Journal of Pre-College Engineering Education Research (J-PEER)

Volume 9 | Issue 2 Article 6

2019

Argument-Driven Engineering in Middle School Science: An Exploratory Study of Changes in Engineering Identity Over an Academic Year

Lawrence Chu
The University of Texas at Austin, chu.lawrence@utexas.edu

Victor Sampson
The University of Texas at Austin, victor.sampson@utexas.edu

Todd L. Hutner
The University of Alabama, thutner@gmail.com

See next page for additional authors

Recommended Citation

Chu, L., Sampson, V., Hutner, T. L., Rivale, S., Crawford, R. H., Baze, C. L., & Brooks, H. S. (2019). Argument-Driven Engineering in Middle School Science: An Exploratory Study of Changes in Engineering Identity Over an Academic Year. *Journal of Pre-College Engineering Education Research (J-PEER), 9*(2), Article 6.
https://doi.org/10.7771/2157-9288.1249

Argument-Driven Engineering in Middle School Science: An Exploratory Study of Changes in Engineering Identity Over an Academic Year

Abstract

The goal of this study was to examine how the use of a new instructional model is related to changes in middle school students' engineering identity. The intent of this instructional model, which is called argument-driven engineering (ADE), is to give students opportunities to design and critique solutions to meaningful problems using the core ideas and practices of science and engineering. The model also reflects current recommendations found in the literature for supporting the development or maintenance of engineering identity. This study took place in the context of an eighth-grade science classroom in order to explore how middle school students' engineering identities change over time as they become more familiar with engineering core ideas and practices. One hundred students participated in this study. These students completed three design tasks during the school year that were created using the ADE instructional model. These students also completed a survey that was designed to measure two important aspects of an engineering identity (recognition and interest) at three different time points. The results of a hierarchical linear modeling analysis suggest that students' ideas about how they view themselves and others view them in terms of engineering did not change over time and their reported interest decreased from one survey to the next. The difficulty of the design tasks and the ways teachers enacted the instructional model are proposed as potential explanations for this counterintuitive finding.

Keywords

engineering education, middle school, attitudes, science and engineering practices, argumentation, instructional model

Document Type

Invited Contributions: Best Papers from ASEE Pre-College Engineering Education

Authors

Lawrence Chu, Victor Sampson, Todd L. Hutner, Stephanie Rivale, Richard H. Crawford, Christina L. Baze, and Hannah S. Brooks

Available online at http://docs.lib.purdue.edu/jpeer

Journal of Pre-College Engineering Education Research 9:2 (2019) 72–84

Argument-Driven Engineering in Middle School Science: An Exploratory Study of Changes in Engineering Identity Over an Academic Year

Lawrence Chu,[1] Victor Sampson,[1] Todd L. Hutner,[2] Stephanie Rivale,[3] Richard H. Crawford,[1] Christina L. Baze,[1] and Hannah S. Brooks[1]

[1] *The University of Texas at Austin*
[2] *The University of Alabama*
[3] *The University of Texas at San Antonio*

Abstract

The goal of this study was to examine how the use of a new instructional model is related to changes in middle school students' engineering identity. The intent of this instructional model, which is called argument-driven engineering (ADE), is to give students opportunities to design and critique solutions to meaningful problems using the core ideas and practices of science and engineering. The model also reflects current recommendations found in the literature for supporting the development or maintenance of engineering identity. This study took place in the context of an eighth-grade science classroom in order to explore how middle school students' engineering identities change over time as they become more familiar with engineering core ideas and practices. One hundred students participated in this study. These students completed three design tasks during the school year that were created using the ADE instructional model. These students also completed a survey that was designed to measure two important aspects of an engineering identity (recognition and interest) at three different time points. The results of a hierarchical linear modeling analysis suggest that students' ideas about how they view themselves and others view them in terms of engineering did not change over time and their reported interest decreased from one survey to the next. The difficulty of the design tasks and the ways teachers enacted the instructional model are proposed as potential explanations for this counterintuitive finding.

Keywords: engineering education, middle school, attitudes, science and engineering practices, argumentation, instructional model

Introduction

An important first step in any effort to increase the number of people who pursue a science, technology, engineering, and mathematics (STEM) degree is to ensure that all students have access to a high-quality STEM education in grades K-12 (National Academies of Sciences, Engineering, and Medicine [NASEM], 2019). One way to ensure that all students have access to a high-quality STEM education is to develop and adopt new academic standards for grades K-12 that require teachers to help students learn to use the core ideas and practices of science, computer science, engineering, and mathematics to explain the world or develop solutions to problems. For example, the new *Framework for K-12 Science Education*, which was used to develop the *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013), was written, in part, "to provide all students with a fair opportunity to learn" (National Research Council, 2012, p. 282).

Any effort to increase students' access to a high-quality STEM education through the use of new academic standards, however, will not do much to increase the number of individuals who decide to pursue a STEM degree if the learning experiences that take place in grades K-12 put some students at a disadvantage or hinder the development or maintenance of STEM interests, aspirations, or identity (e.g., Penuel, 2016; Philip & Azevedo, 2017). It is therefore important to develop new curricular materials and instructional approaches that will not only increase access and opportunities to learn engineering core ideas and practices but also do so in a way that is equitable and inclusive (Moore, Stohlmann, Wang, Tank, & Roehrig, 2014; National Academy of Engineering & National Research Council, 2009; NASEM, 2019; Purzer, Moore, Baker, & Berland, 2014).

With this goal in mind, our group has developed a new instructional model, called argument-driven engineering (ADE), that gives students an opportunity to use the core ideas, crosscutting concepts, and the practices of science and engineering to develop solutions to meaningful problems. In order to ensure that all students have access to STEM experiences in middle school, we designed this instructional model so it can be used in science classrooms rather than in an engineering course. In contrast to engineering classes, which are typically offered as elective courses, science courses are required for all students. As such, we decided to develop an instructional model that can be used in science classrooms because it increases the likelihood that all students enrolled in a school, and not just a select few, will have an opportunity to gain familiarity with the nature of engineering. We also designed this instructional model so that it reflects current recommendations found in the literature about ways to improve student attitudes toward engineering (Committee on K-12 Engineering Education, 2009) and ways to encourage young people, particularly girls and under-represented minorities, to consider engineering as a career option (National Academy of Engineering [NAE], 2008). The purpose of this study was to explore how students' engineering identity changed over time as they completed a series of design challenges following the ADE instructional model in order to conduct an initial test of its potential and promise as a way to increase access and ensure opportunities to learn engineering core ideas and practices are equitable and inclusive.

In the sections that follow, we first define engineering identity in light of the frameworks most relevant to this study. We then review the literature of the impact of K-12 engineering experiences on student engineering identity. Thirdly, we provide the research question guiding our study. We then detail the methods for data collection and analysis. Next, we provide the results of our study. Finally, we conclude the article by discussing the findings in light of the literature on pre-collegiate engineering education and highlighting the implications of this study for future research and instructional design.

Theoretical Framework: Engineering Identity

Our theoretical framework starts with the assumption that choices regarding college major and career pathways are influenced by the disciplinary identity of the student (e.g., Godwin, Potvin, Hazari, & Lock, 2013; Jones, Osborne, Paretti, & Matusovich, 2014). That is, when a student holds a "strong" engineering identity, they are likely to pursue engineering majors upon entering college and to seek employment as an engineer upon entering the workforce. Conversely, when students hold a "weak" or non-existent engineering identity, they are less likely to major in engineering or to seek out an engineering or engineering-related career. An engineering identity is shaped by experiences and repeated interactions with others.

There are numerous ways to define engineering identity. Morelock (2017), for example, described four perspectives that researchers often use to define engineering identity. These perspectives include definitions that are based on:

1. other aspects of individuals' identities,
2. individuals' self-perceptions and perceptions of engineering as a profession,
3. a set of cognitive, affective, and performance-related variables, and
4. the agency of individuals within the engineering profession.

We situate our definition of identity in the third perspective, where identity comprises a set of cognitive, affective, and performance-related variables. For the purposes of the study, we define identity as comprising of two variables. These variables, which are adapted from Godwin, Potvin, Hazari, and Lock (2016), include engineering recognition and engineering interest.

We define *engineering recognition* as the degree to which students perceive their parents, teachers, and friends as recognizing them as an engineer. Such forms of external recognition have been shown to predict students' identity in both mathematics and physics (Cass, Hazari, Cribbs, Sadler, & Sonnert, 2011; Hazari, Sonnert, Sadler, & Shanahan, 2010) and have been shown to have a similar explanatory impact in engineering as well (Godwin et al., 2013). Parents' perceptions of their students' disciplinary abilities affect students' self-perceptions of their own ability (Bleeker & Jacobs, 2004; Smith, 1991; Turner, Stewart, & Lapan, 2004). Teachers, too, impact students' eventual career choices, particularly in the physical sciences and for female students in high school (Ivie, Cuzjko, & Stowe, 2001). And even when parental influence on identity is absent, the perception of being recognized by friends for one's ability in the domain plays an important explanatory role in eventual interest in the field (Speering & Rennie, 1996).

We define *engineering interest* as the degree to which students find interest in doing engineering. We postulate the more interested a person is in a domain (e.g., engineering, quilting, hiking, etc.), the more frequently they will spend time engaging with that domain. And, the more time one spends engaging with a domain, the more one identifies as a member of that community. In the context of engineering, the more interested a student is in engineering, the more they will choose to engage in engineering experiences. And, the more time the student spends doing engineering, the stronger their engineering identity will become.

Engineering identity formation or maintenance is an important outcome to consider when attempting to increase the number of girls and students of color who pursue engineering degrees upon entering college (McCave, Gilmore, & Burg, 2014) and to promote a more diversified engineering workforce (National Science Foundation, 2017). Individuals' identities develop from the ways they learn in different settings and based on the cultural beliefs that result from participating in those environments (Holland, 2001; Stevens, O'Connor, Garrison, Jocuns, & Amos, 2008). Tonso (2014) explains how, at the post-secondary level, engineering campuses frame the development of students' engineering identity, and the programs in which students participate serve as experiences which influence their engineering identity. As a result, these programs hold the power to influence which behaviors are perceived as desirable and which define what it means to be an engineer over others. In other words, certain behaviors are viewed as "things engineers do" and, when a person exhibits these behaviors, they are perceived as being an engineer. For example, social skills, which are negatively perceived as being feminine qualities (Faulkner, 2007; Tonso, 2007), are often devalued in engineering communities. Yet, social skills are viewed as increasingly important for engineers in the modern work environment.

Given the importance of social forces such as these for the development or maintenance of engineering identity, asset-based perspectives used early on in an individual's education can serve to provide beneficial engineering learning experiences for girls and students of color (Llewellyn et al., 2016). The use of educational experiences that value the cultural and social capital of all students, along with the various knowledges and backgrounds that students bring with them is a way to provide an environment that supports the positive development of all students' engineering identities. This is something that the ADE framework seeks to emphasize in its design and implementation in middle school science classrooms.

Literature Review

Others have looked at identity as being influential in college and career choice relating to engineering. For example, Beam, Pierrakos, Constantz, Johri, and Anderson (2009) conducted focus group interviews with undergraduate freshmen and utilized a case study approach to better understand the development of professional engineering identity. They found that the strength of the relationship between students' engineering identities and the degree to which they related to the engineering profession came from those students' exposure to and familiarity with engineering, particularly through formal and informal engineering experiences during their pre-college education. Their identities were also dependent on their knowing of or being introduced to an engineer during that period of time. The study noted limitations of not having longitudinal data on identity development and of lacking broader sampling across educational settings, as all participants came from a single institution. Additionally, while helpful in exploring some of the constructive factors potentially contributing to the development of engineering identity, the methodological constraint of only using case studies and solely sampling undergraduate students does little to provide empirical evidence of the effective implementation of its findings among pre-college student populations.

Another study by Danforth, Lam, Mehrpouyan, and Hughes (2016) did focus on high school students and utilized a summer outreach program geared toward encouraging college participation and the pursuit of engineering degrees. Those authors found that, as a result of the program, students' interest in attending the university associated with the study increased on a survey of student attitudes. Also, students' engineering content knowledge, as demonstrated on a self-developed instrument, increased from pre- to post-test. While the findings may provide useful information for the implementation of this specific summer program, the study was limited by the use of non-validated instruments in the measurement of student attitudes and engineering knowledge. Also, given the nature of the program, findings from the study may only be relevant to students who voluntarily selected to participate in the summer outreach, limiting their application in formal K-12 settings.

Using a different approach, Baldwin, Daniel, and Williams (2016) developed an engineering design course for middle school and high school students that met over ten Saturdays for two hours each week. The course introduced students to the engineering design process and focused on the development of "teamwork, problem solving, and verbal communication skills" (p. 2). It involved five design projects that incorporated research components and design criteria and constraints. The authors showed that students' engineering interest and self-efficacy was maintained during the course and that students also improved their understanding of engineering and of what engineers do. As noted by the authors, the study looked to eventually implement the courses more broadly and to study the particular aspects of the program associated with the attitudinal gains. As a weekend course, questions still remain with regards to what implementation at the formal classroom level would look like for all students.

Along these lines, Lachapelle and Cunningham (2017) used an engineering curriculum implemented across a number of participating elementary schools. Their "treatment" curriculum had students engage with design challenges that required the use of scientific ideas. While the treatment condition received a more open-ended, authentically based experience of engineering, the "comparison" curriculum lacked a design challenge context and was implemented in a more closed-ended, directed instruction format (p. 3). Results from the study showed that students participating in the treatment curriculum demonstrated a higher enjoyment, desire to learn, and valuation of engineering than those in the comparison group. While this study took place in elementary classrooms and utilized instruments that were tested for reliability through the use of factor models, it lacked discussion of the particular curricular and pedagogical elements that may have contributed to the gains seen on these attitudinal measures.

This research, when taken together, suggests a need to study the identity formation of middle school students as they participate in engineering design within a science class. Prior work often focuses on identity formation in older students, yet career identity formation starts much earlier than high school (Turner & Lapan, 2005). Work with younger students often is situated in out-of-school contexts, thereby limiting the applicability of this work to students who have access to such extracurricular opportunities. Thus, research is needed on the formation of engineering identity in science classes when students participate in engineering design.

Purpose of the Study and Research Questions

The objective of this study is to examine participation in ADE in relation to changes in middle school students' engineering identity over time. This study of engineering identity is important not only for developing new curricula and pedagogy for engineering in science classrooms, but also for addressing nationwide problems with diverse representation and participation in engineering degree programs and occupations. This current study contributes to the current base of knowledge in that it takes place in the context of a middle school science classroom and provides engineering experiences to all students in the class. It is predicted that, as students become more familiar with and grow in their ability to participate in the practices that engineers use and apply in their professional work, those students will identify more as central members of the scientific and engineering community. Given this objective, the research question guiding this study is: How does participation in three STEM design challenges—developed using the ADE instructional framework—during a science course affect students' engineering identity over time?

Methods

ADE Overview

The ADE instructional model is unique among efforts to increase access to engineering experiences for students in three important ways. First, it is intended to be implemented in science classes and not as a standalone elective. Thus, all students have an opportunity to participate in engineering design. Second, ADE is different from what is generally seen in the literature in that the framework fits within a two-week period, not an entire semester as prior design-based instructional frameworks require. Finally, ADE places a unique emphasis on argumentation and writing, in line with the NGSS engineering practices of arguing from evidence and obtaining, evaluating, and communicating information (NGSS Lead States, 2013).

The ADE model serves as a template for the implementation of STEM design challenges (SDCs) that are compatible with middle school science courses. ADE specifies a sequence of activities that allow students to engage in engineering design by incorporating disciplinary core ideas and mathematics principles, use evidence-based argumentation to develop and critique design solutions, and participate in collaborative and individual learning through writing and discourse. An SDC is the context through which students participate in the ADE instructional framework. That is, an SDC specifies the problem that students need to solve (e.g., developing a highway crash safety barrier) and highlights ways that the solution to the problem benefits others. The ADE instructional framework consists of eight stages (see Table 1). These stages are *introducing the problem*, *concept generation*, *concept selection*, *design argumentation*, *design testing*, *evaluation argumentation*,

Table 1
STEM design challenge (SDC) stages.

SDC stage	General components
Introducing the problem	• Provide design challenge • Identify needs and constraints
Concept generation	• Research the problem • Generate concepts
Concept selection	• Determine criteria for evaluation • Concept evaluation
Design argumentation	• Concept design argument • Critique and feedback
Design testing	• Iterations of the design • Testing and evaluation
Evaluation argumentation	• Design evaluation argument • Critique and feedback
Report development	• Written report • Critique and feedback
Reflection and discussion	• Reflect on product and process • Develop plans for future work

http://dx.doi.org/10.7771/2157-9288.1249

report development, and *reflection and discussion*. Implementation of all eight stages of the ADE instructional framework involves active student engagement in science and engineering practices. Depending on teacher implementation, each SDC takes 300–400 minutes to complete.

ADE provides teachers with a way to emphasize the use of core ideas and practices of engineering, mathematics, and science to develop a solution to a problem. A key feature of this instructional model is the provision of multiple opportunities for students to participate in argumentation. Here, "argumentation" is used to describe the process of proposing, supporting, challenging, and refining claims (Sampson & Clark, 2008). This focus on argumentation during the engineering design process encourages students to focus on "how they know what they know" as they develop, evaluate, and refine solutions to problems. Furthermore, this instructional model encourages students to use evidence-based decision-making and exposes students to the knowledge-building practices of the scientific and engineering community (Bricker & Bell, 2008; Duschl, Schweingruber, & Shouse, 2007).

ADE is unique in that it is intentionally developed to be an instructional model and not a specific curriculum. As an instructional model, it can be used as a template for other curriculum developers, which is important since teachers often adapt curricula in ways that deviate from the research-based principles with which those curricula initially aligned (Cronin-Jones, 1991; McLaughlin, 2006). The design of the instructional model is intended to optimize widespread adoption, in light of teacher and classroom limitations, thus maximizing student learning of engineering.

Context

We developed four SDCs using the ADE instructional model, with each SDC corresponding to one of the four NGSS student performance expectations for middle school that specifically incorporate engineering practices. The data we report in this paper are related to three of the four SDCs: *Developing a Passive Vaccine Storage Device*, *Developing a Hand Warmer for Homeless Individuals*, and *Developing a Biodiversity Monitoring Device*. Table 2 lists each SDC along with the NGSS disciplinary core ideas and engineering standards covered by each.

The three SDCs were implemented in all eighth-grade science classes in two middle schools in a southern state of the USA. These two schools were selected because of a pre-existing relationship between the researchers and the school district. The district recommended working with the selected schools because both the principals and the teachers were generally receptive to implementing novel and innovative instructional practices. Data from this study come from one of the two middle schools—Delorean Middle School (DMS). DMS is located in a city with a population of just over 100,000. It has an enrollment of over 1,000 students. The student body is 39% Hispanic, 36% White, 14% African American, and 5% Asian. In this school, 32% are eligible for free or reduced-price lunch, and 8.5% of the students are English language learners. It is located near a large metropolitan city known for being a major hi-tech center.

Two teachers at the school agreed to participate in the study. One teacher is a middle-aged African American woman who has been a teacher at the school for three years and had previously worked as a researcher in a science industry. The other teacher is a middle-aged White male who taught for over 20 years in a private school prior to working at this school.

Sample

A total of 103 students from the two teachers' classes assented and received parental consent to participate in this study. All of these students participated in the SDCs in their classes. However, only 75 students completed all three surveys and answered the demographic questions. Student demographics of this sample are available in Table 3. We did not include a comparison group because our objective in this exploratory study was to examine changes in student engineering identity as a first test of promise and potential of this new approach.

Data Collection

The survey instrument used for this study was adopted from the items developed by Godwin (2016) for the measurement of engineering identity. The three latent constructs tested in the original scale were recognition (e.g., "My parents see me as an engineer"; Cronbach's alpha = 0.77), interest (e.g., "I am interested in learning more about engineering"; Cronbach's alpha = 0.89), and performance/competence (e.g., "I am confident that I can understand engineering in class"; Cronbach's alpha = 0.88). The author reported good model fit via overall fit indices (CFI = 0.96; TLI = 0.95; RMSEA = 0.077).

The survey was administered at three time points. This first administration was before students started the first SDC, the second administration of the survey took place after the second SDC, and the final administration was after the students finished the third SDC. Although teachers were asked to give surveys as soon as possible after finishing an SDC, surveys were generally administered within two weeks of SDC completion. The period of time between Surveys 1 and 2 was eight weeks, and the time between Surveys 2 and 3 was twelve weeks.

Data Analysis

Responses on the survey were scored from 0 to 6, with 0 representing strongly disagree, and 6 strongly agree.

Table 2
Description of the four STEM design challenges (SDCs).

SDC	Performance expectations	Disciplinary core ideas	Science and engineering practices
Developing a Passive Vaccine Storage Device	MS-PS3-3: Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer	Energy is spontaneously transferred out of hotter region or objects and into colder ones	• Designing solutions ◦ Undertake a design project to construct a solution that meets specific needs and constraints ◦ Evaluate potential designs based on prioritized criteria • Planning and carrying out investigations ◦ Plan an investigation and identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed
Developing a Hand Warmer for Homeless Individuals	MS-PS1-6: Undertake a design project to construct, test, and modify a device that either releases or absorbs thermal energy by chemical processes	Some chemical reactions release energy, others absorb and store energy	• Analyzing and interpreting data ◦ Apply concepts of statistics to analyze and use graphical displays to characterize trends or relationships in data • Designing solutions ◦ Optimize performance of a design by prioritizing criteria, making tradeoffs, and revising a design • Engaging in an argument from evidence ◦ Make a written argument that supports the performance of a device based on empirical evidence concerning whether or not the technology meets relevant criteria and constraints
Developing a Biodiversity Monitoring Device	MS-LS2-5: Evaluate competing design solutions for maintaining biodiversity and ecosystem services	Biodiversity describes the variety of species found in Earth's terrestrial and oceanic ecosystems. The completeness or integrity of an ecosystem's biodiversity is often used as a measure of its health	• Analyzing and interpreting data ◦ Apply concepts of statistics to analyze and use graphical displays to characterize trends or relationships in data • Designing solutions ◦ Optimize performance of a design by prioritizing criteria, making tradeoffs, and revising a design • Engaging in an argument from evidence ◦ Make a written argument that supports the performance of a device based on empirical evidence concerning whether or not the technology meets relevant criteria and constraints
Developing a Highway Crash Safety Barrier	MS-PS2-1: Apply Newton's third law to design a solution to a problem involving the motion of two colliding objects	For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction	• Designing solutions ◦ Undertake a design project to construct a solution that meets specific needs and constraints • Planning and carrying out investigations ◦ Evaluate potential designs based on prioritized criteria ◦ Plan an investigation and identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed

Note. Under 'Science and engineering practices,' solid bullets points denote relevant practices while open bullet points represent the components of the practices aligned to each SDC.

Prior to the main analysis, an exploratory factor analysis was conducted for the original 11 items (using scores from Survey 1) to combine related items and create composite scores. The purpose of the exploratory factor analysis was to confirm the constructs under which these items factored in the original measurement tool (Godwin, 2016) and to better understand how the latent constructs underlying the items were impacted by the addition of new items and the exclusion of certain others from the original tool.

We identified six items that measure two different factors (see Table 4) that are aligned with our theoretical framework. The first factor is *engineering recognition.* This factor measures the degree to which students identify themselves and perceive their family, teacher, and friends as recognizing them as an engineer. Higher scores on this factor indicated a greater sense of recognition as an engineer. The second factor is *engineering interest*. This factor measures the degree to which students find interest in doing engineering. Higher scores on this measure indicate greater degrees of interest in engineering.

We then conducted a growth curve analysis to examine how engineering identity changed over time, specifically on the factors of *engineering recognition* and *engineering interest*. We decided to use a growth curve analysis because it addresses the effect of individual variables on the status of outcomes at time = 0 (defined by the researcher). We decided to use hierarchical linear modeling for the growth curve analysis because it allows for unequal time intervals and nonsynchronous measurement of repeated measures (Raudenbush & Bryk, 2002).

Student survey data were input into SPSS as two separate SPSS files, one for each level of analysis. Level 1 data comprise repeated measures, which are within-persons occasions, with *time* being the only predictor. Each student was assigned a summarized rating score at each time point for both *recognition* and *interest*, a score that equals the mean of the items factoring under each respective construct (Carifio & Perla, 2008). Level 2 data include the student-level predictors which in this study included gender, coded as *female* (dummy coded male = 0, female = 1); *ethnicity*, which included White, Hispanic/Latino, Black/African American, Native American/American Indian, Asian/Pacific Islander, other, and multiple, but which was recoded as *ethnicity_rec*, dummy coded as 0 = White, 1 = all other ethnicities (Asian/Pacific Islander was originally grouped with White as a minority group over-represented in engineering (National Science Foundation & National Center for Science and Engineering Statistics, 2017). However, because the label included both Asian and Pacific Islander and the literature has shown the "Asian" label to be problematic (Corwyn & Bradley, 2008; Kao, 1995), the decision was made to keep Asian/Pacific Islander in a separate grouping); and *knowing an engineer*, coded as 0 = knows an engineer, 1 = does not know an engineer. The *time* variable was recoded (*time_rec*) such that the repeated measures coded Survey 1 = −2, Survey 2 = −1, and Survey 3 = 0. This way, the interpretation of the coefficient as associated with the expected outcome score when time = 0 represents time at Survey 3. The variables chosen at Level 1 included student IDs (recoded as integers from 1 to 75), *time_rec*, *recognition*, and *interest*, and the variables chosen at Level 2 included the same recoded student IDs, as well as *female*, *ethnicity_rec*, and *KnowEngineer*.

Table 3
Frequencies of student demographics.

Demographic	*n*	%
Sex		
Male	37	49%
Female	38	51%
Total	75	100%
Race/ethnicity		
Asian/Pacific Islander	8	11%
Black/African American	5	7%
Hispanic/Latino	22	29%
Native American/American Indian	1	1%
White	29	39%
Multiple	1	1%
Other	9	12%
Total	75	100%
Know an engineer		
Yes	34	45%
No	41	55%
Total	75	100%

Results

Mean scores by each item on the survey for each administration are shown in Table 5.

Table 4
Survey items comprising the factors of interest.

Factor	Cronbach's alpha	Mean (pre-survey)	Survey items
1: Engineering recognition	0.823	2.43	My family sees me as an engineer My teacher sees me as an engineer My friends see me as an engineer
2: Engineering interest	0.896	3.18	I want to learn more about engineering I enjoy engineering I see myself pursuing a career in engineering

Table 5
Frequencies of responses by survey items.

Survey items	Survey 1			Survey 2			Survey 3		
	Mean	N	SD	Mean	N	SD	Mean	N	SD
a My family sees me as an engineer	2.73	74	1.80	2.78	72	2.00	2.83	75	1.85
b My teacher sees me as an engineer	2.50	72	1.38	2.69	72	1.74	2.53	75	1.66
c My friends see me as an engineer	2.01	74	1.85	1.90	72	1.86	1.85	75	1.84
d I want to learn more about engineering	4.14	74	1.83	3.49	72	1.99	3.23	75	1.98
e I enjoy engineering	3.71	75	1.92	3.46	72	1.92	3.25	75	1.89
f I see myself pursuing a career in engineering	2.54	74	2.01	2.31	72	2.07	2.45	75	1.93

Table 6
Output from unconditional model with *recognition* as outcome.

Final estimation of fixed effects (with robust standard errors)					
Fixed effect	Coefficient	Standard error	t-ratio	Approx. d.f.	p-value
For INTRCPT1, π_0					
INTRCPT2, β_{00}	2.402	0.180	13.348	74	<0.001
For TIMEREC slope, π_1					
INTRCPT2, β_{10}	−0.020	0.076	−0.262	74	0.794
Final estimation of variance components					
Random effect	Standard deviation	Variance component	d.f.	χ^2	p-value
INTRCPT1, r_0	1.449	2.100	74	504.113	<0.001
TIMEREC slope, r_1	0.471	0.222	74	149.287	<0.001
level-1, e	0.655	0.430			

Engineering Recognition

An unconditional model for *recognition* was first set up. The outcome variable was *recognition*, and *time_rec* was added as the predictor, uncentered. The residual (r_1) was selected to allow growth rate to vary across persons. The models were as follows:

Level 1: $RECOGNITION_{ti} = \pi_{0i} + \pi_{1i}*(TIMEREC_{ti}) + e_{ti}$

Level 2: $\pi_{0i} = \beta_{00} + r_{0i}$

Level 2: $\pi_{1i} = \beta_{10} + r_{1i}$

After inspecting graphs of all student cases, the functional form, though varying, seemed to be linear. Thus, a linear functional form was determined to be most fitting. Analysis of the unconditional model yielded the results shown in Table 6.

From the results shown in Table 6, on average, the engineering recognition score at Survey 3 (β_{00}) was 2.40. The t test result suggests that this recognition score is different from zero in the population ($p < 0.001$). The change in engineering recognition score from one survey to the next (β_{10}) was not different from zero in the population ($t = -0.262$, $p = 0.794$). The variance in recognition score at Survey 3 is 2.10. The statistical test result suggests that the recognition score at the third survey differs across students in the population ($\chi^2 = 504.113$, $p < 0.001$). The variance in engineering recognition growth rate is 0.22. The statistical test result suggests that recognition growth rates vary across students in the population ($\chi^2 = 149.287$, $p < 0.001$).

Because variance in engineering recognition scores at Survey 3 and the growth rate varied across students in the population, a conditional model was set up in an attempt to explain this variance with predictors. In the Level 2 equations, *Female*, *KnowEngineer*, and *Ethnicity_rec* were added as explanatory variables, all uncentered. The models were as follows:

Level 1: $RECOGNITION_{ti} = \pi_{0i} + \pi_{1i}*(TIMEREC_{ti}) + e_{ti}$

Level 2: $\pi_{0i} = \beta_{00} + \beta_{01}*(FEMALE_i) + \beta_{02}*(KNOWENGI_i) + \beta_{03}*(Ethnicity\_rec_i) + r_{0i}$

Level 2: $\pi_{1i} = \beta_{10} + \beta_{11}*(FEMALE_i) + \beta_{12}*(KNOWENGI_i) + \beta_{13}*(Ethnicity\_rec_i) + r_{1i}$

Analysis of the conditional model yielded the results shown in Table 7.

From the results in Table 7, it can be seen that, by holding knowing an engineer and ethnicity constant, females have a recognition score that is 1.08 points less than that of males at Survey 3 (β_{01}). This relationship between gender and recognition is statistically significant ($t = -3.271$, $p = 0.002$). After including *Female*, *Know-Engineer*, and *Ethnicity_rec* in the model, the variance remaining in engineering recognition score is 1.60. The proportion of variance explained (PVE) for final status is 0.24, which suggests that 24% of variation in Survey 3 recognition scores is due to the predictors included in the model. The statistical test result suggests that variance still remains in the population ($\chi^2 = 383.664$, $p < 0.001$). After including these explanatory variables in the model, the variance remaining in the growth rates is 0.23.

Table 7
Output of conditional model with *recognition* as outcome.

Final estimation of fixed effects (with robust standard errors)					
Fixed effect	Coefficient	Standard error	*t*-ratio	Approx. d.f.	*p*-value
For INTRCPT1, π_0					
INTRCPT2, β_{00}	3.500	0.281	12.433	71	<0.001
FEMALE, β_{01}	−1.079	0.330	−3.271	71	0.002
KNOWENGI, β_{02}	−0.671	0.338	−1.985	71	0.051
ETHNICITY, β_{03}	−0.364	0.319	−1.144	71	0.256
For TIMEREC slope, π_1					
INTRCPT2, β_{10}	0.101	0.141	0.715	71	0.477
FEMALE, β_{11}	−0.203	0.140	−1.453	71	0.151
KNOWENGI, β_{12}	−0.026	0.144	−0.179	71	0.858
ETHNICITY, β_{13}	−0.007	0.154	−0.049	71	0.961
Final estimation of variance components					
Random effect	Standard deviation	Variance component	d.f.	χ^2	*p*-value
INTRCPT1, r_0	1.265	1.601	71	383.664	<0.001
TIMEREC slope, r_1	0.478	0.229	71	145.457	<0.001
level-1, *e*	0.656	0.430			

Table 8
Output from unconditional model with *interest* as outcome.

Final estimation of fixed effects (with robust standard errors)					
Fixed effect	Coefficient	Standard error	*t*-ratio	Approx. d.f.	*p*-value
For INTRCPT1, π_0					
INTRCPT2, β_{00}	2.932	0.202	14.525	74	<0.001
For TIMEREC slope, π_1					
INTRCPT2, β_{10}	−0.255	0.084	−3.046	74	0.003
Final estimation of variance components					
Random effect	Standard deviation	Variance component	d.f.	χ^2	*p*-value
INTRCPT1, r_0	1.594	2.539	74	412.462	<0.001
TIMEREC slope, r_1	0.439	0.193	74	116.938	0.001
level-1, *e*	0.815	0.664			

The statistical test result suggests that variance in the growth rates remains in the population, after including *Gender*, *KnowEngineer*, and *Ethnicity_rec* ($\chi^2 = 145.457$, $p < 0.001$).

Engineering Interest

Next, an unconditional model for *interest* was set up. The outcome variable was changed to *interest*. The models were as follows:

Level 1: $INTEREST_{ti} = \pi_{0i} + \pi_{1i}*(TIMEREC_{ti}) + e_{ti}$

Level 2: $\pi_{0i} = \beta_{00} + r_{0i}$

Level 2: $\pi_{1i} = \beta_{10} + r_{1i}$

Looking at graphs of all student cases, the functional form seemed to be linear. Thus, a linear functional form was determined to be most fitting. Analysis of the unconditional model yielded the results shown in Table 8.

From the results shown in Table 8, on average, students decrease in engineering interest by 0.26 points from one survey to the next (β_{10}). This decrease is greater than zero in the population ($t = -3.046$, $p = 0.003$). The variance in interest score at Survey 3 is 2.54. The statistical test result suggests that the interest score at the third survey differs across students in the population ($\chi^2 = 412.462$, $p < 0.001$). The variance in engineering interest growth rate is 0.19. The statistical test result suggests that interest growth rates do vary across students in the population ($\chi^2 = 116.938$ $p = 0.001$).

Because variance in engineering interest scores at Survey 3 and in engineering interest growth rates varied across students in the population, a conditional model was set up in an attempt to explain this variance with predictors. In the Level 2 equations, *Female*, *KnowEngineer*, and *Ethnicity_rec* were added as explanatory variables, all uncentered. The models were as follows:

Level 1: $INTEREST_{ti} = \pi_{0i} + \pi_{1i}*(TIMEREC_{ti}) + e_{ti}$

Level 2: $\pi_{0i} = \beta_{00} + \beta_{01}*(FEMALE_i) + \beta_{02}*(KNOWENGI_i) + \beta_{03}*(Ethnicity\_rec_i) + r_{0i}$

Level 2: $\pi_{1i} = \beta_{10} + \beta_{11}*(FEMALE_i) + \beta_{12}*(KNOWENGI_i) + \beta_{13}*(Ethnicity\_rec_i) + r_{1i}$

Analysis of the conditional model yielded the results shown in Table 9.

From the results in Table 9, it can be seen that, holding constant ethnicity and knowing an engineer, engineering interest among females is less than males by 1.32 points at Survey 3 (β_{01}). This relationship between gender and

Table 9
Output of conditional model with *interest* as outcome.

Final estimation of fixed effects (with robust standard errors)					
Fixed effect	Coefficient	Standard error	*t*-ratio	Approx. d.f.	*p*-value
For INTRCPT1, π_0					
INTRCPT2, β_{00}	3.993	0.303	13.166	71	<0.001
FEMALE, β_{01}	−1.317	0.339	−3.883	71	<0.001
KNOWENGI, β_{02}	−1.159	0.341	−3.398	71	0.001
ETHNICITY, β_{03}	0.474	0.345	1.373	71	0.174
For TIMEREC slope, π_1					
INTRCPT2, β_{10}	−0.145	0.145	−1.002	71	0.320
FEMALE, β_{11}	−0.196	0.148	−1.319	71	0.191
KNOWENGI, β_{12}	−0.237	0.145	−1.636	71	0.106
ETHNICITY, β_{13}	0.236	0.156	1.511	71	0.135
Final estimation of variance components					
Random effect	Standard deviation	Variance component	d.f.	χ^2	*p*-value
INTRCPT1, r_0	1.316	1.731	71	292.317	<0.001
TIMEREC slope, r_1	0.423	0.179	71	109.233	0.003
level-1, *e*	0.816	0.666			

interest is statistically significant ($t = -3.883$, $p < 0.001$). Holding gender and ethnicity constant, students who do not know an engineer have an interest score of 1.16 points less than students who do know an engineer at Survey 3 (β_{02}). This relationship between knowing an engineer and interest score is statistically significant ($t = -3.398$, $p = 0.001$). After including gender, knowing an engineer, and ethnicity in the model, the variance remaining in engineering interest score is 1.731. The statistical test result suggests that variance still remains in the population ($\chi^2 = 292.317$, $p < 0.001$). Also, after including these explanatory variables, the variance remaining in engineering interest growth rate is 0.179, with variance still remaining in the population ($\chi^2 = 109.233$, $p = 0.003$). The PVE for final status is 0.32, which suggests that 32% of variation in Survey 3 *interest* scores is due to the predictors included in the model. Additionally, PVE in growth rates is 0.07, implying that 7% of variation in change in *interest* scores across time is associated with these predictors.

Discussion

Over the course of the academic year, students' engineering interest decreased on average from one survey to the next, while their engineering recognition remained the same. On the third and final survey—administered after students had participated in their third SDC—females scored lower on average than males in engineering recognition and engineering interest, controlling for student ethnicity and knowing an engineer. Also, on the third survey, students who do not know an engineer had a lower average engineering interest score than those who do know an engineer, holding constant gender and ethnicity.

The results from these analyses included both expected findings along with several unexpected and counterintuitive findings. The finding that female students have lower scores than male students in both engineering recognition and interest at Survey 3 aligns with prior research, as the need to support interest in engineering degrees and careers despite gender differences is well documented in the literature (e.g., Bonous-Hammarth, 2000; Brainard & Carlin, 1998; Eccles, 2007; Stevens, O'Connor, & Garrison, 2005). The more unexpected finding, however, is the significant student decrease in engineering interest on average from one survey to the next. Given the effort to expose students to engineering and the explicit inclusion of ways in which engineers and engineering help to improve society and make the world a better place within the ADE framework, we expected student attitudes on this factor to improve or, at the very least, remain unchanged (NAE, 2008).

Classroom observations and speaking to the teachers involved in the study, however, might help us understand this unexpected finding. For example, one teacher explicitly stated that they cut out the section of the framework that has students write about and discuss the potential benefit of the task for addressing societal needs (e.g., the benefit of designing hand warmers for the homeless in the city in which the students live and go to school) after the first SDC. Such changes to the framework make it difficult to test the promise and potential of this approach as a way to increase interest in engineering. This change does help explain the observed results.

Another explanation for the decrease in engineering interest is that the SDCs which students were asked to complete were rigorous and difficult. For example, regarding the design task "Developing a Biodiversity Monitoring Device," in some of the classes at one of the schools, not one group of students was successful in accomplishing the design challenge within the constraints of the task. For this specific task, the research team has already made plans for improving the feasibility of the challenge for the future.

However, this points to another possible reason for the observed results, and to a research challenge in general, which is the goal of integrating engineering core ideas and practices in the middle school science classroom and the potential unintended consequences of this goal. Another paper resulting from this study explores the tensions that science teachers express with teaching engineering during the school year, namely that of reconciling the amount of time the design tasks take to complete, along with the perceived lack of overlap between the engineering standards and those tested on state exams—which are a high priority for the schools in which these teachers teach (Brooks et al., 2018). Furthermore, given that the use of the ADE framework seems to be one of the first or early attempts in the literature to integrate engineering directly into the middle school science classroom, there is a need for further studies into the appropriateness or fit of engineering in middle school science contexts.

The matter of teacher expertise in engineering may also serve as an explanatory factor of the observed changes in students' attitudes, given that neither of the teachers in the study have a degree or professional experience in an engineering field. A possible result is that the instruction and guidance provided may not have facilitated the engagement of student interest or encouragement of students through difficult aspects of the design challenges. However, interestingly, it was noted that while interest in engineering decreased over time, student attitude scores on engineering recognition stayed the same, on average. Thus, while student attitudes toward wanting to learn more about engineering, toward their enjoyment of engineering, and toward their thoughts of pursuing an engineering career decreased over the period of these three surveys, their perceptions of family, teacher, and friends seeing them as an engineer remained unchanged. While the hope, undoubtedly, is that both interest in engineering and perceived recognition of students as engineers will increase, the unique and novel exposure to rigorous engineering design tasks within the context of their middle school science classrooms may perhaps lead to a more accurate assessment and appreciation of future coursework and experience in engineering. For students who had a successful personal experience with the SDCs, their sense of preparedness for work in engineering may have grown stronger. However, the research team will need to work to find ways of better supporting students who may not have felt as successful in order to foster the same sense of preparedness across all groups of students, especially for girls and underrepresented minorities. Regardless, it is clear that much work needs to be done to have engineering thoughtfully integrated into the science classroom; simply inserting it into a set of standards is not enough.

Other findings from the analyses point to the benefit of knowing an engineer on engineering attitudes and interest, which has also been documented in the literature (e.g., Pierrakos, Beam, Constantz, Johri, & Anderson, 2009). Not knowing an engineer is shown to be associated with a disadvantage in the factor of interest in engineering, namely average interest score by Survey 3. This may suggest that, though students on average may show a dip in their feelings of interest in engineering (over a period of about five months), students who know an engineer and have some idea of what an engineer's work authentically looks like may recognize that the challenge "comes with the territory." As a result of this, along with an exposure for the first time to an engineering framework that explicitly attempts to integrate engineering design, argumentation, and scientific core ideas, these students may not decline in their interest as much as their counterparts who do not have this personal connection outside of the classroom.

Limitations and Implications

This study faced a number of limitations, including a small number of time points (three), a lack of a comparison group, and minimal collection of open-ended data. Looking ahead, each of these issues will be addressed in future studies. For example, we plan to collect data over a greater number of time points, giving the students the space to "rebound" from any changes in attitudes linked to not being accustomed to the framework. We also have plans to include a comparison group in additional studies in order to look directly at the impact of student exposure to the ADE framework. Finally, open-ended survey items will be included and themed to increase the robustness of quantitative findings.

Acknowledgments

An earlier version of this article was previously published in the Proceedings of the 2018 ASEE Annual Conference & Exposition, and was recognized as the 2018 Best Diversity Paper of the Pre-College Engineering Education Division.

References

Baldwin, T. B., Daniel, A., & Williams, B. (2016). Impact of an introductory engineering design course on minority middle and high school students' self-efficacy and interest in engineering. Paper presented at 2016 ASEE Annual Conference & Exposition, New Orleans, LA. 10.18260/p.25532.

Beam, T. K., Pierrakos, O., Constantz, J., Johri, A., & Anderson, R. (2009). Preliminary findings on freshmen engineering students' professional identity: Implications for recruitment and retention. Paper presented at the 2009 ASEE Annual Conference & Exposition, Austin, TX, June 14–17.

Bleeker, M. M., & Jacobs, J. E. (2004). Achievement in math and science: Do mothers' beliefs matter 12 years later? *Journal of Educational Psychology*, *96*(1), 97–109. http://dx.doi.org/10.1037/0022-0663.96.1.97

Bonous-Hammarth, M. (2000). Pathways to success: Affirming opportunities for science, mathematics, and engineering majors. *Journal of Negro Education*, *69*(1/2), 92–111.

Brainard, S. G., & Carlin, L. (1998). A six-year longitudinal study of undergraduate women in engineering and science. *Journal of Engineering Education*, *87*(4), 369–375.

Bricker, L. A., & Bell, P. (2008). Conceptualizations of argumentation from science studies and the learning sciences and their implications for the practices of science education. *Science Education*, *92*(3), 473–498.

Brooks, H. S., Hutner, T. L., Sampson, V., Chu, L., Crawford, R. H., Rivale, S., & Baze, C. L. (2018). Tensions arising when teaching scientific disciplinary core ideas via engineering practices. Proceedings of the 2018 Annual Meeting of the American Society for Engineering Education, Salt Lake City, Utah.

Carifio, J., & Perla, R. (2008). Resolving the 50-year debate around using and misusing Likert scales. *Medical Education*, *42*(12), 1150–1152.

Cass, C. A. P., Hazari, Z., Cribbs, J., Sadler, P. M., & Sonnert, G. (2011). Examining the impact of mathematics identity on the choice of engineering careers for male and female students. *Proceedings of the 41st ASEE/IEEE Frontiers in Education Conference, Rapid City, SD*. http://dx.doi.org/10.1109/FIE.2011.6142881

Committee on K-12 Engineering Education. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. Washington, DC: National Academies Press.

Corwyn, R. F., & Bradley, R. H. (2008). The Panethnic Asian label and predictors of eighth-grade student achievement. *School Psychology Quarterly, 23*(1), 90–106. 10.1037/1045-3830.23.1.90

Cronin-Jones, L. L. (1991). Science teacher beliefs and their influence on curriculum implementation: Two case studies. *Journal of Research in Science Teaching*, *28*(3), 235–250.

Danforth, M., Lam, C., Mehrpouyan, H., & Hughes, R. (2016). Impact of a hands-on, exploratory engineering outreach program on knowledge and attitudes of high school students. Paper presented at 2016 ASEE Annual Conference & Exposition, New Orleans, LA. 10.18260/p. 25528.

Duschl, A., Schweingruber, H. A., & Shouse, A. W. (2007). *Taking science to school: Learning and teaching science in grades K-8*. Washington, DC: National Academies Press.

Eccles, J. S. (2007). Where are all the women? Gender differences in participation in physical science and engineering. In S. J. Ceci & W. M. Williams (Eds.), *Why aren't more women in science? Top researchers debate the evidence* (pp. 199–210). Washington, DC: American Psychological Association.

Faulkner, W. (2007). Nuts and bolts and people: Gender-troubled engineering identities. *Social Studies of Science*, *37*(3), 331–356.

Godwin, A. (2016). The development of a measure of engineering identity. Paper presented at 2016 ASEE Annual Conference & Exposition, New Orleans, LA. 10.18260/p.26122.

Godwin, A., Potvin, G., Hazari, Z., & Lock, R. (2013). Understanding engineering identity through structural equation modeling. *Proceedings of the ASEE/IEEE Frontiers in Education Conference*, Oklahoma City, OK, pp. 50–56. http://dx.doi.org/10.1109/FIE.2013.6684787.

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.

Hazari, Z., Sonnert, G., Sadler, P. M., & Shanahan, M. C. (2010). Connecting high school physics experiences, outcome expectations, physics identity, and physics career choice: A gender study. *Journal of Research in Science Teaching*, *47*(8), 978–1003.

Holland, D. C. (2001). *Identity and agency in cultural worlds*. Cambridge, MA: Harvard University Press.

Ivie, R., Cuzjko, R., & Stowe, K. (2001). Women physicists speak: The 2001 International Study of Women in Physics. *American Institute of Physics Report*. Retrieved from http://www.aip.org/statistics/trends/reports/iupap.pdf

Jones, B. D., Osborne, J. W., Paretti, M. C., & Matusovich, H. M. (2014). Relationships among students' perceptions of a first-year engineering design course and their engineering identification, motivational beliefs, course effort, and academic outcomes. *International Journal of Engineering Education*, *30*(6), 1340–1356.

Kao, G. (1995). Asian Americans as model minorities? A look at their academic performance. *American Journal of Education*, 121–159.

Lachapelle, C. P., & Cunningham, C. M. (2017). Elementary engineering student interests and attitudes: A comparison across treatments. Paper presented at 2017 ASEE Annual Conference & Exposition, Columbus, OH. https://peer.asee.org/28211

Llewellyn, D. C., Pyke, P., Paterson, S., Landrum, R. E., Scarritt, A., Cullers, J. B. S., & Warner, D. L. (2016). Better together: Connecting with other disciplines builds students' own skills and professional identity. Paper presented at 2016 ASEE Annual Conference & Exposition, New Orleans, LA. 10.18260/p.26381

McCave, E. J., Gilmore, J., & Burg, K. (2014). Engineering and science student preparedness for research: Exploring the connections between student identity and readiness for research. Paper presented at the American Society for Engineering Education Annual Conference, Indianapolis, IN.

McLaughlin, M. W. (2006). Implementation research in education: Lessons learned, lingering questions, and new opportunities. In M. I. Honig (Ed.), *New directions in education policy implementation: Confronting complexity* (pp. 209–228). Albany, NY: State University of New York Press.

Moore, T. J., Stohlmann, M. S., Wang, H. H., Tank, K. M., & Roehrig, G. H. (2014). Implementation and integration of engineering in K-12 STEM education. In S. Purzer, J. Strobel, & M. Cardella (Eds.), *Engineering in pre-college settings: Synthesizing research, policy, and practices*. West Lafayette, IN: Purdue University Press.

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. https://doi-org.ezproxy.lib.utexas.edu/10.1080/03043797.2017.1287664

National Academies of Sciences, Engineering, and Medicine. (2019). *Science and engineering for grades 6–12: Investigation and design at the center*. Washington, DC: National Academies Press. https://doi.org/10.17226/25216

National Academy of Engineering. (2008). *Changing the conversation: Messages for improving public understanding of engineering*. Washington, DC: National Academies Press. https://doi.org/10.17226/12187

National Academy of Engineering and National Research Council. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. Washington, DC: National Academies Press. https://doi.org/10.17226/12635

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press. https://doi.org/10.17226/13165

National Science Foundation. (2017). *Broadening participation in engineering (BPE)*. Directorate for Engineering.

National Science Foundation & National Center for Science and Engineering Statistics. (2017). *Women, minorities, and persons with disabilities in science and engineering: 2017*. Special Report NSF 17-310. Arlington, VA. Retrieved from www.nsf.gov/statistics/wmpd/

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: National Academies Press.

Penuel, W. R. (2016). Studying science and engineering learning in practice. *Cultural Studies of Science Education*, *11*(1), 89–104. 10.1007/s11422-014-9632-x

Philip, T. M., & Azevedo, F. S. (2017). Everyday science learning and equity: Mapping the contested terrain. *Science Education*, *101*, 526–532. 10.1002/sce.21286

Pierrakos, O., Beam, T. K., Constantz, J., Johri, A., & Anderson, R. (2009). On the development of a professional identity: Engineering persisters vs engineering switchers. *39th IEEE Frontiers in Education Conference*, San Antonio, TX, pp. 1–6.

Purzer, S., Moore, T., Baker, D., & Berland, L. (2014). Supporting the implementation of the Next Generation Science Standards (NGSS) through research: Engineering. Retrieved from https://narst.org/ngsspapers/engineering.cfm

Raudenbush, S. W., & Bryk, A. S. (2002). *Hierarchical linear models: Applications and data analysis methods* (Vol. 1). Thousand Oaks, CA: Sage.

Sampson, V., & Clark, D. B. (2008). Assessment of the ways students generate arguments in science education: Current perspectives and recommendations for future directions. *Science Education*, *92*(3), 447–472.

Smith, T. E. (1991). Agreement of adolescent educational expectations with perceived maternal and paternal educational goals. *Youth and Society*, *23*, 155–174.

Speering, W., & Rennie, L. (1996). Students' perceptions about science: The impact of transition from primary to secondary school. *Research in Science Education*, *26*(3), 283–298.

Stevens, R., O'Connor, K., & Garrison, L. (2005). Engineering student identities in the navigation of the undergraduate curriculum. *Proceedings of 2005 ASEE Annual Conference & Exposition* (pp. 5529–5536).

Stevens, R., O'Connor, K., Garrison, L., Jocuns, A., & Amos, D. M. (2008). Becoming an engineer: Toward a three dimensional view of engineering learning. *Journal of Engineering Education*, *97*(3), 355–368.

Tonso, K. L. (2007). *On the outskirts of engineering: Learning identity, gender, and power via engineering practice*. Rotterdam, The Netherlands: Sense.

Tonso, K. (2014). Engineering identity. In A. Johri & B. Olds (Eds.), *Cambridge Handbook of Engineering Education Research* (pp. 267–282). Cambridge, UK: Cambridge University Press. doi:10.1017/CBO9781139013451.019

Turner, S., & Lapan, R. (2005). Evaluation of an intervention to increase non-traditional career interests and career-related self-efficacy among middle-school adolescents. *Journal of Vocational Behavior*, *66*, 516–531. 10.1016/j.jvb.2004.02.005

Turner, S. L., Steward, J. C., & Lapan, R. T. (2004). Family factors associated with sixth-grade adolescents' math and science career interests. *Career Development Quarterly*, *53*, 41–52.