Identity, Critical Agency, and Engineering: An Affective Model for Predicting Engineering as a Career Choice

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Abstract

Background Prior to college, many students have no experience with engineering, but some ultimately choose an engineering career. Women choose engineering at lower rates than men. This article uses critical engineering agency (CEA) to understand first-year students' attitudes and self-beliefs to predict the choice of an engineering career.

Purpose/Hypothesis We investigated how first-year students' math and physics identities and students' beliefs about the ability of science to improve the world predict choice of engineering as a career and whether these beliefs differ by gender.

Design/Method The data were from the Sustainability and Gender in Engineering survey distributed during fall 2011 (N = 6,772). Structural equation modeling was used to understand first-year students' affective beliefs for predicting engineering career choice.

Results Math and physics identities are important for predicting engineering choice at the beginning of college. Recognition from others and interest in a subject are positive predictors of physics and math identities. Students' performance/competence beliefs alone are negative predictors of engineering career choice but are mediated by interest and recognition from others. Student identities and agency beliefs are significant predictors of engineering career choice, explaining 20% of the variance. We also found gender differences in students' math and physics identities and agency beliefs.

Conclusions This article emphasizes the importance of students' recognition beliefs and the importance of agency beliefs for women in predicting engineering career choice.

Keywords critical engineering agency; identity; career choice; gender; structural equation modeling

Introduction

Increasing diversity in engineering is an important focus of engineering education research for several reasons. First, there is a need for better quality and more creative engineering solutions to solve complex global problems (Committee on Prospering in the Global Economy, 2007). Students from diverse backgrounds may bring with them new ideas that can contribute to these innovative engineering solutions. Additionally, a diverse engineering population that is

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at the helm of engineering decision making will give greater voice to populations that have not been historically well represented in science, technology, engineering, or mathematics (STEM) fields (National Science Board, 2003). Engineering has often been defined by a narrow framing of who engineers are and what they do. Broadening participation in engineering requires paying close attention to the type of person whom we ask students to become and studying how students embrace or avoid these promoted identities.

Prior to college, most students have little to no direct engineering experience or meaningful exposure to engineering practice (Committee on K-12 Engineering Education, 2009). Often high school students who intend to major in a variety of STEM fields take the same math and science courses regardless of future intended major. A lack of direct engineering experience makes the choice of an engineering career more difficult than for other science, technology, and math disciplines, such as biology or chemistry, which offer at least some direct, explicit experiences for students in high school (Marra, Rodgers, Shen, & Bogue, 2009; Seymour & Hewitt, 1997; Williams, Engerman, & Fleming, 2006). Although students' interest in STEM-related subjects develops much earlier in elementary and middle school, students interested in STEM often choose engineering as a career in high school. A study of 6,860 students' engineering career decisions found only 280 were interested in engineering careers at the beginning of high school (Cass, Hazari, Sadler, & Sonnert, 2011). The largest increase of students interested in engineering careers occurred during their high school years, with 81% of interested students indicating desire to choose engineering careers by the end of high school. During high school, students have the opportunity to take advanced math and science courses; such courses may increase the likelihood of choosing an engineering career.

This article focuses on students' self-beliefs in the first semester of college to understand the effect of these beliefs on engineering career choice. Students must be empowered to choose engineering careers before beginning their college education in order for engineering programs to attract the largest possible number of students. It is more difficult for students to switch majors once in college than to intend an engineering major from the start (Ohland, Sheppard, Lichtensetin, Eris, Chachra, & Layton, 2008). There are other stages at which talented students are being lost; however, this study focuses specifically on the transition from high school to college. Examining the self-beliefs of students choosing engineering at the beginning of college can help explain this complicated decision and highlight opportunities to increase the enrollment of students in engineering.

Women in Engineering

Women are underrepresented in engineering with fewer than 20% of bachelor's degrees awarded to women (Yoder, 2014), and the percentage of bachelor's degrees awarded to women has not significantly changed in the last three decades (National Science Board, 2014). Multiple studies have demonstrated that women's self-beliefs significantly affect their choice of engineering as a career and their persistence in an engineering path. Although female students perform as well as male students in engineering (Geisinger & Raman, 2013; Hill, Corbett, & St. Rose, 2010; Min, Zhang, Long, Anderson, & Ohland, 2011), women's self-perceptions of their performance and their confidence in their engineering skills are often lower than those of male students (Cech, Rubineau, Silbey, & Seron, 2011). These lower performance and confidence beliefs decrease their desire to choose and remain in engineering.

Traditional roles for male and female students create gendered patterns for entrance to engineering professions and for their identity development as engineers. Often, women face the double burden of authoring their identity as engineers while also combatting the traditional stereotypes about engineering as a masculine field (Jorgenson, 2002). Women who experience incompatibility between their gender identity and STEM identities have heightened stress, tend to doubt their ability to perform, develop negative achievement expectations, and report lower performance, despite previous success in their area of study (Ancis & Phillips, 1996; Rosenthal, London, Levy, & Lobel, 2011). These negative attitudes result in fewer women choosing engineering careers.

Female students who develop an identity in STEM early on in their academic careers are more likely to choose STEM careers (Bieri Buschor, Berweger, Keck Frei, & Kapper, 2014). We believe that understanding the subject-related identities that students have at the beginning of college that predict engineering career choice will provide ways to attract and retain women in engineering. The underrepresentation of women in engineering coupled with prior research that shows the importance of students' attitudes and self-beliefs on engineering career satisfaction and persistence give strong incentive to understand how and why students choose engineering careers. In this analysis, we focus on students' affective states through the framework of critical engineering agency (CEA). Educators and researchers can use the outcomes of this study to support students' attitudes and develop students' desire to choose engineering as a career. This support, focused on students' attitudes and self-beliefs in turn, can create a more diverse engineering field and more creative engineering solutions.

Critical Engineering Agency

This study introduces into engineering education a new theoretical framework that we adapted from critical agency frameworks in science and mathematics education (Basu, 2008; Basu & Calabrese Barton, 2009; Basu & Calabrese Barton, 2010; Basu, Calabrese Barton, Clairmont, & Locke, 2008; Mallya, Mensah, Contento, Koch, & Calabrese Barton, 2012; Turner & Font, 2003). The critical engineering agency (CEA) theory in our research uses multiple subject-related identities along with students' agency beliefs to predict students' engineering career choice. We define *identity* as how students see themselves as powerful thinkers and doers of a specific subject and *agency beliefs* as how students view the world with a critical mindset to advance the world as a more equitable place (Basu et al., 2008). This article is the first application using quantitative measures of a critical agency framework in engineering education.

In CEA, identity involves the authoring of one's self within a particular context and is a continually evolving, self-reflexive process (Johnson, Brown, Carlone, & Cuevas, 2011). Students who enter science and engineering often need to see themselves as the "kind of people who would want to understand the world scientifically" (Brickhouse, Lowery, & Schultz, 2000, p. 443). Students who aspire to be engineers have different professional and vocational identities than their peers (Capobioanco, French, & Diefes-Dux, 2012; Matusovich, Barry, Meyers, & Louis, 2011). Examining the identities of students choosing engineering can illustrate what kinds of STEM-related identities they hold prior to experiences in engineering. In the past, researchers have focused on understanding engineering and professional identity development at the college level while students are in an engineering program. For example, McCain, Chachra, Kilgore, Chen, and Loshbaugh (2008) studied the development of an engineering identity at the undergraduate level and found distinct differences based on the culture of an institution and students' perceptions of engineering practice.

There are few studies, however, that focus on the consequences of student experiences prior to college and of other self-beliefs that may be precursors to the development of an affinity for engineering (Capobioanco et al., 2012), although the need for such research has been stressed in the past (Pierrakos, Beam, Constantz, Johri, & Anderson, 2009). Much of the existing research has acknowledged the need for understanding students' multiple STEM identities prior to their choice of engineering in college (Capobianco, Diefes-Dux, Mena, & Weller, 2011; Matusovich et al., 2011; Pierrakos et al., 2009). Considering these identities is important because students' self-beliefs can affect their educational choices and, potentially, the later development of an engineering identity (Hsieh, Sullivan, Sass, & Guerra, 2012; Wang, Eccles, & Kenney, 2013). Understanding the beliefs that precede engineering identity development will help educators and researchers develop a better understanding of how and why students are drawn to engineering as well as the reasons why others may move away from it because of their perceptions that engineering conflicts with their view of themselves, their career aspirations, and other self-beliefs.

Identity Constructs

Identity development, specifically related to a student's role, in our prior work has been framed around three key constructs in math and science education: interest, performance/competence, and recognition. These constructs have been researched both qualitatively (Basu & Calabrese Barton, 2009; Calabrese Barton & Tan, 2009; Carlone & Johnson, 2007; Gee, 2000; Varelas, 2012) and quantitatively (Godwin, Potvin, Hazari, & Lock, 2013; Godwin, Potvin, & Hazari, 2013; Hazari, Sonnert, Sadler, & Shanahan, 2010; Potvin & Hazari, 2013). Carlone and Johnson (2007) initially framed identity as consisting of three constructs, namely, perceived recognition, belief in ability to perform, and belief in one's competence. By these definitions, a "good" science student was one who could demonstrate meaningful knowledge and understanding of STEM content, had fluency in discussing these topics, and believed that she could do well in these types of courses. She also recognized herself and was recognized by others as the type of person who does science (Carlone & Johnson, 2007). Hazari, Sonnert, Sadler, and Shanahan (2010) built on this research in two ways. First, they added interest to the framework of understanding students' STEM-related identities. Interest was defined as students' desire to participate in STEM-related activities and finding STEM an enjoyable pursuit. Their second contribution was a quantitative measure of these four constructs (i.e., interest, performance, competence, and recognition beliefs). In a factor analysis, these four constructs only factored into three underlying constructs consisting of interest, performance/competence, and recognition (Hazari et al., 2010). Students did not respond differently to types of questions intended to measure how they believed they could perform in class and how well they could understand class content. Hazari et al. (2010) hypothesized that the overlap of performance and competence beliefs into one construct was due to students' inability to distinguish grades from building conceptual knowledge in a course. These quantitative measures of identity have been used in several studies to understand the effect of students' physics and math identities on physics, math, and engineering career outcomes (Cribbs, Hazari, Sonnert, & Sadler, 2015; Godwin, Potvin, Hazari, & Lock, 2013; Hazari et al., 2010; Potvin et al., 2013). Our framing of identity focuses on these three constructs to understand how physics and math identities relate to one another and affect the choice of engineering in college. Although these constructs capture students' STEM-related identities, we acknowledge that these are only a small part of their overall identities; however, we believe that the way they see themselves with respect to STEM, in particular, has the potential for furthering our understanding of what contributes to engineering outcomes. Below, we discuss the three constructs of identity and how they relate to prior work and our study.

Interest Interest in a specific subject plays a key role in a student's choice of an engineering career. Previous studies have shown that students who are interested in engineering show special engagement and skill in math and science (Godwin, Potvin, & Hazari, 2013; Potvin, Tai,

& Sadler, 2009) and that identities in math, science, and physics are connected to students' choice of engineering as a career in college. A strong physics connection (Li, Swaminathan, & Tang, 2009) may be explained by the conceptual connections between engineering and physics content that emphasizes the extensive heavy application of math in physical science. Additional parallels between these areas exist in the numbers of women enrolling in engineering and physics programs across the United States (Chen, 2013), although whether they are a consequence of similarities in the content, culture, or other factors is not clearly understood.

Performance/Competence Students' performance/competence beliefs have also been shown to be an important part of identity development and engineering choice. This construct is related to students' self-efficacy beliefs, which have been shown to be a significant positive predictor of engineering persistence (Marra et al., 2009; Mau, 2003). Traditional measures of self-efficacy have focused on task-specific behaviors and actions related to students' beliefs about their abilities to reach goals (Bandura, 1986). Fouad et al. (2002) found that performance influences career choices, albeit indirectly through self-efficacy development. Cleaves (2005) also measured students' self-efficacy through detailed longitudinal interviews and found that taking science courses beyond required courses involved a variety of considerations including not only interest and enjoyment but also competency beliefs such as "confidence in their own ability to do science" (p. 484). Students' beliefs about their ability to perform the practices of their discipline and understand the content of their discipline – whether science, math, or engineering – affects their ability to see themselves as the kind of person who can legitimately participate in these areas (Marsh, Hau, & Kong, 2002). In the framing of our research from an identity perspective, we acknowledge an overlap of performance/competence beliefs with self-efficacy measures. However, we distinguish performance/competence beliefs as specifically subject-related and broader than task-scale behaviors.

Recognition Recognition has more recently become a focus in science identity research. Students' perceptions of how others view them are vitally important to how students see themselves. Authority figures like parents and teachers are especially influential. Parental perceptions and expectations of students' abilities to participate in STEM significantly improve students' later success (Bleeker & Jacobs, 2004; Dorie & Cardella, 2013; Jacobs & Eccles, 2000; Turner, Steward, & Lapan, 2004). Students integrate parental messages, along with teacher and peer messages, into how they see themselves and ultimately choose a career.

These recognition messages from others are important not only in childhood but also during engineering identity development in college. Tonso's (1999, 2006) ethnographic studies of an elite engineering program provided examples of how female students who showed great skill in engineering but were not recognized by their peers and instructors had weaker identities as engineers and did not feel as if they belonged in the culture of engineering.

In sum, these prior studies highlight the importance of the three identity constructs for students at all levels, including students with STEM identities in high school who are making decisions about engineering careers in college.

Previous research on the CEA framework has identified that the development of multiple identities in physics, math, and science – measured by the constructs of interest, performance/competence, and recognition – is generally important for students who choose engineering in college (Godwin, Potvin, Hazari, & Lock, 2013; Godwin & Potvin, 2014). In these prior studies, the most significant subject-related identities for predicting an engineering career choice were physics and math. Students who chose engineering careers in college and persisted in engineering were significantly more likely ($p < 0.001$) to see themselves more as a physics person than a chemistry or biology person (Cass, Hazari, Sadler et al., 2011). Because of these findings and how identity has been previously framed, we chose to measure physics and math identities to predict engineering career choice in college (Cass, Hazari, Cribbs, Sadler, & Sonnert, 2011; Cribbs, Hazari, Sadler, & Sonnert, 2012; Hazari et al., 2010; Potvin, Beattie, & Paige, 2011; Potvin, Paige, & Beattie, 2012).

The CEA framework is not simply a model of students' identities, it also involves students' agency beliefs. This article focuses on students' self-beliefs about their own agency to change their world through everyday actions and their broader goals of using STEM to make this change by choosing a career in engineering (Godwin, Potvin, & Hazari, 2013). Agency beliefs are focused on how students perceive their empowerment rather than on their explicit actions, as is typically the case with research on agency. The "critical" aspect of CEA incorporates the ways students think critically about STEM and become critics of themselves and the world around them through self-reflection. Being a critic, in this latter sense, is not defined as simply making negative judgments, but rather evaluating, judging, and analyzing. The development of their CEA can lead to students' professional identity development; advance their position or status in their community, society, or the world; and alter their world in ways they envision through science and engineering (Basu et al., 2008). Critical agency theory incorporates expressing identity through actions that are relevant to one's own world and critical of the social and cultural structures in place.

Research Questions

This study uses structural equation modeling (SEM) to examine the direct and indirect influence of students' self-beliefs in several identity domains and their agency beliefs on their engineering career choice in college. This research, conducted at a single point in time, is a snapshot of the physics and math identities and agency beliefs that students hold when choosing an engineering career in college. This article addresses four research questions through quantitative methods.

Research Question 1: What are the relationships among students' identities in high school that predict their choice of an engineering career?

Research Question 2: How do students' agency beliefs predict a choice of an engineering career?

Research Question 3: To what extent do students' beliefs differ between men and women?

Research Question 4: How well does the critical engineering agency framework describe students' choice of an engineering career?

Methods

Data Source

The data used in this article are from the Sustainability and Gender in Engineering (SaGE) survey, which drew on responses from students at two- and four-year institutions across the United States (Klotz et al., 2014, "SaGE Survey," 2011). This dataset is a nationally representative, stratified random cluster sample of college students enrolled in introductory English courses during the beginning of the fall semester of 2011. The choice to survey in traditional, introductory English courses allowed for data to be collected from non-STEM and STEM students, who included a representative fraction of engineering majors. Drawing from a stratified random sample of colleges and universities across the United States, the SaGE survey study collected data from 6,772 students. The stratification accounted for the size of the college and prevented over-sampling of the smaller, but numerous liberal arts colleges in comparison with the relatively few, large public universities. In total, 50 college and universities agreed to participate in the paper-and-pencil survey, and some completed surveys were returned from every one of these institutions (100% institutional response rate). The SaGE survey included 47 anchored (5-point scale), multiple choice, and categorical questions on students' career goals; their high school science and math experiences, science enrollment and achievement (courses taken, grades, Advanced Placement test scores); attitudes about sustainability, science and engineering; and demographic information.

Survey Items

Specific items to measure engineering career choice and math and physics identity were taken directly from the Persistence Research in Science and Engineering study, as developed and validated by Hazari et al. (2010) and used in our prior work (Cribbs et al., 2015; Godwin, Potvin, & Hazari, 2013; Godwin, 2014; Hazari et al., 2010). These identity items included two items measuring interest, six items measuring performance/competence beliefs, and two items measuring recognition (see Tables 1 and 2 for questions). Additionally, a single direct measure of students' overall identities in math and physics was included (e.g., "I see myself as a [math or physics] person").

Students' choice of engineering as a career was determined by utilizing a question that asked students to "Please rate the current likelihood of your choosing a career in the following" for a variety of science, math, and engineering careers on an anchored scale from 0 ("not at all likely") to 4 ("extremely likely"). Students were asked about eight engineering disciplines: bioengineering, chemical engineering, materials engineering, civil engineering, industrial/systems engineering, mechanical engineering, environmental engineering, and electrical/computer engineering. A student's strongest response to any of the eight engineering disciplines was used as a proxy for a student's interest in pursuing a career in engineering. This method was used in order to capture students interested in engineering in general (but undecided on a discipline) as well as students with a very well-specified interest in one or two engineering disciplines. The distribution of students indicating interest in an engineering career is shown in Table 3. Because of the sampling, not all institutions offer engineering as a major. The majority of students at two-year institutions (78%) did not indicate a strong interest in engineering as a career choice. We chose to include students at two-year institutions in this analysis because they provide additional information about a representative sample of potential transfer students who, on the basis of CEA constructs, may choose engineering in the future.

In addition, we developed agency beliefs items to measure students' perceptions of their ability to be a critic of science and their beliefs about the potential for science to make a positive change in the world (see Table 4 for questions). We originally included more items in the SaGE survey to measure agency beliefs, but because the items did not load together as a construct in exploratory factor analysis, we excluded them from this analysis (Godwin, Potvin, & Hazari, 2013). We used the five remaining items that measured student agency beliefs in this study to ascertain how first-year students, especially women, choose an engineering career.

The validity and reliability of the CEA measures were reevaluated for identity items from other studies and established for agency beliefs. Questions were refined on the basis of feedback from members of the grant advisory board and STEM education researchers familiar

Table 1 Confirmatory Factor Analysis Estimates for Physics Identity Subconstructs

Variable						
Latent	Indicator	Standardized factor loadings	Standard error	Item reliability (R^2)	Construct reliability	Average variance extracted
Interest					0.883	0.791
	Q27Phys_d: "I am interested in learning more about [physics]"	0.866	0.025	0.750		
	Q27Phys_g: "I enjoy learning [physics]"	0.912	0.025	0.832		
Recognition					0.886	0.796
	Q27Phys_b: "My parents/relatives/friends see me as a [physics] person"	0.898	0.013	0.806		
	Q27Phys_c: "My [physics] teacher sees me as a [physics] person"	0.886	0.013	0.785		
Performance/competence					0.940	0.724
	Q27Phys_e: "I am confident that I can understand [physics] in class"	0.886	0.014	0.785		
	Q27Phys_f: I am confident that I can understand [physics] outside of class"	0.877	0.014	0.769		
	Q27Phys_h: "I can do well on exams in [physics]"	0.903	0.014	0.815		
	Q27Phys_i: "I understand concepts I have studied in [physics]"	0.921	0.014	0.848		
	Q27Phys_j: "Others ask me for help in [physics]"	0.787	0.012	0.619		
	Q27Phys_n: "I can overcome setbacks in [physics]"	0.711	0.012	0.506		

Note. To summarize acceptable values: Item reliability (R^2) > 0.50, construct reliability > 0.70, and average variance extracted > 0.50.

with physics and math identity and critical agency theory, and on the results of pilot testing in first-year engineering courses at Clemson University and Virginia Tech. We also conducted an in-person pilot of the survey and focus groups with first-year engineering students. Thus, each item of the survey was further examined for face and content validity. Reliability of the items utilized in this study was evaluated by test-retest of 62 students, and the average Pearson's correlation was 0.732; this value falls within the acceptable range (George & Mallery, 2003).

Confirmatory Factor Analysis

To conduct this analysis, we took a two-part approach. First, a measurement model was examined utilizing confirmatory factor analysis to assess how well the indicator items measured the hypothesized latent variables (see Tables 1, 2, and 4). Seven latent constructs related to the

Table 2 Confirmatory Factor Analysis Estimates for Math Identity Subconstructs

Variable		Standardized factor loadings	Standard error	Item reliability (R^2)	Construct reliability	Average variance extracted
Latent	Indicator					
Interest					0.881	0.788
	Q27Math_d: "I am interested in learning more about [math]"	0.866	0.013	0.750		
	Q27Math_g: "I enjoy learning [math]"	0.909	0.013	0.826		
Recognition					0.904	0.825
	Q27Math_b: "My parents/relatives/friends see me as a [math] person"	0.922	0.023	0.850		
	Q27Math_c: "My [math] teacher sees me as a [math] person"	0.894	0.021	0.799		
Performance/competence					0.941	0.727
	Q27Math_e: "I am confident that I can understand [math] in class"	0.897	0.011	0.805		
	Q27Math_f: I am confident that I can understand [math] outside of class"	0.875	0.011	0.766		
	Q27Math_h: "I can do well on exams in [math]"	0.900	0.011	0.810		
	Q27Math_i: "I understand concepts I have studied in [math]"	0.909	0.011	0.826		
	Q27Math_j: "Others ask me for help in [math]"	0.814	0.011	0.663		
	Q27Math_n: "I can overcome setbacks in [math]"	0.703	0.010	0.494		

Note. To summarize acceptable values: Item reliability (R^2) > 0.50, Construct reliability >0.70, and average variance extracted > 0.50.

various components of CEA were measured: the three constructs of identity for each of physics and math, as well as agency beliefs. During this step, the fit indexes of the measurement model were assessed, and convergent validity was checked by examining the factor loadings. This step ensured that the three hypothesized constructs were, in fact, reflected in students' responses. In the models shown in Figures 2 and 3, we standardized the estimates for factor loadings and structural paths range from 0 to 1 so that the magnitude of these loadings can be directly compared within the models.

Table 3 Student Distributions of Self-Reported Likelihood of Choosing a Career in Engineering

0 (Not at all likely)	1	2	3	4 (Extremely likely)
3148	720	783	762	728

Table 4 Confirmatory Factor Analysis Estimates for Agency Beliefs

Latent variable	Indicator variable	Standardized factor loadings	Standard error	Item reliability (R^2)	Construct reliability	Average variance extracted
Agency beliefs					0.927	0.717
	Q29a: "Learning science will improve my career prospects"	0.814	0.012	0.663		
	Q29b: "Science is helpful in my everyday life"	0.895	0.011	0.801		
	Q29c: "Science has helped me to see opportunities for positive change"	0.920	0.010	0.864		
	Q29d: "Science has taught me to take care of my health"	0.794	0.012	0.630		
	Q29e: "Learning science has made me more critical in general"	0.804	0.012	0.646		

Note. To summarize acceptable values: Item reliability (R^2) > 0.50, construct reliability > 0.70, and average variance extracted > 0.50.

Structural Equation Modeling

The second step of this analysis was building the structural model by testing paths between latent observed variables. Figure 1 shows the proposed model constructed from the CEA theoretical framework that was tested using SEM. From previous work on modeling CEA (Cribbs et al., 2015; Godwin, Potvin, Hazari, & Lock, 2013), we built the constructs of physics and math identity with paths from performance/competence to identity mediated by interest and recognition. Items that asked students how much they identify as a physics person or a math person were used as an overall measure of identity (Cribbs et al., 2015; Hazari et al., 2010). We tested the hypothesized model shown in Figure 1 using the lavaan package in R (R Core Team, 2013; Rosseel, 2012).

As is common with survey research of this nature, data were missing for some of the variables included in the study. To moderate the potential biasing effects of this missingness, the data were imputed using the best practice method of full information maximum likelihood (Byrne, 1994; Hu & Bentler, 1999; Schreiber, Nora, Stage, Barlow, & King, 2006; Schumacker & Lomax, 2004). This technique utilizes all of the data in the analysis and has been shown to produce unbiased parameter estimates and standard errors under missing at random and missing completely at random data.

Additionally, the variance of each latent variable was fixed to 1. The estimation method of Satorra and Bentler (2001) was used to account for any non-normality in the data. This method rescales the value of the full information maximum likelihood chi-square test statistic by an amount that reflects the degree of kurtosis. Several simulation studies have shown that this correction is effective with non-normal data (Chou, Bentler, & Satorra, 1991; Curran, West, & Finch, 1996), even in small-to-moderate samples. Thus, it is appropriate to use traditional cutoff values when using this estimation method. We trimmed the model of nonsignificant paths for parsimony following Byrne (1994). The final structural model simultaneously estimates 13

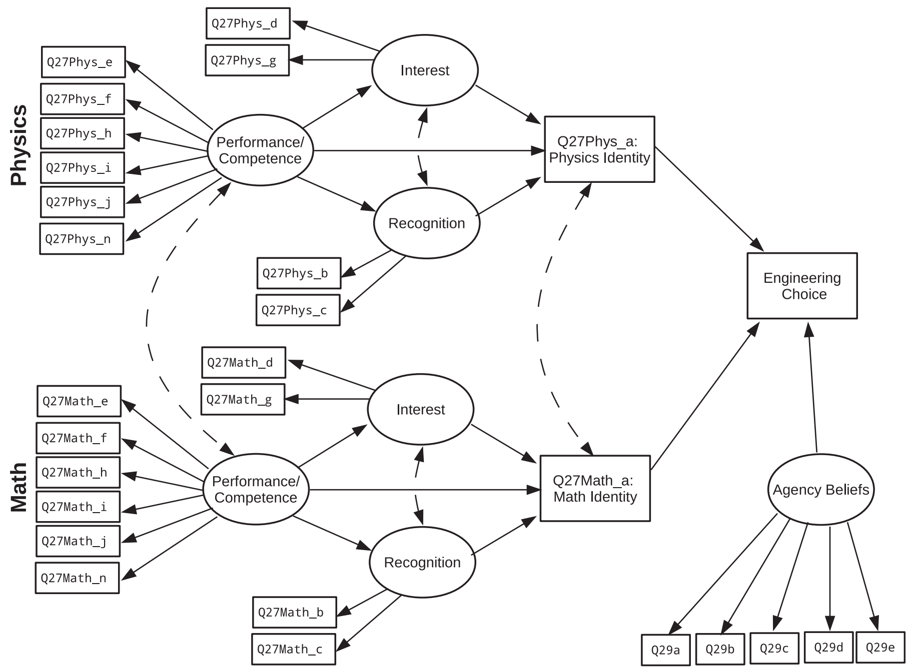

Figure 1 Proposed structural model for the structural equation modeling analysis based on CEA theoretical framework.

paths and one covariance between physics identity and math identity. Following Byrne's (1994) suggestions, we used several fit indexes and path significance tests, including chi-square, to evaluate the model. The chi-square statistic should be nonsignificant at the $p < 0.05$ value (Byrne, 1994). We report the comparative fit index (CFI), non-normed fit index (NNFI), and root-mean-square error of approximation (RMSEA). For both the CFI and NNFI, we use 0.9 as a cutoff for acceptable fit (Hu & Bentler, 1995). For the RMSEA, we use cutoff values less than 0.01, 0.05, and 0.08 to indicate excellent, good, and moderate fit, respectively (MacCallum, Browne, & Sugawara, 1996).

The proposed model (Figure 1) includes mediated paths for the construction of physics and math identities. Maxwell and Cole (2007) argued that mediation in models can result in biased estimates due to the lack of time-responsive data. However, the use of mediated models in cross-sectional studies is acceptable if the bias can be determined to be nonsignificant and the directional influences of the latent variables are essentially instantaneous. In a study of the effects of mathematics self-efficacy on performance on mathematics tests, Pajares and Miller (1995) argued that the effects of interest and self-efficacy were essentially instantaneous on the outcome and the variables should be measured as closely together as possible. In this study, the similar variables of interest and performance/competence are used along with students' perceptions of recognition. These measured constructs are quasi-traits, that is, they do change over time but not instantaneously. We posit that these constructs did not change over the time period for this study (Potvin & Hazari, 2013); they can, therefore, be interpreted in a mediated model. In support of treating these constructs as quasi-traits, as students move further along in their education, their identities become more and more established with each additional interaction with STEM-related subjects. When we asked students about subject-related identities overall, these identities are relatively unchanging when compared with identities measured in moment-to-moment instances for specific situations (Lichtwarck-Aschoff, van Geert, Bosma, & Kunnen, 2008). We argue that students' overall STEM identities are relatively stable, or in equilibrium, unless a disturbance occurs through their experiences and offsets the balance between interest, performance/competence, and recognition. These changes can cause identity renegotiation and new identity development. We attempted to reduce the potential effect of these disturbance by sampling students early in their first year of college before they had new STEM experiences, especially in engineering.

Multiple Group Analysis

After the full structural equation model was evaluated for fit, we compared the model for women and men to see if the proposed structural model was equivalent for these groups (RQ3). We conducted model invariance tests to determine significant differences between men and women in the measurement and structural path parameters. First, a baseline model was created for students who identified their gender as male or female with all parameters freely estimated. Next, a model was created with only factorial equality constraints. The factor loadings between the male and female models were constrained to be equal while the path coefficients were freely estimated across the groups. We conducted a measurement invariance test using chi-square difference when compared with the baseline model. This chi-square difference test, called a modification (mod) index, should be greater than 3.841 ($p < 0.05$) as indicated on a chi-square distribution table with one degree of freedom. A mod index less than or equal to 3.841 would indicate that there was no significant difference in the model fit for men and women; therefore, invariance between item responses or paths could be established for the two models. If noninvariance was indicated by a significant chi-square difference test, then the model would fit significantly better if the item responses or paths identified were estimated separately for men and women. Examination of the mod index for each variable revealed factor loadings that were different between groups, and these loadings were allowed to be freely estimated until the chi-square difference test indicated model invariance. This process was repeated to test for structural invariance by then constraining the regression coefficients to be equal across the models and testing for invariance.

Results

The confirmatory factor analyses in Tables 1, 2, and 4 indicate that the measurement model fit the data. We evaluated individual item reliability with the squared multiple correlation (R^2). Since each correlation was above 0.5, we infer that construct reliability accounted for over 50% of the variance in each measured item in reference to the other observed items (Schreiber et al., 2006). Construct reliability (Sin, 2009), also known as composite reliability, for the various latent constructs ranged from 0.881 to 0.941. This reliability gives an estimate of the overall reliability of an underlying construct, taking into account the individual reliabilities as well as standard errors. Values greater than 0.70 are acceptable (Hair, Anderson, Tatham, & Black, 1998). Although R^2 indicates the reliability of a single measure and the construct reliability, neither one measures the amount of variance that is captured by the construct in relation to the amount of variance due to measurement error (Fornell & Larcker, 1981). The average variance extracted (AVE) provides this information, and for each latent variable, it ranged from 0.717 to

0.825 (Sin, 2009). The AVE is the amount of variance that is captured by the latent variable in relation to the amount of variance due to its measurement error. In other words, it is a measure of the error-free variance of a set of items measuring a single construct. AVE is used as a measure of convergent validity, which should be 0.50 or above (Dillon & Goldstein, 1984). These results confirm that the measurement items measure the hypothesized constructs and capture most of the variance within each block of items. Convergent validity establishes that measures that should be related are in reality related. We evaluated this type of validity by examining the factor loadings in the model; since all of these values were greater than 0.70, we conclude that there is evidence of convergent validity. Discriminant validity, which provides evidence that measures for one latent variable are not overly rated to another latent variable, was established through multiple methods. First, the AVE should be greater than the R^2 correlation between each of the latent variables (Schreiber et al., 2006; shown in Tables 1, 2, and 4). Second, the correlation between items of unrelated latent variables in our study is less than 0.85 (Byrne, 1994). Finally, the overall fit indexes for the measurement model were a CFI of 0.954, NNFI of 0.944, and an RMSEA of 0.056. All of these fit indexes indicate that the measurement variables accurately reflect the latent variables in the measurement model.

We fitted the proposed SEM model for the entire imputed sample in Figure 2. There were 1,288 patterns of missingness found and imputed, and cases which were missing not at random were deleted, for a final sample size of 6,511 from the original 6,772. The chi-square for this model is 10,062 and is significant at the $\alpha < 0.05$ level. Due to the large sample size, the chi-square is artificially inflated, and the chi-square is expected to be significant without indicating a poorly fitting model (Schumacker & Lomax, 2004). The RMSEA indicates a reasonable fit of the model, with the observed data having a value of 0.065 (90% confidence interval $\pm$ 0.001). The RMSEA is largely invariant with increasing sample size, unlike the chi-square test. For sample sizes of 500 or greater, the RMSEA is sensitive to increasing misfit. Thus, it is appropriate to use this supplementary fit statistic in the presence of large sample sizes, to check whether the sample size is influencing the chi-square statistic, and hence its significance (Tennant & Pallant, 2012). The CFI also suggested good fit, with a value of 0.947. Finally, an NNFI of 0.939 indicates acceptable fit and can be influenced by larger sample sizes since it is calculated from the chi-square statistic. Research Questions 1 and 2 can be answered from this model. This model shows how identity in both physics and math as well as students' beliefs about what science and engineering can do for the world predict an engineering career choice.

To answer Research Question 3, we compared our model for students who identified themselves as either male or female in the SaGE survey. The model invariance tests, based on the modification indexes, revealed paths that were significantly different between men and women. We conducted both a chi-square difference test and a delta comparative fit index (CFI) test to determine model invariance. Cutoff values of 0.01 were used for the delta CFI tests (Fan & Sivo, 2009). The parameter estimates have been added in Figure 3 for the final trimmed model with differences in freely estimated paths shown. The loadings for students' responses to the question "I can overcome setbacks in math" (men = 0.771, women = 0.681) differed significantly (p = 0.009, Cohen's d = 0.36) and were freely estimated, while the remaining loadings were constrained to be equal in the measurement model. The regression estimates for the paths from physics identity, math identity, and agency beliefs to engineering choice were estimated freely, while the rest of the structural model paths were constrained as equal. For both physics and math identity predicting engineering choice male and female responses differed significantly (physics: p = 0.003, Cohen's d = 0.12; math: p = 0.009, Cohen's d = 0.19). For agency beliefs predicting engineering choice, male and female responses also differed

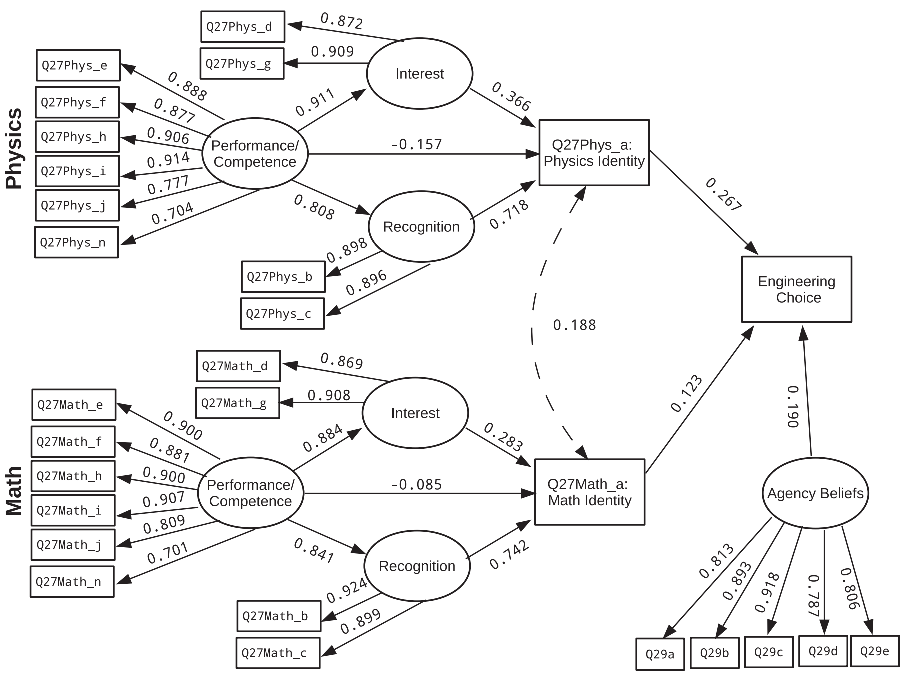

Figure 2 Results of final structural equation model for all students. All paths are significant at the $p < 0.001$ level.

significantly (p = 0.026, Cohen's d = 0.08). We compared the model parameters separately by estimating the model parameters for each group and performing a between-group test of significance (Hsieh, Rai, & Keil, 2008; Keil et al., 2000; Qureshi & Compeau, 2009; Venkatesh & Morris, 2000). These effect sizes, reported as Cohen's d for the structural model paths, represent small, but significantly different effects between men and women (Cohen, 1988). On average, large sample studies have smaller effect sizes than smaller studies. However, as sample size increases above 2,000, the effect sizes become more reliable and less likely to be artifacts of other disturbances (Slavin & Smith, 2009). The findings of larger, well-controlled studies should be considered as more conclusive evidence of the effects than the findings of small studies. The sizes of these effects are consistent with average effect sizes in education for broad measures such as nationally normed tests (Cohen's d = 0.10) from which large policy decisions are made (Lipsey et al., 2012). Whereas the findings of these gender comparisons indicate small effects, these differences may have nontrivial effects on engineering recruitment and career choice.

The fit parameters for this model were a chi-square = 4,389 with 705 degrees of freedom, CFI = 0.954, NNFI = 8.950, and RMSEA = 0.061 (90% confidence interval ± 0.002); all values indicated good fit for the gender comparison model. The total variance explained in the linear engineering career choice outcome was 20.2% for the model shown in Figure 2 (adjusted R^2 of engineering career choice scale). This result answers Research Question 4 and shows that this model of first-year students' self-beliefs explains just over one-fifth of the variance in choice of engineering as a career.

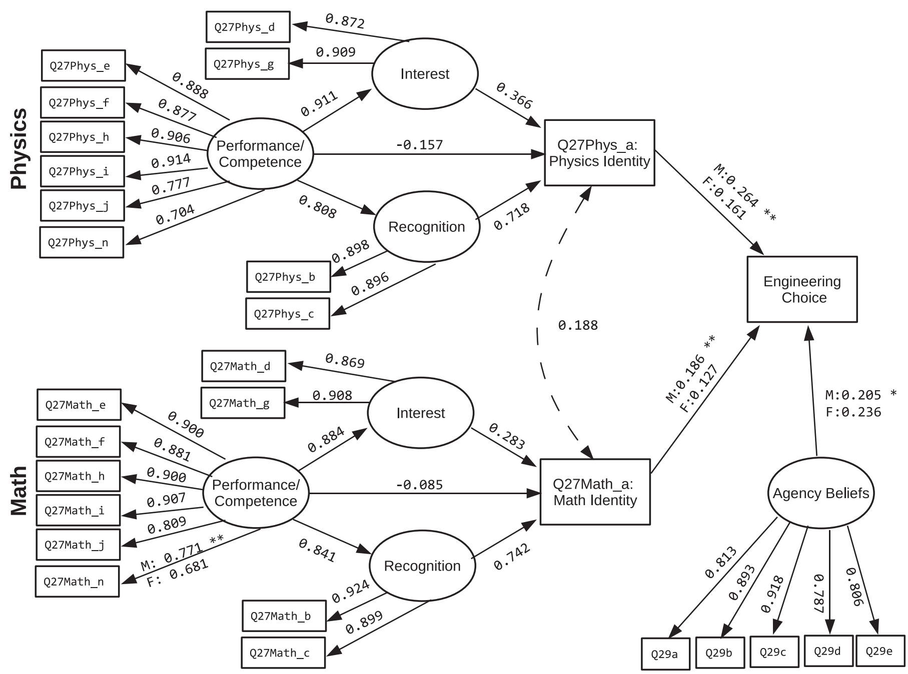

Figure 3 Results of fitting gender comparison structural equation model (F=female; M=male). For gender comparisons, * indicates *p*-values < 0.05 and ** indicates *p*-values between 0.01 and 0.001. All other paths in the model are significant at the $p < 0.001$ level.

Answering the Research Questions

To discuss our results, we first describe how the models address each of the research questions for this study.

RQ1: What are the relationships among students' identities in high school that predict the choice of an engineering career? In our model, physics and math recognition beliefs each have the largest direct effect on physics and math identity (with factor loadings of 0.718 and 0.742, respectively), and we have seen that they are critically important for engineering career choice. Although the importance of recognition has been cited in studies of identity (Carlone & Johnson, 2007; Gee, 2000), our research confirms its importance in a large-scale national dataset. Furthermore, our research clarifies that performance/competence beliefs alone are not sufficient to predict identity development. The direct path estimates for performance/competence beliefs to the overall measure of both physics and math identity are negative (loadings of −0.157 and −0.085, respectively). These negative path loadings indicate that performance/competence beliefs without interest and recognition beliefs negatively predict subject-related identities in physics and math. When performance/competence beliefs are mediated by interest and recognition, the estimates for predicting subject-related identities in physics and math are positive. Performance/competence beliefs are important to both interest and recognition beliefs; however, alone they negatively predict an identity in either math or physics. From this finding, we conclude that performance/competence beliefs must also be present with interest and recognition beliefs to predict students' subject-related identities.

Identity is not simply a designation for students who are "good at" physics or math homework, tests, or concepts. Identity is more strongly shaped by students' interests and beliefs that they are recognized as the type of person who engages in these subjects. This finding is similar for both men and women (see discussion of RQ3 for a detailed analysis), and interventions designed to support students' identity in math and physics are likely to be beneficial for both genders. The direct link between performance/competence and interest is well documented (Lent, Brown, & Hackett, 1994, 2000). This relationship means that students must develop the beliefs that they can understand and perform proficiently in a course in order for an interest in the subject to also develop. The link between performance/competence and recognition, however, is more complex. Performance/competence beliefs predict students' recognition beliefs (loadings of 0.808 and 0.841 for physics and mathematics, respectively), but the reverse path was not significant in our models; students' feelings of recognition did not predict students' performance/competence beliefs. Students who are recognized before they feel competent may not internalize the recognition, and very often teachers do not recognize students who are not excelling in their classrooms. Recognition is the most important part of an identity development in this model, with loadings of 0.718 and 0.742 for physics and mathematics identities, respectively. Students who feel recognized by their peers, family, and teachers are more likely to identify as a "math person" or "physics person," and the estimates for these paths in Figure 2 are over twice as large as any other direct path to identity. Fostering experiences which increase recognition beliefs for students in high school math and science classrooms may be a vital component to attracting and retaining a more diverse pool of engineering students.

RQ2: How do students' agency beliefs predict a choice of an engineering career? The models show that students' agency beliefs also play an important role in their choice of an engineering career. The direct path for all students between agency beliefs and the choice of engineering is 0.190 (significant at the $p < 0.001$ level, as with all paths shown in Figures 2 and 3). When compared with physics or math identities for all students in Figure 2, agency beliefs were a stronger predictor than math identity but weaker predictors than physics identity for predicting a choice of engineering (math identity loading = 0.123, agency beliefs loading = 0.190, and physics identity loading = 0.267). The construct of agency beliefs is somewhat distinct from the more traditionally defined construct of agency. The agency belief construct captures how students feel they are empowered to make changes, not necessarily the actions of empowered change that they take, measured more easily through qualitative methods. The finding that agency beliefs are a significant, positive predictor of engineering career choice along with students' identity beliefs is important because this finding allows us to understand ways high school students could come to perceive engineering as a relevant and interesting career pathway in college. Students who believe they can make a positive change in the world and in their own lives and who have strong self-beliefs about their role as physics and math people may choose engineering careers at significantly higher rates in college than if they do not have critical engineering agency beliefs.

RQ3: To what extent do students' beliefs differ between men and women? We found small gender differences in physics and math identities between women and men (Figure 3). Women had lower estimates than men for the path between seeing themselves as a "physics person" (women = 0.161, men = 0.264; $p = 0.003$) and a "math person" (women = 0.127, men = 0.186; $p = 0.009$) and their choice of an engineering career. Although the estimates predicting engineering career choice were positive and significant at the $p < 0.001$ level for both men and women, seeing themselves as the type of person who does physics or math was less predictive of the choice of engineering for women than for men. This difference may arise from fact that often women identify less with the subjects of math and physics because of lower recognition beliefs (Bingham, 2001) and performance/competence beliefs (Zeldin & Pajares, 2000), both of which are important for women's identity development (Carlone & Johnson, 2007; Gee, 2000; Lent et al., 2003). Studies have also shown that women lose interest in math and science early in their education (National Science Board, 2003). This loss of interest may lead to lower math and physics identities for women in general, even for those who choose engineering. This outcome would explain why women may not rely as much on identifying with math and physics when choosing engineering – they do not have the sources of recognition and interest to develop those identities as much as men do. Lower identities in math and physics may lead to fewer women choosing engineering because they do not see themselves as the kind of person who can do engineering. This finding is consistent with other research that shows that STEM identities are essential to students' actual career choices (Brickhouse et al., 2000) and later persistence within that chosen career (Min et al., 2011).

For both men and women, agency beliefs were a small, but significant positive predictor of engineering career choice ($p < 0.001$). This path was stronger for women than for men, with loadings of 0.236 and 0.205, respectively ($p = 0.026$). For women, the path from their agency beliefs to engineering career choice was stronger than the paths from both math and physics identities to engineering career choice. This finding is supported by Chinn's (1999) study of female students; she found that agency related to engineering was important for their choice of engineering careers. This agency was influenced by powerful adults (such as teachers) and by curricular choices that did not alienate women or minorities but rather incorporated content and strategies personally meaningful to them. Holding positive agency beliefs, coupled with choosing an engineering-related career, is an important first step towards actualizing the potential to create change in the world. Capobianco's (2006) longitudinal study of four engineering women documented the importance of women's beliefs that they could improve the world with their engineering degrees. Two students reported in Capobianco's study (2006), Jess and Brianna, described gendered discrimination in their engineering courses due to male peers' attitudes and being silenced in the classroom. Both of these students overcame this discrimination and authored their engineering identities by seeing the unique contributions they had to offer on engineering projects and relationships in their internship and co-op positions. The development of agency allows students to act against established social structures and cultural norms both within and outside engineering as a male-dominated field. Agency also allows them to take action and separate their own actions from what is done to them (Roth & Tobin, 2007).

This combination of findings regarding RQ3, that women's physics and math identities are less predictive of engineering career choice than for men and that their agency beliefs are more predictive of an engineering career, suggests that the critical engineering agency beliefs that could lead women into engineering differ not only in which aspects of the framework are important but also in how these beliefs may be formed. This finding could indicate that women show weaker physics or math identities on average (therefore, they choose engineering less frequently) or that physics or math identities are less important for women in making engineering-related choices. The implication is that efforts to recruit women that solely focus on building their physics, math, or engineering identities will be less effective than those that also emphasize their empowerment – or, at least, their perceived empowerment – in changing their world through engineering. Drawing upon our research, we believe that a woman who develops agency within a science course will be more likely to choose engineering, and thus resist traditional gender stereotypes. It is important to consider agency beliefs when understanding how affective beliefs influence the choice of engineering for students, especially women.

RQ4: How well does critical engineering agency as an explanatory framework describe students' choice of an engineering career? In this study, the sample is large and representative of the national college population; and specifically, the gender distribution of 55% women, matches the national population. For student choice of an engineering career at the beginning of college, this CEA model of self-beliefs explains 20.2% of the variance (adjusted R^2 of engineering career choice). In education research with no controls for additional effects like level of family support, prior academic performance, race, ethnicity, socioeconomic status, and out-of-school experiences, 20% is a large proportion of the variance. Engineering career choice is a complex decision for many students. Explaining one-fifth of the outcomes solely through a model of self-beliefs, such as CEA, is a significant contribution to understanding engineering career choice. From our prior work using the SaGE dataset (Godwin & Potvin, 2014), the critical engineering agency framework explains as much variance in the engineering career choice outcome as the combined variance explained by family support of math and science, academic performance, gender, race, ethnicity, and which high school and higher education institution students attended.

The results of this analysis show how certain student self-beliefs are important for understanding the choice of engineering as a career in college. Engineering identity is a somewhat unclear construct at the transition between high school and college when students often declare a major of study, but before many students have had the opportunity to gain any engineering-related experiences. We have shown that engineering career choice at the beginning of college is connected to two subject-related identities – specifically, physics and math identity. As first identified by Godwin et al. (2013) and Cribbs et al. (2015) a significant, negative direct path from performance/competence to identity was confirmed for both physics and math identities. This finding indicates that even though performance/competence beliefs are related to the development of an identity in math and physics, without interest and recognition as mediating factors, identity development may be substantially hindered. Boaler and Greeno (2000) make a similar point about math learners. They state that performance in a math class is not enough to support a strong development of math identities for students. Thus, if a student feels competent and able to perform in physics or math, but he or she is never recognized or does not develop some interest in the subject, the likelihood of her developing a physics or math identity may be lower. On the other hand, perceiving oneself as competent may be a prerequisite for being recognized or having interest in a particular subject. Self-efficacy beliefs, somewhat conceptually similar to performance/competence beliefs in our framing, are often cited as a key factor in persistence (Marra et al., 2009; Mau, 2003). Without a deeper examination of the ways in which these performance/competence beliefs are related to other important self-beliefs, including identity, interest, and recognition, the subtleties of students' engineering career choice at the transition from high school to college are obscured.

Discussion

This article uses CEA as a framework to understand students' subject-related identities and agency beliefs as predictors of engineering career choice. We found that students' identities prior to having significant engineering experiences comprise multiple subject-related identities that correspond more closely with students' subject-related experiences in high school. This finding is consistent with previous studies on the types of students who choose engineering as a major in college, specifically, students who excel and show interest in math and science (Seymour & Hewitt, 1997; Tonso, 2006; Zhang, Thorndyke, Ohland, Carter & Anderson, 2003). We also found that agency beliefs and also an important predictor of engineering choice, especially for women.

Understanding the transition between high school and college is important for addressing the "gender filter" that excludes many women from STEM careers (Blickenstaff, 2005). As students move through their academic careers from middle school to high school to college, the fraction of students interested in STEM declines (disproportionately so for women), and the pathways for students choosing STEM careers become smaller and less diverse. Although prior research has documented student persistence and attrition in engineering majors across the college years (Cech & Waidzunas, 2011; Marra, Rodgers, Shen, & Bogue, 2012; Min et al., 2011), students' choice of engineering as a career while in high school is not well understood. The self-belief model utilizing CEA alone explains one-fifth of the variance in students' engineering career intentions at the beginning of college. Many other factors may predict engineering career choice, including structural supports and barriers, prior academic success, and other aspects of students' future goals, to name some prominent examples. These factors were not included in this study because the goal was to test how the CEA framework explains engineering career choice rather than factors external to an individual.

Implications for Practice

We found that recognition beliefs had the largest influence on students' math and physics identities. For K-12 instructors who teach courses fundamental to engineering, understanding student identity is valuable for guiding students in engineering career choices and promoting their persistence. Instructors in engineering, physics, and math courses can improve students' engineering self-beliefs by recognizing that their students can do STEM. One practical way that recognition can be incorporated into high school science and college engineering courses is through valuing the background knowledge and lived experiences of student. Educators can provide students with opportunities to take on open-ended STEM-related challenges and recognize students in the classroom for various types of successes rather than more traditional STEM pedagogies in which educators only reward a single answer to a closed-ended problem. Providing new ways for educators to recognize students in the classroom can help reduce the gendered patterns of STEM career choice and instructor recognition of students prevalent within engineering culture (Tonso, 2006).

Agency beliefs are a positive direct predictor of engineering choice. Emphasizing the utility of science and engineering to cause meaningful change in the world can positively affect students' self-beliefs and increase the likelihood of them choosing a career in engineering. Developing agency beliefs is a valuable use of classroom resources because such beliefs benefit all students, but more so for women. For the engineering community, representing engineering not only as a technical discipline centered on math, equations, systems, and computing, but also focusing on the social impact of engineering products and careers may foster a connection with engineering for women more interested in careers that make a positive impact on the world (Committee on Public Understanding of Engineering Messages, 2008). Engineering educators can show the utility of science and engineering through student-oriented classroom discussions or demonstrations and real-world examples of engineering and science. Incorporating such topics will likely help to increase the number of STEM students, which is a national goal (President's Council of Advisors on Science and Technology, 2012), and also to increase the proportion of women in engineering who remain a persistently underrepresented group in this field (Yoder, 2014).

This research can inform the implementation of the Next Generation Science Standards (NGSS) in K-12 schools (NGSS Lead States, 2013). Unlike previous science standards, the NGSS explicitly include practices and core ideas from engineering and technology. Exposure to engineering practices and ideas before college may improve students' understanding of and interest in engineering, especially since current students have a very limited understanding of what engineers do in their careers (Dabbagh & Menascé, 2006). The goal of integrating engineering into the standards is to help students understand the similarities and differences between science and engineering by making the relations between them explicit (Pratt & Bybee, 2012). In contrast, traditional approaches to fostering science or math identity development are more structured around classroom environments. These approaches do not allow students to draw on their rich knowledge that is based on nonschool experiences (Bricker & Bell, 2012; Brickhouse et al., 2000; Brickhouse & Potter, 2001). As the NGSS are implemented, care must be taken to provide learning opportunities that make students feel competent and give them opportunities to demonstrate that competence. If teachers implement these standards without explicit attention to the ways they support different possible identities, it may be difficult to foster the kinds of identities that cause students to engage in learning engineering practices or concepts, especially for underrepresented students (Buxton, 2005; Johnson et al., 2011). The goals of the NGSS to integrate engineering into the curriculum can provide further opportunities for students to engage with engineering in ways that stimulate their interest and provide new ways for teachers to recognize students. These opportunities can help them author identities related to engineering. However, the research base examining the effect of integrating engineering into K-12 education on affective outcomes is sparse, especially with respect to designing integrated STEM experiences to support the interest and identity development that promotes career interest in engineering.

Limitations and Future Work

This study was unable to examine how the measured constructs interact over time because the data utilized in this analysis are cross sectional. Without longitudinal data, the ability to see how identity changes and develops over time and how changing agency beliefs influence engineering career choice is limited. Identity is formed and negotiated over time through students' experiences and is a self-reflexive process. Our findings can only offer a snapshot of how students' STEM identities predict a choice of an engineering career in college. However, our findings shed light on the STEM-related identities that increase the likelihood of choosing an engineering career, the relationship between identity constructs of interest, performance/competence, and recognition, and the importance of agency beliefs for women in their choice of engineering careers. The items used to measure students' agency beliefs are a first attempt at measuring students' beliefs about how science and engineering can improve their lives and the world. As this theoretical framework is better understood, new questions that capture more diverse aspects of students' agency beliefs can be developed and utilized in the CEA framework. Another limitation of this study is the aggregation of the engineering disciplines asked in the survey into an overall measure of engineering choice. Our future work includes examining disciplinary differences in students' critical engineering agency. In addition, the goal of this study was not to understand what students believe it means to be an engineer but simply whether they are interested in engineering as a career and how their physics and math identities and their agency beliefs can affect this interest. We hope to address students' ontological understanding of engineering careers in future work. Finally, this analysis examines only one facet of diversity in engineering. Although gender is a persistent issue facing engineering, other factors like race, ethnicity, and class influence who becomes an engineer and are important considerations for promoting more equitable participation in engineering.

We do not know if some aspects of the subject-related identities discussed in this article will change or become incorporated into a distinct engineering identity as students complete engineering courses, have direct experience with practicing engineers, and develop the skills needed in an engineering career. Future studies that investigate the experiences and changing attitudes and self-beliefs of students throughout their undergraduate careers may give insight into how engineering students' CEA changes over time. Also, the methods used in this study can show connections between large-scale constructs but do not take into account individuals' experiences. Future explanatory studies of how and why these connections might be made and explained are essential to the continuing evidence for using CEA as an affective model. It is especially important to understand how students internalize recognition from teachers, family, and peers into their own identities. We are conducting a qualitative follow-up study on how students feel recognized in the classroom. The results of this follow-up study could help engineering educators better understand how to implement evidence-based recognition practices.

Conclusion

Students' affective beliefs are important to understanding their choices related to an engineering career. Identifying with math and physics upon entrance to college predicts engineering choice for both men and women. These subject-related identities are the types of identities that students hold prior to having direct experience with engineering. By fostering the development of these subject-related identities prior to college enrollment and early in students' college careers, more students may be recruited and retained in engineering. Students' agency beliefs are also important to their engineering career choice. Students who see practical applications for engineering as a way to improve the world are more likely to choose engineering as a career.

Critical engineering agency may be used to understand the affective states of students who choose engineering. As a framework of self-beliefs, it explains approximately one-fifth of the variance in the choice of engineering careers. These affective beliefs strongly influence why students choose engineering as a career. It is imperative to understand how students are developing a sense of identity with engineering both in high school and in college, especially for students who have been traditionally marginalized. The development of the critical engineering agency framework and application through structural equation modeling adds to the current understanding of what leads students to choose engineering as a career at the beginning of college. Because of the complexity of students' engineering career choices in college, many avenues of research may be developed through this framework.

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