A Cross-sectional Study of Engineering Identity During Undergraduate Education

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A Cross-sectional Study of Engineering Identity Development During Undergraduate Education

In this research paper, we explore engineering students' identity development across the four or more years of undergraduate engineering education. The focus of this work is subject-related role identities, or how students position themselves and are positioned by others as the kind of people that engage in engineering, mathematics, or physics. We collected responses from 586 engineering students at a large, public East Coast university using an electronic survey during the spring semester of 2016. Survey items were taken from previously developed instruments and included measures of students' interest in engineering, students' feeling of recognition by others as an engineer, and students' beliefs about their performance/competence in engineering. We also measured students' overall attitudes about their identities as a physics person, math person, and engineer. Student responses were compared by academic year at the university (i.e., first year, second year, third year, or fourth or more year) using ANOVA and post-hoc Tukey's HSD for significant results. Our findings illustrate differences in students' engineering performance/competence and recognition beliefs as well as differences in their engineering, mathematics, physics overall identity measures. The post-hoc Tukey's HSD tests reveal a consistent pattern of identity development with lower identification in the second year of engineering education and identification progressing to the highest levels in the fourth year. This research provides evidence that these subject-related role identity measures can be used with students across undergraduate engineering and that they can differentiate among students by year at a university.

Introduction

Identity is an important indicator for educational and professional outcomes that are important in engineering education[1–8]. In this work, we define identity not only as how a student sees him or herself but also how he or she is positioned by others in the world[9]. These two tensions interplay in the context of engineering and how undergraduate students become engineers.

Over the past few years, interest in quantitatively measuring identity in engineering education has grown. To date, significant qualitative work has advanced our understanding of how students describe identity development and what that means for their development as professional engineers[10–14]. This prior work provides a strong basis for understanding how identity influences important outcomes like student recruitment and retention. However, these in-depth studies are intensely time-consuming and do not allow for a quick measurement of how students develop identities as engineers.

More recently, Godwin published a 2016 ASEE conference proceeding describing the development of a quantitative measure for engineering identity using survey responses from 2,916 first-year students across four U.S. institutions[15]. She focused on measuring students' self-beliefs of their subject-related role identities. The resulting instrument captured three underlying constructs of students' interest in the subject, beliefs about their ability to perform in their courses as well as understand course material (i.e., competence), and beliefs that others recognize them as the type of person that does engineering. These items to measure the three constructs were drawn from measures of science and mathematics identity that were developed from qualitative work in science education. These measures of science, physics, and mathematics

identity have been shown to be significant positive predictors of STEM-related career choice including engineering at the transition from high school to college. However, one limitation of the study was that the items were developed for students in the first year of engineering and had not been used with upper-level students.

Prybutok, Patrick, Borrego, Seepersad, and Kirisits[16] used similar items to measure engineering identity across 563 lower and upper-level undergraduate students in civil and mechanical engineering. These authors found a different factor structure than Godwin[15] and conducted t-tests to examine differences in these constructs. For lower-division students, they found no significant differences by discipline. For upper-division students, they found that mechanical engineering students rated themselves higher on all physics identity constructs (e.g., interest, performance/competence, and recognition [by self and by others]). Finally, in an overall comparison of lower division and upper division students, they found that lower-division had higher math interest while upper-division students had higher physics recognition. These findings indicate that there were some significant differences in students' STEM role-identity measures across mathematics and physics; however, the authors found no differences across engineering measures. The results of this study could be limited by the disciplinary interests of students (e.g., only civil and mechanical rather than a representative sample of the entire engineering population), the smaller sample sizes for comparisons, and the differences in constructs for the populations (e.g., indicating that the students in this study answered the questions different from those of other studies).

Pierrakos, Curtis, and Anderson[17] have also proposed a different measure of engineering identity from a psychological perspective. They developed items measuring multiple dimensions of engineering identity based on a thorough literature review and results from their prior work. This instrument, the Engineering Student Identity Survey (E-SIS), measures 11 subconstructs using 38 questions. The items measuring students' self-enhancement, social support, visibility of affiliation, and sense of belonging were able to discriminate between first-year students second-year students. All other subconstructs distinguished between first-year students and upper-level students. However, evidence for the construct validity of these items was not provided and the survey was only administered to 260 engineering students at a single university. This survey still needs to be tested in broader contexts and provide strong evidence of validity for use. However, it is a promising new survey to capture additional dimensions of students' engineering identity development.

These studies have started to develop robust and valid measures for quantitatively understanding students' engineering identity. However, these studies show mixed results for the use of items across engineering students' developmental trajectories. As these items are developed and used, it is important that they differentially measure engineering identity as students are developing as engineers. Accordingly, the purpose of this study is to explore differences in students' reported engineering identity measures by year in an engineering undergraduate program. The results of this study can add to our understanding of how students' develop identities as engineers for an aggregate group during their undergraduate education. If the measures capture the same overall levels of engineering identity in year one as in the final years of an engineering degree, then they are not sensitive enough to understand students' development as engineers.

Research Questions

To address our purpose, we answer the following research questions:

> RQ1. Do engineering students differ in identity measures by year in their undergraduate program?

> RQ2. Is there a pattern of identity development across the engineering undergraduate years?

Methods

Data

The data for this study came from a survey instrument that was electronically administered to the entire College of Engineering at a large, public East Coast university. The survey was administered in the spring of 2016 and included 137 items measuring student innovation, integration, identity, belongingness, engineering year and major, and demographic information. A total of 586 students had valid responses, which was determined using a filter question asking students to mark a particular response; this item was used to filter out indiscriminate responders from the survey results. Of the valid responses, there were no missing data. A slightly larger proportion of women answered the survey, 33% of responses, than the overall female engineering population, 21%. The distribution of respondents across years at university are as follows: 34.6% (203 students) in the first year, 21.2% (124 students) in the second year, 19.8% (116 students) in the third year, and 24.4% (143 students) in the fourth year or beyond. This distribution provides a large enough sample size to examine differences by year. We have also reported racial and ethnic composition as self-identified by participants in Table 1.

Table 1. Racial and ethnic composition of sample compared to College of Engineering. Some demographics may be reported more than once.

Race/Ethnicity	Percentage of Sample (Number)	Percentage in College of Engineering
American Indian or Alaska Native	0.8 (5)	0.05
Asian	16.6 (97)	11.0
Black or African American	3.1 (18)	2.9
Hispanic	3.6 (21)	5.4
White	78.1 (458)	63.5
More than one race	5.1 (30)	4.1

The questions used in this analysis are an overall measure of students engineering, physics, and mathematics identity as well as the averaged constructs of interest, recognition, and performance/competence for engineering only. The overall measures of identity for the three subjects of physics, mathematics, and engineering asked students to respond on an anchored scale from 1 – "Strongly Disagree" to 7 – "Strongly Agree" for the question, "I see myself as a (physics person, math person, or engineer)." The responses varied for each subject area according to prior literature demonstrating that students in their undergraduate careers more strongly identify as a "physics person" or "math person" than a physicist or mathematician, respectively. The full set of items used to measure the subject-related constructs of interest (e.g.,

three items), recognition (e.g., three items), and performance/competence (e.g., five items) are published in Godwin's work, but a sample of some of the items are presented in Table 2 below.

Table 2. Example of items of subject-related role engineering identity constructs.

Latent Construct	Sample Item
Interest	I enjoy learning engineering
	I am interested in learning more about engineering
Recognition	My instructors see me as an engineer
	My peers see me as an engineer
Performance/Competence	I am confident that I can understand engineering in class
	I can do well on exams in engineering

Analysis
Before conducting the analysis to answer the research questions posed in this paper, we first analyzed the students' responses for evidence of validity. One of the limitations of Godwin's prior work was that the survey was only used with early career undergraduates[15]. While others have used these items with upper-level students, we wanted to ensure that the questions we were asking had validity evidence for our study population before proceeding. The purpose of these analyses was to provide evidence that the questions used were valid in our study context; however, we do not claim that they are exhaustive measures of validity. First, we checked the data to see if it met assumptions of multivariate normality. The skew and kurtosis were evaluated for each item to ensure that the assumptions of multivariate normality were not severely violated (absolute value of skewness of 2.0 or higher and kurtosis of 7.0 or higher)[18,19]. Next, we conducted a maximum likelihood exploratory factor analysis with a promax rotation. A promax rotation allowed constructs we theorized were related to be correlated and is a best practice for education research[20]. We examined both a scree plot and parallel analysis to determine the number of factors and used a cutoff of 0.32 for the minimum loading of an item, which equates to approximately 10% overlapping variance with the other items in that factor[21]. We examined all of the items to see if the items hypothesized to measure particular constructs, in fact, did. Finally, we calculated the internal consistency as measured by Cronbach's alpha with values above 0.7 being an acceptable cutoff for newly developed scales and values above 0.8 preferred[22].

To answer the first research question, we conducted a one-way analysis of variance (ANOVA) for each overall measure of physics, mathematics, or engineering identity items as well as for each of the engineering identity constructs (e.g., interest, recognition, or performance/competence). The results of this analysis indicate if the outcomes are significantly different by year in college. To ensure that the assumptions of an ANOVA held, we also checked the homogeneity of variance using a Levene's test because it is more robust against departures from normality than a Bartlett's test[23].

If significant differences by year were found, a post hoc TukeyHSD test was conducted to determine which years showed significant differences. Additionally, the means of each year with a 95% confidence interval were plotted to represent visually significant differences. This analysis was conducted using the R statistical software program[24] and an alpha value of 0.01 was used to reduce the risk of Type I error.

Results

Checking data for underlying assumptions

Our examination of the data revealed skewness of items ranging from -0.44 to -1.52—indicating non-normal distributions, but still within the assumptions of maximum likelihood factor analysis. Kurtosis ranged from 2.51 to 5.61—also indicating non-normal distributions, but still within the assumptions of maximum likelihood factor analysis. The scree plot and parallel analysis indicated three factors for the maximum likelihood exploratory factor analysis. We conducted the factor analysis and the factors loaded as hypothesized with the lowest loading well above the cutoff of 0.32 at 0.57. Additionally, the communalities of the factors fell within the recommended range of 0.4 to 0.7 with the range for this administration being 0.50 to 0.88. The Cronbach's alpha values for each construct were 0.93, 0.90, and 0.90 for interest, recognition, and performance/competence, respectively. This analysis indicates that the items used to measure engineering identity constructs have validity evidence for their use in this study.

We then examined the data for homogeneity of variance before conducting an ANOVA for the engineering identity constructs (e.g., interest, recognition, and performance/competence). The Levene's tests were non-significant for each averaged engineering identity construct as well as the overall measures of mathematics, physics, and engineering identity. A non-significant result indicated that the variances of the populations do not significantly differ (or can be assumed to be equal).

Comparison of student responses by year

A one-way between subjects ANOVA was conducted to compare the effect of year in college on engineering identity constructs. This analysis was conducted to see if students further along their education pathway have stronger identity beliefs than students earlier on in their undergraduate education. There was a significant difference by year for recognition [$F(3, 581) = 7.49$; $p = 0.00007$] and performance/competence [$F(3, 581) = 3.99$; $p = 0.0079$] beliefs. The ANOVA for interest by year did not have significant results. We also examined the effect of year in college on the overall measures of mathematics, physics, and engineering identity. There was a significant effect of year in college on students' reported mathematics identity [$F(3, 581) = 3.96$; $p = 0.0083$], physics identity [$F(3, 581) = 3.88$; $p = 0.0092$], and engineering identity [$F(3, 581) = 6.37$; $p = 0.0003$].

Because we found statistically significant results, we needed to compute a post hoc test. We selected the Tukey post hoc test to compare each of our conditions to every other condition. Post hoc comparisons for engineering recognition using the Tukey HSD test indicated that the mean score for the fourth year (M = 5.70, SD = 1.05) was significantly different from the first year (M = 5.17, SD = 1.33) and second year (M = 1.31, SD = 0.84). Tukey HSD test for engineering performance/competence beliefs indicated a significant difference between year four (M = 5.32, SD = 1.21) and year one (M = 5.69, SD = 1.04). These results indicate that students later on in their engineering careers have higher, although only moderately higher on the measurement scale, engineering recognition and performance/competence beliefs.

The mathematics identity Tukey HSD test show significant differences between year three (M = 5.79, SD = 1.13) and year two (M = 5.19, SD = 1.46). Tukey HSD test for physics identity

revealed significant differences between year three (M = 4.72, SD = 1.82) and two (M = 3.97, SD = 1.90) as well. Finally, engineering identity measure showed a significant difference between year four (M = 5.02, SD = 1.70) and two (M = 5.74, SD = 1.35) as well as a borderline significance (p = 0.011) between years four and one. These results indicate a significant jump in math and physics identities between the second and third year of college. Additionally, physics identity has the lowest average scores among the identity measures. The results of the engineering identity comparison showed that the last year of engineering has the highest overall measure of identity and can distinguish between earlier years. This trend is similar to the engineering constructs of recognition and performance/competence.

An examination of the data visually also shows a trend in the identity measures. For all of the measures, there is a dip in year two that rises rapidly in years three and four (see Figures below). The figures represent the average value for each construct or overall measure of identity by year with the 99% confidence interval plotted. First, the constructs of engineering identity are presented including recognition (Figure 1) and performance/competence (Figure 2) beliefs.

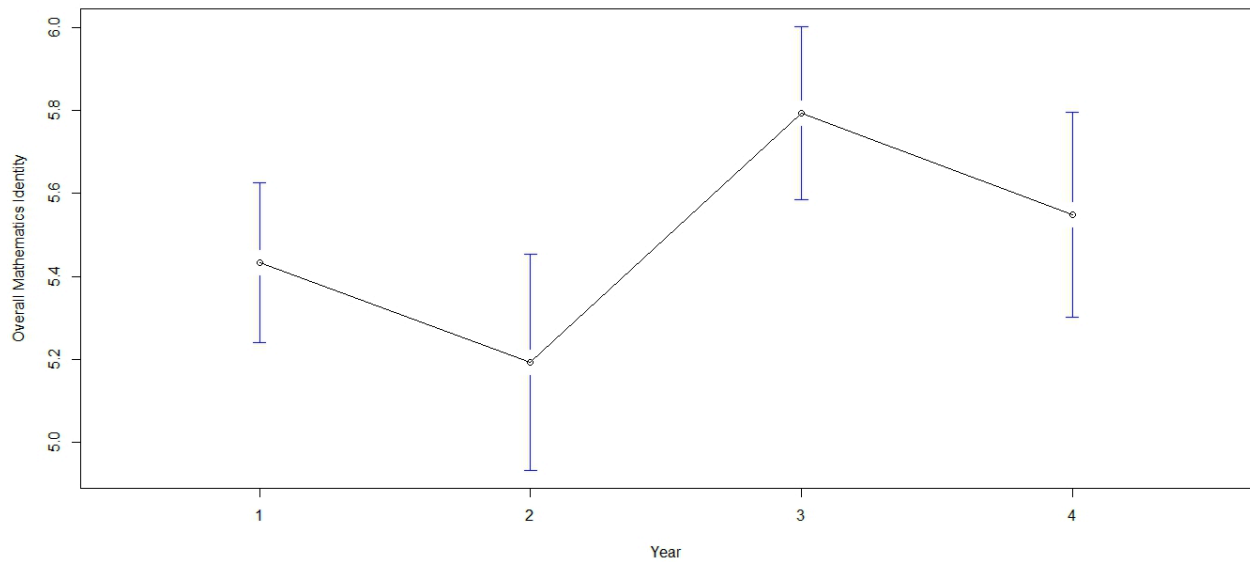**Figure 1.** Engineering recognition beliefs by year. This figure was generated using the gplots package[25] in R[24].
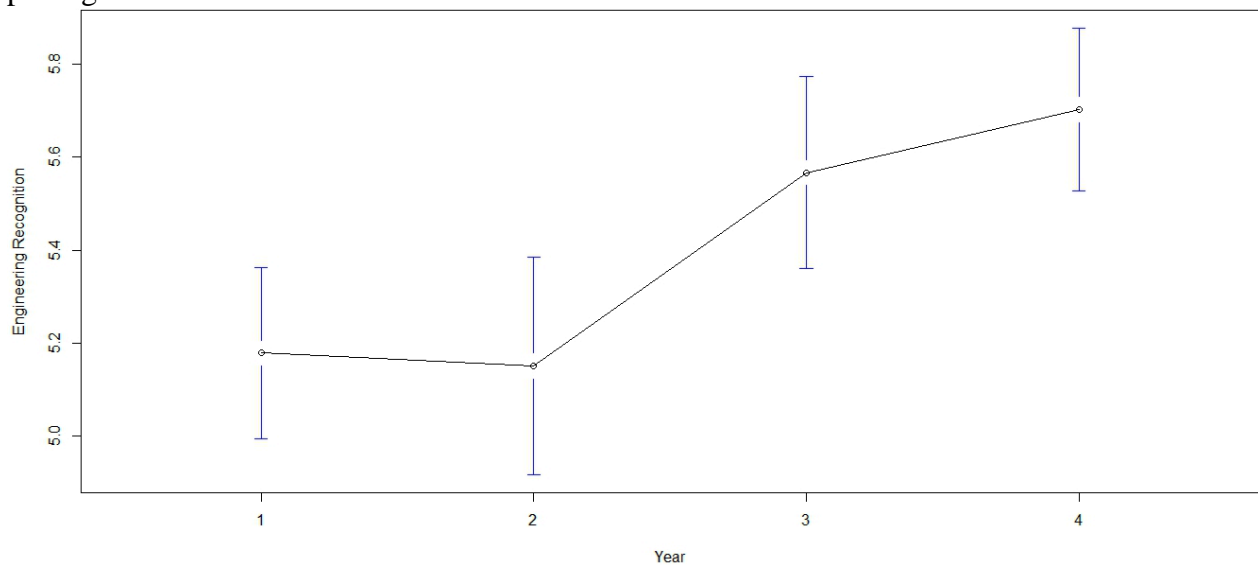
Figure 2. Engineering performance/competence beliefs by year. This figure was generated using the gplots package[25] in R[24].
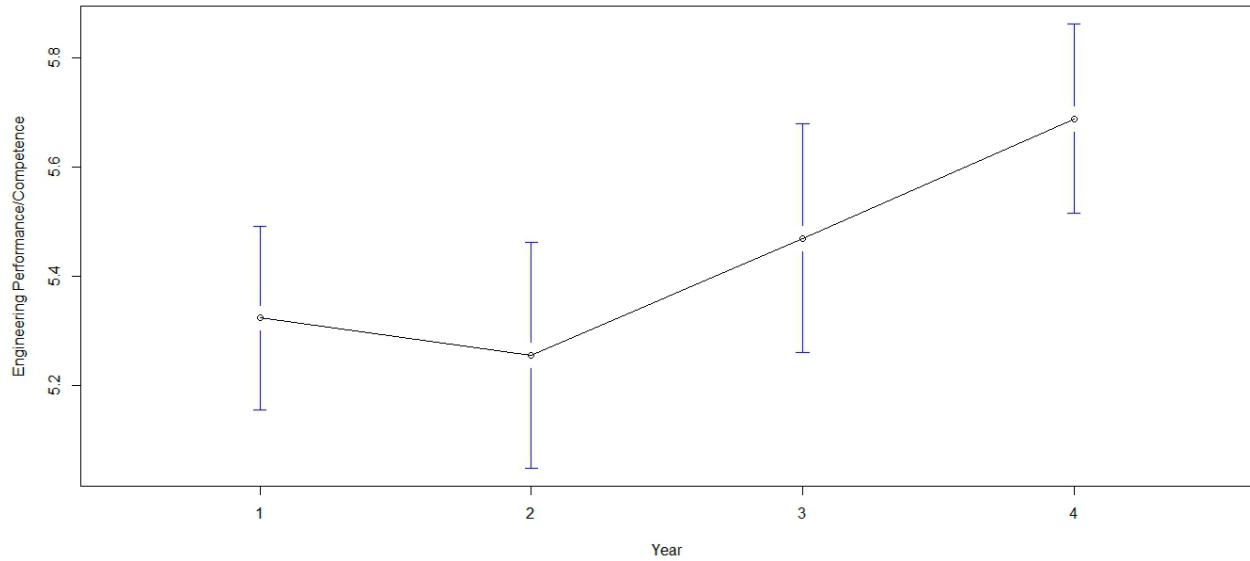

Figures 3-5 show the averages for student responses to the overall measures of identity for the subject areas of mathematics, physics, and engineering, respectively.

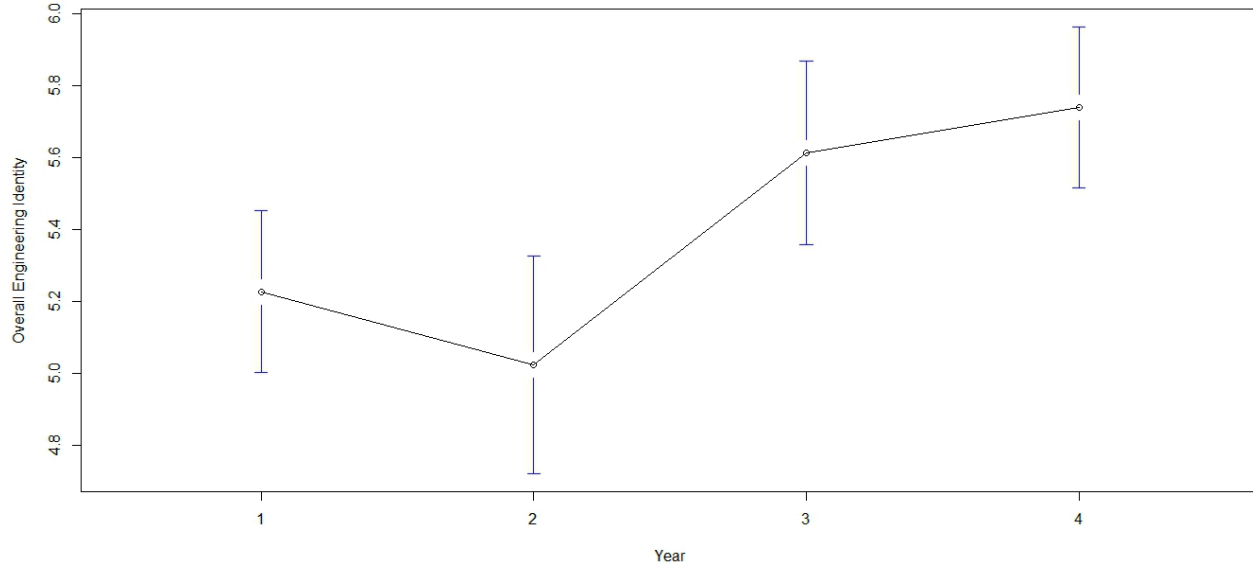**Figure 3.** Overall mathematics identity by year. This figure was generated using the gplots package[25] in R[24].

Figure 4. Overall physics identity by year. This figure was generated using the gplots package[25] in R[24].
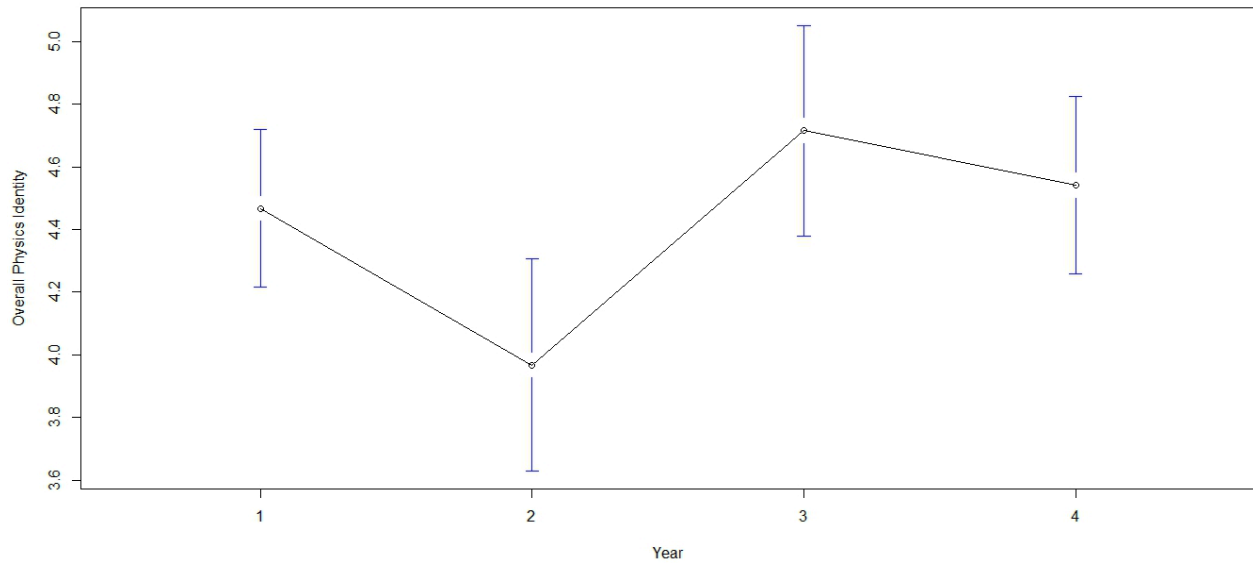
Figure 5. Overall engineering identity by year. This figure was generated using the gplots package[25] in R[24].

Discussion

The measurements developed for engineering identity show significant differences across years in college for all constructs except for engineering interest. Additionally, the single item measures of mathematics, physics, and engineering identity show significant differences as well. Engineering recognition and performance/competence beliefs in year four are higher than in years one or two. The lack of significant differences for interest may be explained by student persistence. Students who are interested in engineering careers choose engineering as a major and remain in engineering so long as that interest is sustained[26–29]. Consistent with other work, performance/competence beliefs which are a broader subject-related (rather than task-related) measure similar to self-efficacy does increase over students' undergraduate engineering education[30,31]. Previous work showed that recognition beliefs were the most significant predictor

of engineering choice[31]. This paper does indicate the recognition increases over the span of the undergraduate years and may be an important factor not only in engineering choice but in engineering identity development as well.

Mathematics and physics identities show a slightly different pattern than engineering identity constructs or the overall measure of engineering identity. The significant differences found occurred between years two and three rather than years four and one or two. These measures show a sharper decline in mathematics and physics identity from year one to year two and a sharp increase in year three. This result may be due to required courses taken in year two for many engineering program's curricula. Students often encounter the most difficult calculus sequences and electricity and magnetism courses during this time of development. These courses or other external factors may be influencing the types of STEM identities students assume during their second and third years.

All of the identity measures show a similar qualitative trend of a dip in reported identity construct or overall identity measures during the second year and an increase to the highest level at the end of their undergraduate career. This trend may be related to a phenomenon known as the "sophomore slump." Over 40% of students leave engineering in the first two years of college[32]. In the second year of study, engineering students face the academic pressure of demanding schedules and discipline-specific coursework that affect student success and retention. While the transition to college for freshman is difficult, the transition into the second year is even more so [33]. Existing cohort studies indicate that engineering students experience relatively high attrition in the second year and underrepresented students are retained in the second year at a lower rate than majority students[34].

These results coupled with information on the sophomore slump may point to an ideal time in undergraduate engineering students' development for interventions to support, develop, and sustain identity development. Other work has shown that authentic, real-world problems and opportunities to connect engineering experiences with students' own experiences provide strong supports for identity development. First-year engineering courses and capstone courses during the senior year often provide these opportunities. However, these opportunities are less common in the second and third years of undergraduate engineering education. Providing additional ways to sustain students' performance/competence and recognition during the second year may help with retention.

Limitations and Future Work
This study has three limitations that could be addressed through future work. First, a limitation of this study is the cross-sectional nature of this data given that we treated each year cohort is an independent sample. While we have provided evidence that these groups are similar in their variance, the relationships described in this paper are not conclusive about students' identity development over time. Additionally, this measurement only provides a "snapshot" of student identities and does not take into account the fluidity of identity over time. Nevertheless, the trend that consistently shows up across the four years of undergraduate education is starting evidence that upper-level students have a stronger sense of engineering, physics, and mathematics identity. Second, this work has only been conducted at one institution. Further longitudinal exploration across multiple institutions can provide new information about how individual students develop

engineering identity within the context of an institution. Finally, there is a limited understanding of the process by which diverse students form engineering identities in and out of undergraduate classrooms. Based on prior literature of underrepresented students leaving at higher rates within the second year, a deeper exploration into who forms identities and how they are formed could provide additional ways to shape engineering education to help students see themselves within an engineering profession.

Conclusion

This work provides additional validity evidence that the engineering, physics, and mathematics identities items in current use can distinguish between students early on in their undergraduate engineering education and at the end of that education. We found that that students' report a consistent (but in many cases borderline or non-significant) dip in identity during the second year of study. This dip merits further exploration and provides a potential opportunity to provide particular support to students' identity development.

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