to their engineering identity development [27]

Discussion

The articles identified in this literature review show that a wide range of studies regarding engineering identity in pre-college students are being conducted. These studies provide evidence that introducing engineering topics to students of all ages and in many contexts may have a positive effect on students' views of the engineering field and their place within it. These studies provide indications that an early introduction to engineering and other STEM topics may be especially useful to the development of an engineering identity in underrepresented minorities [24]–[26]. Interestingly, it seems that engineering identity does not differ across genders in younger students. This is very different than middle and high school students, where studies show differences between male and female students. However, why elementary school students do not exhibit this gender difference has not been studied. Additional work in these areas can help strengthen and further explain the phenomena observed in these studies.

Across the categories of engineering education in elementary school, middle and high school, and in informal settings, many of the research studies cover similar topics. These topics include program impact on engineering identity, especially focusing on female students, and the desire in the engineering education community to better understand how to support female students as they consider engineering careers (e.g. [39], [40]). These studies showed that the interventions used seemed to be effective for improving engineering identity in pre-college female students, and perhaps other underrepresented minorities. However, many of the interventions that are being investigated only lasted a short period of time (e.g. [23], [24], [29]–[31], [33]–[35], [41]), including interactions as short as one day, or are a retrospective look at factors which influence engineering identity development (e.g. [27], [36]). While these studies provide valuable insight into pre-college engineering identity development of all students, understanding how and what influences engineering identity longitudinally would give a more complete picture, especially

considering previous research which shows a large downturn in interest in math and science for middle school girls (e.g. [42], [43]).

Conclusion and Future Work

Given the breadth of studies identified, but limited depth across the range of studies, more work is needed in order to understand engineering identity development in pre-college students. Fortunately, this area of research appears to be growing, which is consistent with research into K-12 engineering education in general [28]. Though the limits of the literature search stretched back to 2010, more than half of the articles identified for this review were published in 2017 or 2018. As discussed above, further investigation into engineering identity development, especially longitudinal studies, will be important to fully explore how identity develops across students' time in pre-college education. Understanding how engineering identity develops in pre-college students will allow identity development to be supported throughout pre-college education, which may help meet the demands for engineers. Furthermore, while many youth organizations are engaging in engineering or other STEM activities with their members, these organizations seem to be completely absent from the research literature. This may be due to a variety of factors, including that these organizations may focus on programming over research, research that is conducted may not be published, or they may be publishing in venues other than the ones reviewed in this study. Research within these youth organizations may produce insights as to how to develop engineering identities within traditionally underrepresented populations in engineering, such as young women through the Girl Scouts. Additionally, further search terms, including "informal" and "pre-college", have been identified to investigate in future iterations of this work, as they may result in more works regarding engineering identity in pre-college students. This expansion of the search terms may occur during a future systematic literature review. Future work in engineering identity development in pre-college students that will provide further insight into how to support that development, and perhaps understanding and fostering engineering identity development in pre-college students will help meet the growing demand for engineers.

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Appendix

Table 1: Identified articles

Article Title	Author(s)	Age Group	Context
Examining Gender Differences in Engineering Identity Among High School Engineering Students [25]	Buontempo, Riegle-Crumb, Patrick, and Peng	Grades 9-12	Quantitative survey of 459 high school students
Effects of Engineering Design-Based Science on Elementary School Science Students' Engineering Identity Development across Gender and Grade[31]	Capobianco, Yu, and French	Grades 1-5	Qualitative survey of 500+ elementary school students investigating the effect of engineering design-based science
Analyzing predictors of children's formative engineering identity development.[33]	Capobianco, Deemer, and Lin	Grades 3-6	Qualitative survey of 200 elementary school students given over the course of a school year
Engineering Identity Development Among Pre-Adolescent Learners [34]	Capobianco, French, and Diefes-Dux	Grades 1-5	Development of Engineering Identity scale for pre-adolescent students
Boys and girls engineering identity development in early elementary before and after hands-on engineering learning classroom experiences [30]	Douglas, Mihalec-Adkins, and Diefes-Dux	Grades 2-4	Qualitative survey of 818 students, pre- and post-exposure to engineering design instruction
Engaging children in design thinking through transmedia narrative [24]	Ellis, Huff, Rudnitsky, McGinnis-Cavanaugh, and Ellis	Elementary and middle school	Survey of 270 students pre- and post- design thinking intervention.
The Influence of Out-of-school High School Experiences on Engineering Identities and Career Choice [36]	Godwin, Sonnert, and Sadler	First-year college students	Retrospective examination of the experiences of 15,847 first-year college students (includes 2,007 students interested in engineering)
A Mixed-Methods Investigation of Multiple Background Factors Affecting Aerospace Engineering Student Success [27]	Grimes, McFalls-Brown, Mohammadi-Aragh, and Sullivan	First-year college students	Retrospective examination of the high school experiences of 98 aerospace engineering students related to retention and identity

An Investigation Into the Longitudinal Identity Trajectories of Women in Science, Technology, Engineering, and Mathematics [37]	Hughes	College students	A longitudinal study following 11 college-aged women in the years following their participation in a 2-week STEM summer camp
The Single Sex Debate for Girls in Science: A Comparison Between Two Informal Science Programs on Middle School Students' STEM Identity Formation [9]	Hughes, Nzekwe, and Molyneaux	Ages 10-15	Pre- and post- surveys given to 60 students who attended two different STEM summer camps, one co-educational and one all-girls camp
How do middle school girls of color develop STEM identities? Middle school girls' participation in science activities and identification with STEM careers [44]	Kang, Calabrese Barton, Tan, Simpkins, Rhee, and Turner	Middle school	Analysis of 1,821 survey responses regarding STEM identity from middle school girls
Engaging in identity work through engineering practices in elementary classrooms [35]	Kelly, Cunningham, and Rickett	Elementary school	Discourse analysis of two elementary school classrooms engaged in engineering lessons
Developing a STEM Identity Among Young Women: A Social Identity Perspective [26]	Kim, Sinatra, and Seyranian	Middle and high school	Investigation of the factors which influence identity development in female students
An evaluation on engineering identity of K-12 youth using the engineering ambassador network [23]	Wei and Hill	Grades K-12	Pre- and post- surveys from 222 students following a hands-on engineering experience
The Effects of Integrated Science, Technology, and Engineering Education on Elementary Students' Knowledge and Identity Development[29]	Yoon, Dyehouse, Lucietto, Diefes-Dux, and Capobianco,	Grades 2-4	Pre- and Post- surveys for 831 students following integrated science, technology and engineering lessons