12-14-2015

Identity, critical agency, and engineering majors: An affective model for predicting engineering as a career choice.

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Godwin, Allison; Potvin, Geoff; Hazari, Zahra; and Lock, Robynne, "Identity, critical agency, and engineering majors: An affective model for predicting engineering as a career choice." (2015). *School of Engineering Education Faculty Publications.* Paper 12.
http://dx.doi.org/10.1002/jee.20118

Identity, Critical Agency, and Engineering Careers: An Affective Model Engineering Choice

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Abstract

Background – Prior to college, many students do not have experience with engineering, but some ultimately choose an engineering career. Additionally, women choose engineering at lower rates than men, which results in women's underrepresentation. The framework of critical engineering agency (CEA) is utilized to understand student attitudes and beliefs for choosing engineering.

Purpose/Hypothesis – We investigate the relationships among students' math and physics identities in high school that predict choice of engineering careers; how students' beliefs about science and technology predict a choice of engineering careers; whether these beliefs are different by gender; and how well CEA explains students' engineering choice.

Design/Method – The data were drawn from the nationally representative Sustainability and Gender in Engineering (SaGE) survey distributed during Fall 2011 (n = 6,772). Structural equation modeling (SEM) was used to understand students' affective beliefs for predicting engineering choice in college.

Results – Multiple subject-related identities compose engineering students' identity at the beginning of college. Recognition from others and interest in a subject are important predictors of developing an identity. Students' performance/competence alone are not significant predictors of engineering, but are mediated by interest and recognition from others. Student identities and agency beliefs are significant predictors of engineering choice (explaining 20.2% of the variance). Gender differences were found for students' math and physics identities and agency beliefs.

Conclusions – Students' self-beliefs account for approximately one-fifth of the variance in engineering choice in the transition from high school to college. Steps can be taken to improve students' affective beliefs in early engineering experiences through addressing identity and agency beliefs.

Keywords – critical engineering agency, engineering choice, 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 of the 21st Century, 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 at the helm of engineering decision-making should reflect the country's population and give greater voice to populations that have not been historically well-represented in STEM (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 kinds of people that we ask students to become and studying how students embrace or avoid these promoted identities.

Prior to the beginning of college, most students have little to no direct engineering experience or meaningful exposure to an engineering community of practice (Committee on K-12 Engineering Education, 2009). Additionally, the typical or appropriate choice of high school courses is often undifferentiated for students who intend to enter many different science, technology, engineering, or mathematics (STEM) fields. This lack of prior context and content learning makes the choice of engineering especially difficult to understand compared to other STEM disciplines, such as biology or chemistry for example, 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 interest in STEM-related subjects develops much earlier in students' academic careers (i.e., elementary and middle school), often the choice of engineering occurs for STEM-interested students in high school. In a study of 6,860 students' engineering career decisions, 280 were interested in engineering careers at the beginning of high school (Cass, Hazari, Sadler, & Sonnert, 2011). The largest influx of students interested in engineering careers occurred during their high school years with 81% of students choosing engineering in college indicating new interest. During the high school years, students have the opportunity to take advanced math and science courses, including physics, which may have an impact on their choices of engineering in college.

Our work focuses on students' self-beliefs at the transition from high school to college to understand the impact of these beliefs on engineering choice. Students must be empowered to choose engineering before beginning their post-secondary education for engineering programs to attract the largest number of students (since it is more difficult to switch majors than to intend an engineering major from the start). There are other areas in which talented students are being lost (e.g., loss of interest in STEM-related subjects in middle school and the transition from college to the engineering workforce); however, this study focuses specifically on the transition from high school to college. Examining the attitudes of students choosing engineering can shed some light into this complicated decision and create access for more students to choose engineering as a career.

The continued lack of women in engineering

Although some professions such as law, medicine, and business have achieved equal (or near equal) representation of women, engineering remains a field predominated by men, with bachelor's degree recipients comprising less than twenty percent women overall (19.5% in 2013-2014 nationally, GE Fund, 2002; Yoder, 2014). Despite significant efforts to positively impact female enrollment in engineering, the number of bachelor's degrees awarded to women has not significantly changed in the last three decades (National Science Board, 2014). Other demographics factors such as race, ethnicity, or class that could be considered as part of identity development may also have a significant impact on engineering access and choices in college; however, this study focuses on gender specifically.

Performance in math and science is not the primary reason that women do not choose engineering as a major or leave engineering (Geisinger & Raman, 2013; Hill, Corbett, & St Rose, 2010; Min, Zhang, Long, Anderson, & Ohland, 2011). Although female students perform as well as male students in engineering, women's self-perception of their performance and their confidence in their engineering skills are often lower than that of male students (Cech, Rubineau, Silbey, & Seron, 2011). Traditional roles for male students and female students create gendered patterns for access to engineering professions and their identity development as engineers. Often, women face the double load of authoring their identity as engineers while also contradicting the traditional stereotypes surrounding engineering as a masculine field (Jorgenson, 2002). A perceived incompatibility between women's gender and STEM identity is one reason researchers cite for the lack of representation of women in STEM fields. Women who experience this incompatibility 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). Developing an identity in STEM early is a vital step to increase both STEM enrollment and persistence in college, especially for women (Bieri Buschor, Berweger, Keck Frei, & Kapper, 2014).

Previous findings on students' choice of engineering as a career and the lack of women in engineering give strong incentive to continue to understand how and why students choose engineering. We investigate students' engineering choice using structural equation modeling

(SEM) to examine connections between latent and measured variables. This approach to understanding quantitative data is an improvement over regression models because it allows a more nuanced examination of the relationships between variables and the predicted outcome as well as allowing for multiple indicators per latent variable with no collinearity problems. In this analysis, we focus on students' affective states through the framework of critical engineering agency (CEA). Developing this understanding can help educators and researchers provide support for developing students' desire to choose engineering which in turn, can create a more diverse engineering field and more creative engineering solutions.

Critical engineering agency

This study situates a new framework in engineering education which we adapted from critical agency frameworks previously used to understand student identity development and agency 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). Critical engineering agency (CEA) in our work uses multiple subject-related identities along with students' agency beliefs to examine how students see themselves a powerful thinker and doer of a particular subject (identity) and how they view the world with a critical mindset to advance the world as a more equitable place (agency beliefs) (Basu et al., 2008). This work is the first application of a critical agency framework within an engineering context using quantitative measures.

In CEA, identity is defined as 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 and attitudes they hold prior to experiences in an engineering community of practice. 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. The effect of school culture on engineering identity development also has been noted in other work which found explicit gender bias in an engineering school culture that alienated women (Tonso, 2006).

There are few studies, however, that focus on the impact of student experiences prior to college and 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 prior research has acknowledged the need for understanding multiple STEM identities prior to the choice of engineering (Capobianco, Diefes-Dux, Mena, & Weller, 2011; Matusovich et al., 2011; Pierrakos et al., 2009). Considering these identities is important because students' self-beliefs can impact 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 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 due to their perceptions that engineering conflicts with their view of themselves, their career aspirations, and other self-beliefs.

Identity development, specifically related to a students' role, has been framed around three key constructs in math and science education: 1) interest, 2) performance/competence, and 3) 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) framed identity as consisting of three factors, 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. Additionally, she recognized herself and was recognized by others as the type of person who does science (Carlone & Johnson, 2007). Hazari and colleagues (2010) built on this work in two distinct ways. First, interest was added to the framework of understanding students' STEM-related identities. This interest was defined as students' desire to participate in STEM-related activities and finding STEM as an enjoyable pursuit. The second contribution was a quantitative measure of these four areas. In a factor analysis, these four subconstructs only factored into three underlying subconstructs including: interest, recognition, and performance/competence. 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. The authors hypothesized that the overlap of these two constructs was due to students' inability to distinguish grades from conceptual knowledge in a course. These quantitative measures of identity have been used in several studies to understand the impact of students' physics and math identities on physics, math, and engineering career outcomes (Cribbs, Hazari, Sonnert, & Sadler, 2015; Hazari et al., 2010; Potvin et al., 2013). Our framing of identity focuses on these three areas to understand how physics and math identities relate to one another and impact engineering choice in college. Though these subconstructs capture students' STEM-related identities, we acknowledge that these are only one 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 impacts engineering outcomes.

Interest in a particular subject plays a key role in the choice of an engineering career. Previous studies have shown that students who are interested in engineering show particular interest and skill in math and science (Godwin, Potvin, & Hazari, 2013; Potvin, Tai, & Sadler, 2009) and that these identity constructs are connected to students' choice of engineering as a career in college. In particular, students' physics and math identities have been found to be the vital parts of their precursor identities for the choice of engineering careers (Godwin, Potvin, Hazari, & Lock, 2013). The connection to math is not surprising from the strong connections drawn in earlier literature (Li, Swaminathan, & Tang, 2009); a strong physics connection may be explained by the conceptual connections between engineering and physics content that emphasizes the heavy application of math with physical science. Additional parallels between these areas exist in the numbers of women enrolling in engineering and physics programs across the U.S. (Chen, 2013), though whether they are a consequence of similarities in the content, culture, both, or other factors is not clearly understood.

Students' performance/competence beliefs have also been shown to be an important part of identity development and engineering choice. This idea is related to students' self-efficacy beliefs, which have been shown to be a significant positive predictor in engineering persistence (Marra et al., 2009; Mau, 2003). Traditional measures of self-efficacy have focused on task-specific behaviors and actions related to students' attainment beliefs (Bandura, 1986). Fouad and colleagues (2002) found that performance influences career choices, albeit indirectly through self-efficacy development. Cleaves (2005) also captured this self-efficacy domain through in-depth longitudinal interviews with students and found that post-compulsory science-taking choices involved a variety of dynamic considerations including not only interest and enjoyment, but 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 – has an impact on 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 work 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 is also an important part of identity development that has more recently become a focus in science identity research. How others view a student is vitally important to how a student sees himself or herself. Parental perceptions and expectations of students' abilities to participate in STEM have significant impacts on students' later success (Bleeker & Jacobs, 2004; Dorie & Cardella, 2013; Jacobs & Eccles, 2000; Turner, Steward, & Lapan, 2004). Parental messages, along with teacher and peer messages, are integrated into how students see themselves and ultimately choose a career. These recognition messages are not only important early in children's lives from parents, but also during engineering identity development in college through teachers and peers. 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 professors had weaker identities as engineers and did not feel like they belonged in the culture of engineering. In sum, these prior studies highlight the importance of the aforementioned identity constructs for students across all educational stages including students with STEM identities in high school making relatively uninformed (by practice or personal knowledge) decisions about engineering in college.

Previous work in the CEA framework has identified that the development of multiple identities in physics, math, and science, measured by the subconstructs of interest, performance/competence, and recognition, generally are important for students who choose engineering in college (Godwin, Potvin, Hazari, & Lock, 2013; Godwin & Potvin, 2014). In this study the most significant subject-related identities for predicting engineering choice were physics and mathematics. The choice of these identities in our work is consistent with previous work which demonstrated that students who chose and persisted in engineering were significantly more likely ($p < 0.001$) to see themselves as a "physics person" over both chemistry and biology subject areas (Cass, Hazari, Sadler et al., 2011). Because of these findings and the previous framing of identity, we chose to measure physics and math identities in the CEA framework employing the three subconstructs: interest, performance/competence, and recognition (Cass, Hazari, Cribbs, Sadler, & Sonnert, 2011; Cribbs, Hazari, Sadler, & Sonnert, 2012; Hazari et al., 2010; Potvin, Beattie, & Paige, 2011; Potvin, Paige, & Beattie, 2012).

Critical engineering agency is not simply a model of students' identities, it also involves students' agency beliefs. Agency, in this case, refers to the capacity of an agent, a person or other entity, to act in the world, and this paper focuses on students' self-beliefs about their own agency in certain contexts. That is, this application of CEA as theoretical framework refers to students' perceptions of their ability to change their world through everyday actions and their broader goals through agency beliefs which is related to but distinct from agency. Students' agency beliefs involve how students see and think about STEM as a way to better themselves and the world (Godwin, Potvin, & Hazari, 2013) along with being a critic of themselves and science in general. The "critical" aspect of CEA incorporates the ways in which students become evaluators of STEM as well as 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 as evaluating, judging, and analyzing. The development of CEA can subsequently lend to students' professional identity development, advance their position or status in their community, society, or the world, and/or alter their world in ways they envision through science and engineering (Basu et al., 2008). In this prior work, agency may be an expression of identity whereas critical science agency simultaneously incorporates expressing science identity (through actions) that are relevant to one's own world and critical (questioning) of the social and cultural structures in place. Other prior research has focused on the identity-agency relationship (i.e., how associations impact how we act and how we act changes how we author ourselves) (Boaler & Greeno, 2000; Sfard & Prusak, 2005) and on the structure-agency relationship (i.e., how cultural and social structures impact how we act and how we can change structures through our actions) (Calabrese Barton, Tan, & Rivet, 2008; Varelas, 2012; Varelas, Settlage, & Mensah, 2015).

Research questions

This study uses SEM to examine the direct and indirect influence of students' self-beliefs in multiple identity domains and their agency beliefs on their undergraduate engineering intentions. This research was conducted at a single time point and acts as a "snapshot" of the physics and math identities and agency beliefs that students hold, on average, when choosing engineering in college. This paper addresses four research questions through quantitative methods.

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

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

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

Research Question 4: How well does critical engineering agency as an explanatory framework describe students' choice of engineering careers?

Methods

Data source

The data used in this paper were drawn from the Sustainability and Gender in Engineering (SaGE) survey which drew on responses from students at 2- and 4-year institutions across the U.S. (Klotz et al., 2014, "SaGE Survey," 2011). This data set is a nationally representative, stratified random cluster sample of postsecondary 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 alike, including a representative fraction of engineering majors. Drawing from a stratified random sample of colleges and universities across the U.S. available from the National Center for Education Statistics (NCES), the survey study collected data from 6,772 students attending 50 different institutions. The stratification accounted for the size of the institution and prevented over-sampling of the smaller, but numerous, liberal arts colleges in comparison to the relatively few, large public state universities. In total, fifty institutions agreed to participate in the paper-and-pencil survey, and some number of completed surveys were returned from every one of these institutions (100% institutional response rate). The SaGE survey included 47 anchored (5-point), multiple choice, and categorical questions on students' career goals, their high school science and math experiences, science enrollment and achievement (courses taken, grades, AP test scores, etc.), student attitudes about sustainability, science and engineering, as well as demographic information.

Survey Items

Specific items to measure engineering career choice and math and physics identity were used from previous studies with validity evidence (Cribbs et al., 2015; Godwin, Potvin, & Hazari, 2013; Godwin, 2014; Hazari et al., 2010). Items measuring math and physics identity were taken directly from the PRiSE study, as developed and validated by Hazari and colleagues (2010). These items were developed to measure math and physics identities, and 100% of the questions to measure math and physics identities were used verbatim from this study. The items measure the subconstructs of interest (two items e.g., "I am interested in learning more about this subject"); performance/competence (six items e.g., "I am confident that I can understand this subject in class" and "I can do well on exams in this subject"); and recognition (two items e.g., "My parents see me as a [math or physics] person"). Additionally, a single direct measure of students' overall identities in math and physics were included (e.g., "I see myself as a [math or physics] person"). To understand students' likelihood of choosing an engineering career, they were asked the question: "Please rate the current likelihood of you choosing a career in the following." The fourteen career options were "Mathematics," "Science/math teacher," "Environmental science," "Biology," "Chemistry," "Physics," "Bioengineering," "Chemical engineering," "Materials engineering," "Civil engineering," "Industrial/systems engineering," "Mechanical engineering," "Environmental engineering," and "Electrical/computer engineering." Students were asked to rate the likelihood of choosing a career in each discipline on an anchored scale from 0 ("not at all likely") to 4 ("extremely likely"). In the current analysis, students' choice of engineering was taken to be the strongest response to any of the eight engineering responses. This method was chosen to include students interested in engineering generally (but as-yet undecided on a particular discipline) as well as students with a very well-specified interest in one or two engineering disciplines. The sample included in this study is representative of national enrollment in 2- and 4-year institutions across the U.S. Because of this sampling, not all institutions offer engineering as a major. The majority of students at 2-year institutions (78%) did not indicate a strong interest in engineering as a career choice. We chose to include students at 2-year institutions in this analysis because they provide additional information about a representative sample of students who may or may not choose engineering based on CEA constructs, including potential transfer students.

Additionally, we specifically created the agency beliefs items used in this work to measure students' perceptions of their ability to be a critic of science and the potential for science to make these kinds of impactful changes. Agency beliefs are a subconstruct of CEA in addition to physics and math identity. Some examples of these questions include: "Science has helped me see opportunities for positive change" and "Science has made me more critical in general." These agency beliefs capture students' beliefs about the impact of science to measure how these perceptions interact with how they "identify themselves as experts in one or more realms associated with physics [and math]" (Basu & Calabrese Barton, 2009, p. 346) as quantitative measures. We originally included more items in the SaGE survey to measure agency beliefs, but because they did not load together as a construct in exploratory factor analysis, we excluded from this analysis (Godwin, Potvin, & Hazari, 2013). The five remaining items that measured student agency beliefs were used in this study to ascertain how students, especially women, become empowered to choose engineering in college. Note that all of the measured variables used to build the latent constructs in this analysis are listed in Tables 1, 2, and 3.

The validity and reliability of that data provided by these measures were re-evaluated for identity items from other studies and established for agency beliefs used to measure CEA. Lending to content validity, questions were refined based on feedback from assessors on the grant advisory board and STEM education researchers familiar with physics and math identity and critical agency theory as well as the results of pilot testing in first-year engineering courses at two universities. An in-person pilot of the survey and focus groups were also conducted 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 the factor analysis and SEM in this study (e.g., identity and agency beliefs measures) was evaluated by test-retest of 62 students, and the average Pearson's correlation was 0.732 (which falls into the "acceptable" range; George & Mallery, 2003).

Confirmatory Factor Analysis

To conduct this analysis a two-part approach was undertaken. First, a "measurement model" was examined utilizing confirmatory factor analyses to assess how well the indicators items measured the hypothesized latent variables (see Tables 1, 2, and 3). Seven latent constructs related to the various components of CEA were measured: the three subconstructs of identity (performance/competence beliefs, interest, and recognition beliefs) for each of physics and mathematics, and agency beliefs. During this step, the fit indices of the measurement model were assessed and convergent validity was checked by examining the factor loadings. This step ensured that the subconstructs we hypothesized that we were measuring were, in fact, captured in our data. In all of the models shown, we standardized the estimates for factor loadings and structural paths range from zero to one so that the magnitude of these loadings can be directly compared within the models.

Structural equation modeling

The second step of this analysis involved building the “structural model” by testing paths between latent variables. Figure 1 shows the proposed model constructed from the CEA theoretical framework that was initially tested using SEM. From previous work on modeling CEA (Cribbs et al., 2015; Godwin, Potvin, Hazari, & Lock, 2013), the constructs of physics and math identity were built to include mediating paths from performance/competence to identity via interest and recognition. Items that asked students the degree to which 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). These identities, along with agency beliefs, were hypothesized to predict the choice of engineering as a major/career (RQ1 and RQ2). The hypothesized student beliefs model represented in Figure 1 was tested using the lavaan package in R (R Core Team, 2013; Rosseel, 2012).

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

Additionally, the variance of each latent variable was fixed to one. A Satorra-Bentler estimation method (Satorra & 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. The model was trimmed of non-significant paths and for parsimony following Byrne (1994). This structure simultaneously estimates thirteen regression equations and one covariance between physics identity and math identity. Several fit indices and path significance tests were used the evaluate the model based on Byrne's suggestions (1994), including chi-square [should be non-significant at the $p < 0.05$ value (Byrne, 1994)], Comparative Fit Index (CFI) [acceptable values occur above 0.9 (Hu & Bentler, 1995)], Non-Normed Fit Index (NNFI) [acceptable values occur above 0.9 (Hu & Bentler, 1995)], and root mean square error of approximation (RMSEA) [values less than 0.01, 0.05, and 0.08 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 non-significant 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 quasi-traits measured do not change over the time period of interest (Potvin & Hazari, 2013), and can therefore be interpreted in a mediated model. This argument is upheld by the discussion that as students move further along in their education, their identities become more and more established with each additional interaction with STEM-related subjects. At the macro level when students are asked to think reflexively back on these experiences, these identities are relatively stable compared to measuring than moment-to-moment instances of identity in specific situtations (Lichtwarck-Aschoff, van Geert, Bosma, & Kunnen, 2008). Only significant changes or experiences dramatically shift students' overall identities. In this study, university freshmen were asked about their self-beliefs in traditional subjects like math and science, which have been practiced over numerous years of formal education. We argue that their overall STEM identities are relatively stable, or in equilibrium, unless a perturbation occurs and offsets the balance between interest, performance/competence, and recognition. These perturbations cause identity renegotiation and new identity development. We attempted to reduce the potential impact of these perturbations in the sampling of students in the first few months of their freshman year in college before they had new STEM experiences, especially in their new engineering communities of practice. Additionally, the magnitude of bias for mediated models can be estimated based on the stability coefficients of the latent variables (Maxwell & Cole, 2007). The bias for stable variables within a time of interest is negligible if the stability coefficients are similar. In this case, the equilibrium between the identity variables results in stable measurements and non-significant bias according to simulations by Maxwell and Cole (2007) on the estimates presented in this paper.

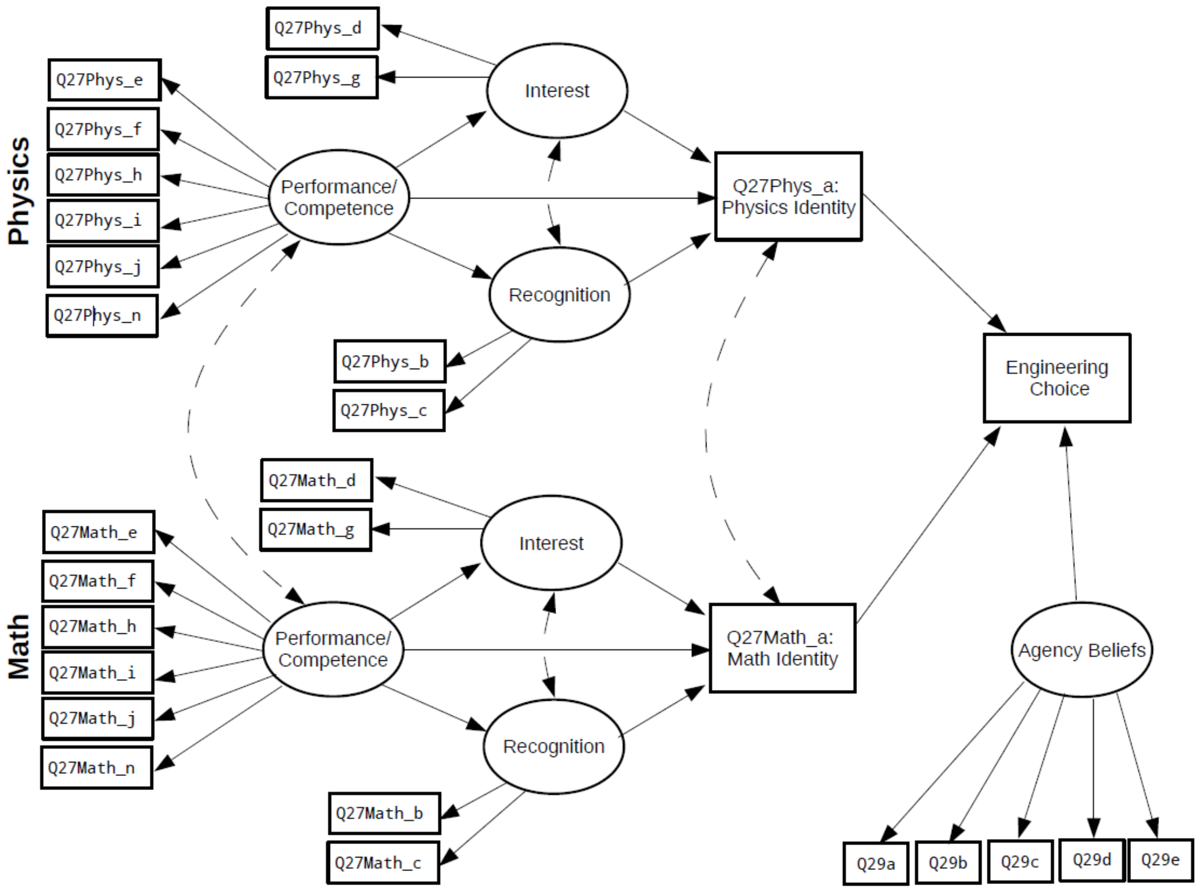

Figure 1: Diagram of proposed structural model for the structural equation modeling analysis based on CEA theoretical framework.

Multiple group analysis: Testing for model invariance

After the full SEM model was evaluated for fit, the model was compared for females and males to see if the proposed structure was equivalent across these groups (RQ3). Model invariance tests were conducted to determine significant differences for men and women in the measurement and structural path parameters. First, a baseline model was created for males and females with all parameters freely estimated. Next, a model was created with only factorial equality constraints - the factor loadings between the male and female model were constrained to be equal while the regression coefficients were freely estimated across the groups. A measurement invariance test was conducted based on the chi-square diff statistic when compared to the baseline model. This chi-squared difference, called a mod or modification 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 not a significant difference in the model fit for men and women and, therefore, invariance between item responses and/or paths could be established across the two models. If non-invariance was indicated by a significant chi-square difference test then the model would fit significantly better if the paths identified were estimated separately for men and women. Examination of the modification 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 CFA analyses included in Tables 1, 2, and 3 indicate that the measurement model fit the data. Individual item reliability was evaluated with the square multiple correlation (R^2). Each correlation was above 0.5 indicating 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 a better estimate of the overall reliability of an item taking into account the individual reliabilities as well as standard errors. Values greater than 0.70 are acceptable (Hair, Anderson, Tatham, & Black, 1998). Though the squared multiple correlation (R^2) indicates the reliability of a single measure and the construct reliability the reliability of the construct as a whole, 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 was calculated for each latent variable ranging from 0.717 to 0.825 (Sin, 2009). The average variance extracted 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 different terms, it is a measure of the error-free variance of a set of items measuring a single construct. Average variance extracted is used as measure of convergent validity, which should be 0.50 or above (Dillon & Goldstein, 1984). These results demonstrate that the items hypothesized to measure a single construct do, in fact, measure the intended construct and capture a strong majority of the variance within each block of items. Convergent validity establishes that measures that should be related are in reality related. This type of validity was evaluated by examining the factor loadings in the model, since all of these values were greater than 0.70, we provide evidence for convergent validity. Discriminant validity provides evidence that measures for one latent variable are not overly rated to another latent variable and was established through multiple methods. First, the AVE should be greater than squared multiple correlation between latent variables (Schreiber et al., 2006) which we established (AVE shown in Tables 1, 2, and 3). Additionally, the correlation between items of unrelated latent variables in our study is less than 0.85 (Byrne, 1994). The overall fit indices for the measurement model were a CFI of 0.954, NNFI of 0.944, and an RMSEA of 0.056. All of these fit indices indicate that the measurement variables accurately reflect the latent variables in the measurement model.

Table 1

Confirmatory factor analysis estimates for physics identity subconstructs.

Latent Variable	Indicator Variable	Standardized Factor Loadings	Standard Error	Item Reliability (R^2)	Construct Reliability	Average Variance Extracted
	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		
	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		
	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.

Table 2

Confirmatory factor analysis estimates for math identity subconstructs.

Latent Variable	Indicator Variable	Standardized Factor Loadings	Standard Error	Item Reliability (R^2)	Construct Reliability	Average Variance Extracted
	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		
	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		
	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.

Table 3

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
	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.

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 in which were missing not at random (MNAR) were deleted, for a final sample size of 6,511 from the original 6,772. The chi-square statistic for this model is 10,062 and is significant at the $\alpha < 0.05$ level. Due to the large sample size, the chi-square statistic is artificially inflated, and the chi-square statistic is expected to be significant without indicating a poorly fitting model (Schumacker & Lomax, 2004). The degrees of freedom reported are 331. The RMSEA indicates a reasonable fit of the model with the observed data with a value of 0.065 (90% confidence interval ± 0.001). Additionally, 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 inform if 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/engineering can do for the world (agency beliefs) which together encompass CEA predict a choice of engineering.

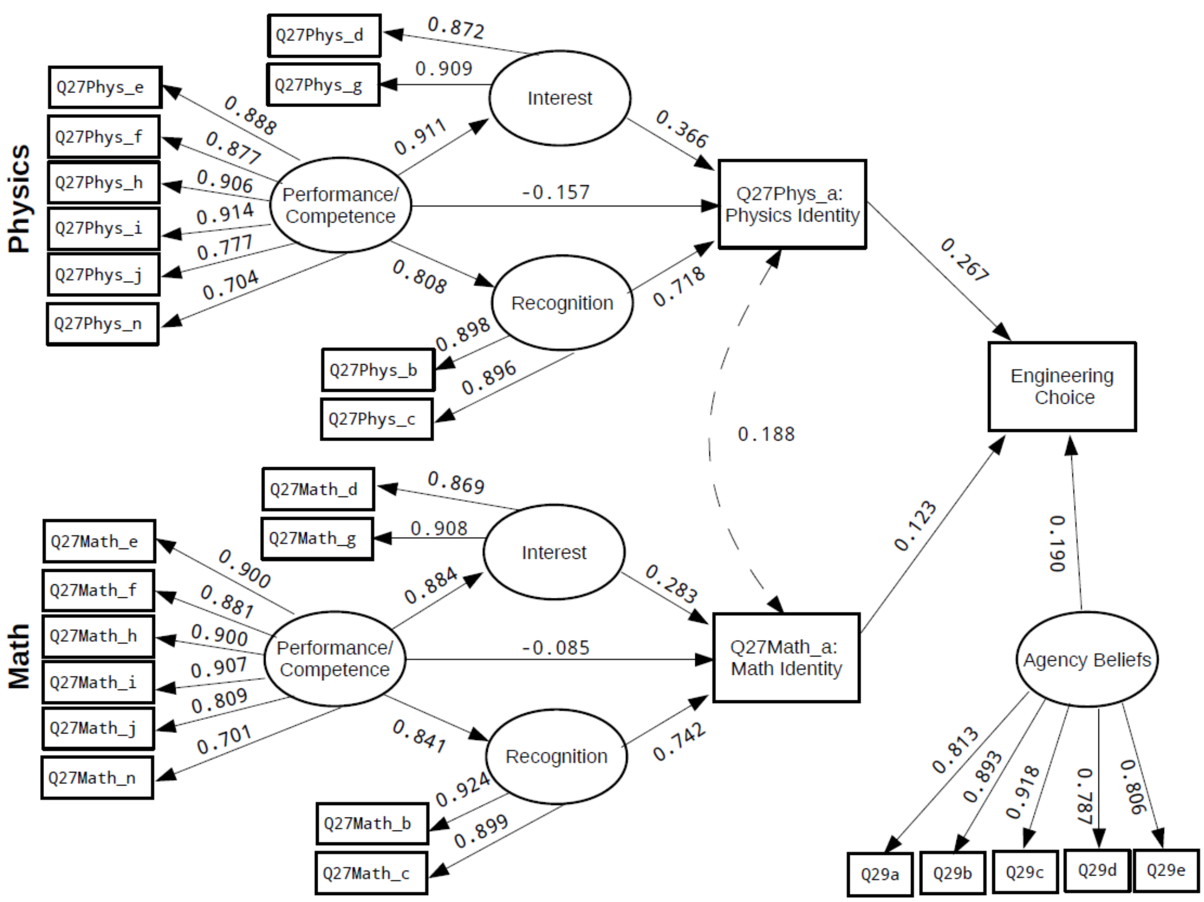

Figure 2: Results of final structural equation model for all students. All paths are significant at the $p < 0.001$ level

To answer Research Question 3, this model was compared for students who identified themselves as either male or female in the SaGE survey. The model invariance tests based on the modification indices revealed paths that were significantly different between males and females. Both a chi-square difference test and a delta CFI test were conducted 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 highlighted. The loadings for students' responses to the question: "I can overcome setbacks in math" (M (male) = 0.771; F (female) = 0.681) were freely estimated while the remaining loadings were constrained to be equal in the measurement model. Additionally, the regression estimates for the paths from physics identity, math identity, and agency beliefs were estimated freely while the rest of the structural model paths were constrained 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 significantly ($p = 0.026$, Cohen's $d = 0.08$). These separate model parameter comparisons were conducted by estimating the model parameters for each group separately and performing a between-group test of significance across the groups (Hsieh, Rai, & Keil, 2008; Keil et al., 2000; Qureshi and Compeau, 2009; Venkatesh and Morris, 2000). These effect sizes 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 2000 the effect sizes become more reliable and less likely to be artifacts of other disturbances (Slavin and 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 size 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 non-trivial effects on engineering recruitment and choice which is a complex and nuanced decision.

The fit parameters for this model were: a chi-square of 4,389 on 705 degrees of freedom, RMSEA of 0.061 (90% confidence interval 0.059 to 0.063), CFI of 0.954, an NNFI of 0.950, all indicating good fit for the gender comparison model. The total variance explained in the linear engineering career choice outcome was 20.2% for the model pictured in Figure 2 (Adjusted R^2 of engineering career choice scale). This result answers Research Question 4 and shows that this model of students’ self-beliefs explain just over one fifth of the variance in choice of engineering.

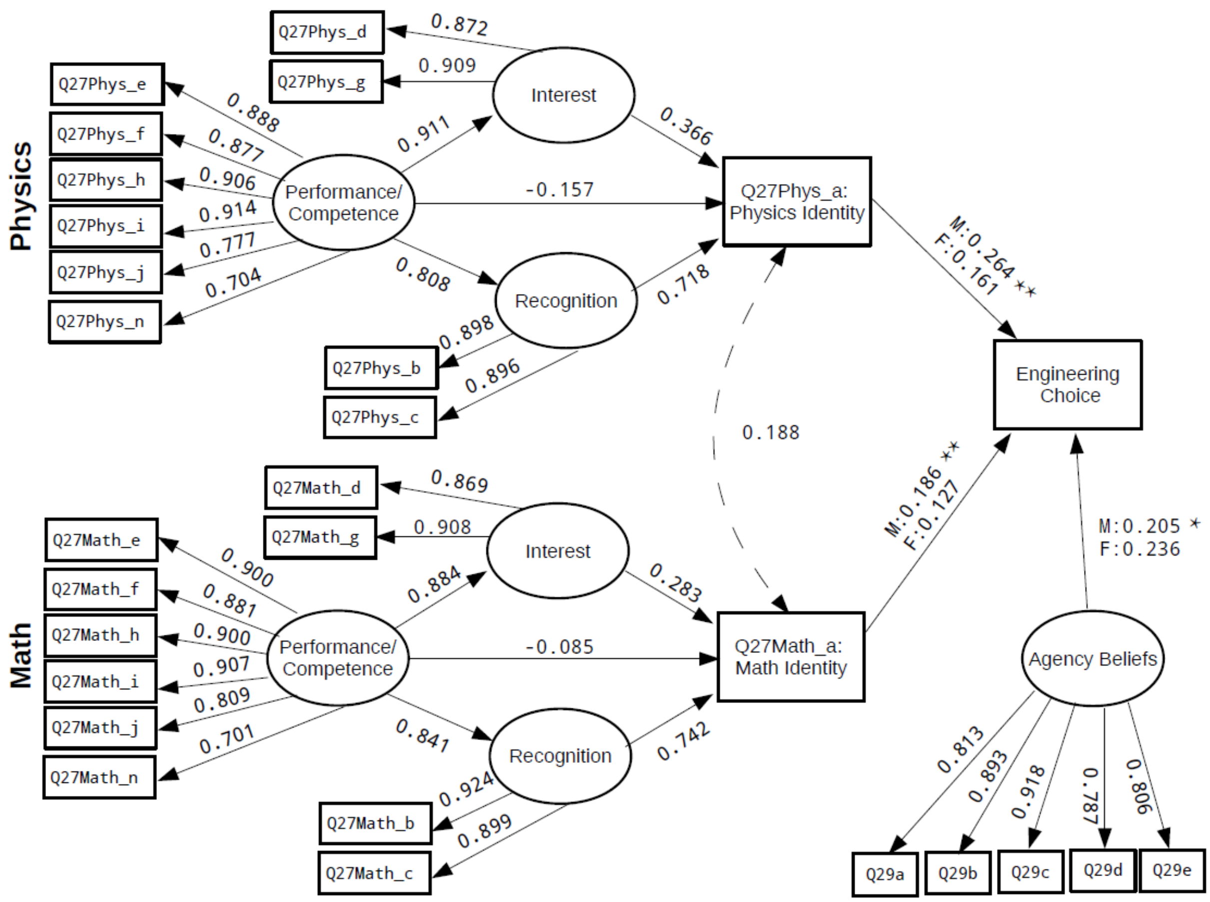

Figure 3: Results of fitting gender comparison structural equation model (F=Female; M=Male). For gender comparisons, * indicates p-values < 0.05 and ** indicates p-values between 0.01 and 0.001. All other paths in the model are significant at the $p < 0.001$ level.

Addressing the research questions

To discuss our results, we first describe how the resultant 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 engineering careers?

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 work confirms its importance in a large-scale national data set. Furthermore, our work clarifies that performance/competence beliefs are not sufficient to predict identity development, with direct negative paths (loadings of −0.157 and −0.085 for physics and math identity, respectively) which are mediated by positive indirect paths through interest and recognition beliefs in each case. Performance/competence beliefs are important to both interest and recognition beliefs; however, they do not directly predict an identity in either math or physics. In support of this finding, Marra et al. (2009) found that female engineering students had positive shifts in self-efficacy beliefs while simultaneously having negative shifts in their feelings of inclusion indicating self-efficacy beliefs alone may not capture students seeing themselves as the type of person who can participate in engineering.

Identity is not simply a designation for students who are “good at” physics or math homework, tests, or concepts. Identity is more strongly impacted by students’ interests and beliefs that they are recognized as the type of person that engages in these subjects. This picture is similar for both men and women (see discussion of RQ3 for a detailed analysis), and any attempts to develop students’ identities in these situations 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 accomplish the goals 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 nuanced. 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 contribute positively to 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 engineering careers?

The resultant models show that students' agency beliefs also play an important role in their choice of engineering. 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 to physics or math identities for all students in Figure 2, agency beliefs were stronger predictors 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. This belief measure captures how students feel they are empowered to make changes, not necessarily the actions of empowered change that they take which are more readily measured through qualitative techniques. The finding that agency beliefs is a significant, positive predictor of engineering career choice on top of students' identity beliefs is important because this allows us to understand ways in which high school students could come to perceive engineering as a more relevant and interesting choice in college: those who believe that they can make change in the world and in their lives, coupled with burgeoning self-beliefs about their role as physics and math people, can lead students to choose engineering careers at significantly higher rates than if they do not subscribe meaningfully to these identities or agency beliefs.

RQ3: To what extent do students' beliefs differ among men and women?

Small gender differences in physics and math identity were found between women and men (Figure 3). Women had lower estimates than men for the path between seeing themselves as a "physics person" (F = 0.161 and M = 0.264 with $p = 0.003$) and a "math person" (F = 0.127 and M = 0.186 with $p = 0.009$) and their choice of engineering. Though 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 people" who do physics or math was less predictive of the choice of engineering for women than for men. This difference may be due to the fact that women identify less with the subjects of math and physics due to 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). Additionally, studies have shown that women lose interest in math and science early on in their education (National Science Board, 2003). This loss of interest may feed into depressed math and physics identities for women in general, even 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. This depressed view of themselves with respect to math and physics may lead to fewer women choosing engineering due to the emergent barrier of their self-ascribed identity not being amenable with an identity ascribed to the pursuit of physics, math, or engineering – an identity vital 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 influence on engineering career choice ($p < 0.001$). This influence was stronger for women than for men, with loadings of 0.236 and 0.205, respectively ($p = 0.026$). For women, the path between their agency beliefs and engineering career choice was stronger than the paths between both math and physics identities to engineering career choice. This finding is supported by Chinn's (1999) study of female students, which found that agency towards 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 incorporate content and strategies personally meaningful to them. Holding empowering 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 have a positive impact on the world through their engineering degrees. Two students, Jess and Brianna, described gendered discrimination in their engineering courses through male peers' attitudes and being silenced in the classroom. Both of these students overcame these incidences and authored engineering identities by seeing the unique contributions they had to offer in internship and co-op positions that made a positive impact on their engineering projects and relationships in an industrial setting. The development of agency allows students to act against established social structures and cultural norms both within engineering (as, for example, a male dominated field) and outside of it. It also allows them to take action and separate their own actions from what is done to them (Roth & Tobin, 2007).

This combination of findings in RQ3, that women's physics and math identities are less predictive of engineering career choice than for men and, simultaneously, that their agency beliefs are more predictive, suggests that the factors that could lead women into engineering differ not only in the substance (e.g., women show weaker physics/math identities on average, therefore they choose engineering less frequently) but also in the structure (less importance of physics/math identities for women in making engineering-related choices and greater importance of their agency beliefs). The implication is that efforts to recruit women which solely focus on "building" their physics/math/engineering identities will be less effective than those which also emphasize their empowerment, or at least their perceived empowerment in changing their world through engineering (e.g., agency beliefs).

What students experience (e.g., in a classroom setting) clearly impacts what they intentionally choose for themselves (e.g., their choice of major/career). Teachers' pedagogical choices can impact students' choices and behavior, especially if those pedagogical choices empower students to shape what happens around them or at least to realize that they have the ability to shape what happens in their world. Specific classroom practices including student autonomy and the creation of hybrid spaces can impact students' agency (Basu & Calabrese Barton, 2010; Calabrese Barton & Tan, 2010; Godwin, 2014; Holland, Lachicotte, Skinner, & Cain, 2001; Tonso, 2006). Based on our work, it is likely that a woman who develops agency towards engineering within a science course will be more likely to intentionally choose to pursue engineering, going against social norms and structures, than otherwise. Thus, agency increases the potential for individual and social transformation (Emirbayer & Mische, 1998). Agency beliefs are an important consideration in 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 engineering careers?

In the current study, the sample is large and representative of the national postsecondary population (including 2- and 4-year institutions) with a typical postsecondary population including gender distribution (55% female). For student choice of engineering at the critical juncture between high school and college, this model of self-beliefs explains 20.2% of the variance in choice of engineering (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 in engineering career choice explained by CEA constructs. Engineering career choice is a complex and nuanced decision for many students. Explaining one-fifth of the outcomes solely through a construct of self-beliefs like CEA is a significant contribution. For example, this framework explains as much variance (~20%) in the engineering choice outcome as the combined variance explained by family support of math and science, academic performance, gender, race, ethnicity, and which high school and postsecondary institution students attended (Godwin & Potvin, 2014).

The results of this analysis highlight 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 juncture of 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 community experiences. Engineering identity has been shown to be connected to two subject-related identities – specifically, physics and math identity. As first identified in previous work (Cribbs et al., 2015; Godwin, Potvin, Hazari, & Lock, 2013) a significant, negative direct path from performance/competence to identity was confirmed for both physics and math identities. This indicates that even though performance/competence beliefs are related to the development of an identity in these domains, 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 the performance in a math class is not enough to support a strong development of mathematical identities for students. Thus, if a person feels competent and able to perform in physics or math, both considered difficult topics, 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 depressed. 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 nuances of students' engineering career choice at the transition from high school to college are obscured.

Discussion

This paper represents a quantitative use of CEA as a framework to understand students' affective states in relation to engineering. Students' engineering identity prior to having significant engineering experiences in a community of practice has been found to comprise multiple subject-related identities corresponding to students' subject-related experiences in high school. This finding is consistent with previous studies on the “types” of students who choose engineering; specifically, students who excel in math and science and show interest in these subjects (Seymour & Hewitt, 1997; Tonso, 2006; Zhang, Thorndyke, Ohland, Carter & Anderson, 2003).

Understanding the transition between high school and college is important to address 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 becomes smaller and less diverse. Although prior research has documented student persistence and attrition in engineering majors across the postsecondary years (Cech & Waidzunas, 2011; Marra, Rodgers, Shen, & Bogue, 2012; Min et al., 2011), the choice of engineering as a career in high school is not well understood. The self-beliefs model utilizing CEA alone explains one fifth of the variance in students’ engineering career intentions. Many other factors may potentially predict engineering career choice, including factors such as 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 the current study because of the overriding goal to test how the framework of CEA explains engineering career choice. Additionally, CEA, as we have constructed and tested in this paper, is solely based on students’ self-beliefs including identity and agency factors rather than factors external to an individual. Students often cite a “lack of belonging” as a main reason that they leave engineering (Rodgers & Marra, 2012). The framing of this study begins to measure constructs that add to those feelings and offer some implications for improving belongingness in engineering through students’ identities and agency beliefs (CEA). Our contributions add to the understanding of how identity can be measured quantitatively and how CEA constructs impact engineering career choice with a nationally representative sample.

Implications for Practice

We found that recognition beliefs had the largest influence on students' math and physics identities. For K-12 teachers and professors who teach courses fundamental to engineering, like math and physics, understanding student identity is valuable for guiding students in engineering career choices and promoting their persistence. Instructors in engineering, physics, and math courses can positively impact students' engineering attitudes by recognizing their students as the kind of people that can do STEM. One practical way that recognition can be incorporated into high school science and postsecondary engineering classrooms is through valuing the background knowledge and lived experiences that students bring with them into classrooms, which provides students the opportunities to take on STEM-related challenges. These experiences can give students recognition in the classroom for various types of successes rather than the traditional paths of access to STEM with a single "right" answer that only gives recognition to the "smart" students in the classroom. Creating these opportunities may help reduce the gendered patterns of access and recognition prevalent within engineering culture (Tonso, 2006).

Agency beliefs also had a significant impact on engineering choice. Emphasizing the utility of science and engineering to cause meaningful change in the world and help to make students more critical of themselves and the world around them in high school science and math classrooms (and even freshman engineering courses) can positively affect students' attitudes and increase the likelihood of them choosing a career in engineering. These endeavors are a valuable use of classroom resources because they are positive for all students, but potentially more so for women. For the engineering community, branding engineering as not only a technical discipline centered in 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). For engineering educators, demonstrating the positive utility of science and engineering can be accomplished through student-oriented classroom discussions or demonstrations as well as specific case studies of engineering projects. 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 increase the proportion of women in engineering who remain a persistently underrepresented group in this field (Yoder, 2014).

The timing of this research has implications for the implementation of the Next Generation Science Standards (NGSS) in schools. Unlike previous science standards, NGSS explicitly include practices and core ideas from engineering and technology. This exposure to engineering practices and ideas earlier than college may have an impact on students' understanding of what engineers do and spark additional interest in engineering, particularly since 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 connections between them explicit (Pratt & Bybee, 2012). In contrast, traditional approaches to science regularly favor aspects of science/math identity development that are more structured around classroom environments rather than science itself. These practices do not allow students to access their rich knowledge based on non-school experiences (Bricker & Bell, 2012; Brickhouse et al., 2000;

Brickhouse & Potter, 2001). As NGSS are implemented, care must be taken to provide learning opportunities that make students feel competent and give them opportunities to express 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 support meaningful learning towards engineering practices/concepts, especially for underrepresented students (Buxton, 2005; Johnson et al., 2011). Beyond learning outcomes, the goals of the NGSS to integrate engineering into the curriculum can provide further opportunities for students to engage with engineering in ways that stimulates their interest and helps them author identities related to engineering-. However, the research base examining the effect of such implementations on affective outcomes is sparse; particularly with respect to designing integrated STEM experiences to intentionally support interest and identity development which promotes career interest in engineering.

Limitations and future work

Some limitations of this study include the inability to see 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 restricted. We acknowledge that identity is formed and negotiated over time through students' experiences and is a dialogic and self-reflexive process. This work can only offer a static "snapshot" of how students utilize identities at the end of high school to choose engineering in college. However, this work does shed light on the multiple STEM-related identities that increase the likelihood of choosing an engineering career, the relationship between identity sub-constructs, and the importance of agency beliefs for women in their choice of engineering careers. Additionally, the items used to measure students' agency beliefs are a first attempt at capturing how students view their choice of a career that uses science to affect their surrounding world. As this concept is better understood, new questions that capture more diverse aspects of students' agency beliefs can be developed and utilized in the framework of CEA. Another limitation is the aggregation of engineering as a homogenized monolith rather than examining disciplinary differences in the CEA constructs. 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 and how their disciplinary physics/math identities and agency beliefs can affect these interests. We hope to address their ontological understanding of engineering careers in future work. Finally, this analysis only examines one facet of diversity in engineering. Although gender is a persistent issue facing engineering, other factors like race, ethnicity, and class impact who has access to engineering and are important considerations for promoting more equitable participation within engineering.

We do not know if some aspects of the subject-related identities in this paper will fade 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 of students throughout their undergraduate careers may give insight into how engineering students' CEA changes over time. Also, the methods used in this work have the ability to 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 vital to the continuing evidence for using CEA as an affective model. It is especially important to understand the nuances of 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 to better understand practical ways for engineering educators to implement evidence-based recognition practices.

Conclusion

Students' affective beliefs are vital to understanding their choices related to an engineering career. Identifying with math and physics upon entrance to a university 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 development of these subject-related identities prior to university enrollment and early in students' postsecondary careers, more students may be recruited and retained in engineering. Additionally, students' agency beliefs are also important to their engineering career choice. Seeing practical applications for engineering in the world can provide opportunities to make engineering more attractive by highlighting ways in which engineering can be used to make a positive change in the world.

Critical engineering agency may be used to understand the affective states of students who choose engineering. As a construct of self-beliefs, it alone explains over one fifth of the variance in the choice of engineering careers. These affective beliefs are a demonstrably strong influence on why students choose engineering. With some educators and researchers discussing the focus of engineering education on issues of equality, it is imperative to understand how students are developing a sense of identity with engineering both in high school and in college. This need is especially dire for students who have been traditionally marginalized. The development of the CEA model and application through structural equation modeling adds to the current understanding of what leads students to choose engineering between high school and college. Because of the complexity of students' engineering career choices in college, many avenues of research may be developed through this framework. As these areas grow, the ways in which educators and researchers can empower women to choose engineering should be more effectively explored.

Acknowledgements

This work was supported by the U.S. National Science Foundation through grant 1036617 and graduate research fellowship. The opinions expressed are those of the authors and do not necessarily represent those of the NSF. The authors wish to thank the participants of the SaGE survey and the editors and anonymous reviewers whose constructive comments improved the quality of the final product.

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