Cross-sectional Survey Study of Undergraduate Engineering Identity

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Abstract

Identity is an increasingly popular lens for studying recruitment and retention in engineering. Most of the research conducted on modeling student development of engineering identity and related contributing factors has examined high school students and college freshmen. However, many engineering students drop out in the first two years, as they continue to shape or abandon their engineering identities throughout the course of their college careers. This paper explores engineering identity differences between lower- and upper-division undergraduate engineering students in mechanical and architectural/civil engineering at a large public institution (n=563). In this preliminary analysis, student responses were classified based on the designation of the course in which the surveys were completed: lower-division courses typically include freshmen and sophomores early in their engineering curricula, while upper-division courses typically include juniors and seniors and require lower-division courses as pre-requisites. This designation is established by the institution to distinguish gateway courses from major sequence coursework, since students are admitted directly to their specific engineering majors as first-year students. The new survey instrument borrowed previously validated scales for physics, math, and science identity to measure engineering identity directly. This survey included scales to measure both math and physics identity, multi-item scales thought to construct engineering identity (including direct measures), and background demographic information on the participants. During analysis, t-tests were used to compare differences in survey responses between the upper- and lower-division students, as well as between the mechanical and architectural/civil engineering students. Exploratory factor analysis identified 22 factors. The t-tests suggest that upper-division students exhibited a higher physics recognition by others while lower-division students exhibited a higher math interest, and global agency related to caring about others. However, the upper- and lower-division students did not exhibit significantly different responses to the engineering identity questions. Future work should separate data by year to further differentiate identity as students progress in the major. As engineering undergraduate identity research continues, it will be important to understand how engineering identity develops over all four (or more) undergraduate years. Examining the factors that contribute to successful identity development can be used to increase engineering retention rates by developing solutions that provide freshmen and sophomores opportunities to identify themselves as engineers at an earlier stage.

Introduction

Engineering is stereotypically, and accurately, thought of as a field lacking in diversity, with low representation of female and minority students.[1,2] The lack of diversity might be due in part to the high dropout rate for engineering majors in college, which one 2008 study found to be about 43 percent of all students.[3] Though much research has been conducted on predicting what will lead students to pursue engineering, exposing P-12 students to engineering to foster interest at an earlier age[2], and determining why students leave engineering[4], few studies have been conducted on how undergraduate engineers who persist to graduation develop throughout their college careers. Thus, in recent years, the framework of engineering identity and the factors that encompass it, based on previous research on physics and math identities, has been used as a lens to study engineering students.

Engineering identity is both a subset of and affected by the larger student identity, which also includes personal and social identities.[1] Identity can be defined as how students perceive themselves to fit into a given group, in this case engineering,[5] which in turn affects how they progress along the academic and career path in their field.[6]

The engineering identity framework utilized in the study is partially based off a physics identity model composed of four basic factors: performance, competence, interest, and recognition.[5,7] Performance describes a student's belief in their ability to perform in their classes or when conducting engineering tasks.[8] If a student performs poorly in class, they are less likely to identify themselves as an engineer. Competence describes a student's belief in their ability to understand engineering material, which is often similarly reflected in a student's performance in class.[8] Interest describes how motivated a student is in the content and career they are pursuing, often encompassing the motives a student has for pursuing engineering.[7,9] The motivations a student has for pursuing engineering can include both personal and global agencies, or one's capacity to have an effect on one's own life or the lives of others, respectively.[5] Recognition can often be broken into two categories: recognition by self and recognition by others. Recognition by others describes how other students, professors, family, and friends see the student in the context of engineering, and how that message is transferred to the student often affects their self-recognition.[9]

These four factors (performance, competence, interest, and recognition) are measured using survey scales previously developed for math and physics, though performance and competence tend to load onto the same factor.[7] Although these studies have explored relationships between math/physics identity and pursuit of an engineering major, they have not attempted to measure engineering identity directly. This cross-sectional study focused on developing a similar scale for engineering identity and comparing it to math and physics identities in mechanical, architectural, and civil engineering students. These branches of engineering were chosen because of their high dependency on physics and math, along with interest from faculty and administrators that facilitated access. It also extends prior studies by surveying undergraduate students who have persisted beyond their first year. Examining the factors that contribute to successful identity development can be used to increase engineering retention rates by enabling universities to alter engineering programs according to student needs, providing freshmen and sophomores with opportunities to identify themselves as engineers at an earlier stage.

Methodology

Participants

Participants in the study were architectural engineering (AE), civil engineering (CE), or mechanical engineering (ME) students. Since architectural and civil engineering students are in the same department and overlap significantly in their course requirements, data from these students were combined into one set (labeled CE) for this paper. (Students at this institution are admitted directly into specific engineering majors; there is no general or freshman engineering program.)

Survey Development and Data Collection

The survey was developed from previously validated scales on math, physics, and general science identity, career interest/intentions, and adapted scales to address other engineering factors such as design efficacy and creativity. The final survey consisted of 119 items, including 18 multi-item Likert scale questions and 1 open response question. Specific items corresponding to significant factors and newly created scales are listed in the Appendix.

The survey was administered in six civil engineering courses, two architectural engineering courses, and four mechanical engineering courses during the second week of the Fall 2015 semester at a large public institution with high-ranking engineering programs. The survey was given at the beginning or end of class and required about ten minutes to complete.

The data analyzed here (n= 563 students) were gathered from 277 mechanical engineers and 286 civil or architectural engineers. Of the mechanical engineers, 211 were from upper-division classes and 66 were from lower-division classes. Of the civil/architectural engineers, 147 were from upper-division classes and 139 were from lower-division classes. The response rate for the mechanical engineers equaled 67.4% and the response rate for the civil/architectural engineers equaled 73.1%.

Data Cleaning and Sorting

Only surveys with a signed informed consent form were included in the data analysis. Student identification numbers were used to gather additional demographic information from the university for each student. This included data on race, gender, major, GPA, and other pertinent identifying information. All non-mechanical, non-architectural, and non-civil engineering students were removed from the data set. The classification as lower- or upper-division student was determined by the coding of courses at the university (generally lower-division corresponds to freshman and sophomore level courses and upper-division refers to junior and senior level courses). Additional analysis showed that less than 4.5% of students were coded incorrectly by comparing their enrollment date to their classification. Plausible reasons for this incorrect placement (supported by institutional data) include a large proportion of transfer hours, switching majors (thus requiring upper division students to take introductory classes), and students retaking introductory courses.

Data Analysis

Since new scale items were included in addition to the previously validated scales, an exploratory factor analysis was conducted in STATA 14.1, which confirmed existing scales and supported the construction of the new scales (one exception is that the previously validated scale for engineering agency loaded onto multiple smaller factors). The 22 factors were identified and labeled appropriately based on the items that constructed the factor. The Cronbach reliability alpha for all the values, except design efficacy (α=0.6702), was above the minimum 0.70 standard, ranging from 0.7058 to 0.9055.

The primary analysis for these data sets relied on student t-tests, which were performed in three groups: ME lower-division versus CE lower-division responses, ME upper-division versus CE upper-division responses, and all lower-division versus all upper-division responses. F-tests were run to determine the appropriate t-test to use because the variance in the comparison groups could have been equal or unequal. For all of the t-tests conducted, the difference in means was considered significant if the p-value was below 0.002, which was determined using a Bonferroni correction because a large number of t-tests were performed.

Results

The total number of participants in the study (n=563) and the number of lower-/upper-division civil/mechanical engineers are listed in Table 1 for simplicity and reference.

Table 1 Participants (n=563) in the study broken down by category

	Civil and Architectural Engineering (CE)	**Mechanical Engineering (ME)**	**Total in Division**
Lower-Division	139	66	205
Upper-Division	147	211	358
Total in Major	286	277	563

The exploratory factor analysis grouped the 119 items into 22 factors. The factors were tested for statistical significance in various groups. Since the overall sample was composed of both CE and ME students, each ranging from lower to upper classmen, it was important to determine if any of these four sub groups, upper/lower ME/CE, contributed significantly to the overall upper versus lower comparison. Table 2 shows the mean response to each factor and the difference in means between mechanical and civil engineers in lower-division classes. The p-value is listed in the final column, along with an indicator if a significant difference was found.

Table 2 T-tests by major on lower-division students (no significant differences were found)

Domain	Construct	Mean			P-value
		CE	ME	Difference	
Math	Performance/Competence	4.20	4.31	-0.122	0.2121
	Interest	4.16	4.22	-0.064	0.6123
	Recognition by Others	4.34	4.39	-0.053	0.6239
	Recognition by Self	4.00	4.20	-0.200	0.1073
	Efficacy	4.09	4.10	-0.012	0.9176
Physics	Performance/Competence	3.67	3.83	-0.016	0.2033
	Interest	3.67	4.00	-0.341	0.0332
	Recognition by Others	3.55	3.72	-0.175	0.2660
	Recognition by Self	3.37	3.58	-0.209	0.1732
Engineering	Performance/Competence	4.67	4.29	-0.029	0.7489
	Interest	3.39	3.51	-0.124	0.1309
	Recognition by Others	4.37	4.27	0.099	0.4414
	Recognition by Self	4.26	4.13	0.123	0.3164
	Communication Skills	3.65	3.89	-0.243	0.0211
	Accessibility	3.64	3.22	0.422	0.0104
	Helpfulness (PA)	4.44	4.47	-0.038	0.6492
	Money (PA)	2.95	2.89	0.058	0.5711
	Caring (GA)	4.40	4.15	0.250	0.0102
	Creativity	3.87	4.07	-0.196	0.0606
	Design Efficacy	3.71	3.88	-0.170	0.1735
	Parental Influence	1.46	1.55	-0.081	0.3856
	Mentorship	1.98	2.17	-0.192	0.1473

* p-value < 0.002
PA is Personal Agency; GA is Global Agency
Specific items are listed in thex

None of the factors showed a significant difference between lower-division ME and CE students, which might be expected for early lower-division students with limited exposure to engineering coursework. The same analysis was conducted on the upper-division students to determine if there was a significant difference in responses between majors. Table 3 shows the mean response to each factor and the difference in means between mechanical and civil engineers in upper-division classes. In this case, the following factors showed significant differences: physics performance/competence, physics interest, physics recognition by others, physics recognition by self, and engineering design efficacy. In each of these factors, the ME students rated themselves higher than did the CE students.

Table 3 T-tests by major on upper-division students (significant differences were found)

Domain	Construct	Mean			P-value
		CE	ME	Difference	
Math	Performance/Competence	4.03	4.15	-0.121	0.0964
	Interest	3.85	3.69	0.157	0.1573
	Recognition by Others	4.23	4.41	-0.181	0.0299
	Recognition by Self	3.87	4.07	-0.200	0.0314
	Efficacy	4.09	4.17	-0.083	0.2624
Physics	Performance/Competence	3.63	4.06	-0.425	0.0000*
	Interest	3.35	3.82	-0.474	0.0000*
	Recognition by Others	3.59	4.12	-0.534	0.0000*
	Recognition by Self	3.34	3.87	-0.534	0.0000*
Engineering	Performance/Competence	4.18	4.32	-0.136	0.0239
	Interest	3.32	3.35	-0.024	0.6998
	Recognition by Others	4.25	4.48	-0.229	0.0113
	Recognition by Self	4.31	4.45	-0.141	0.0730
	Communication Skills	3.59	3.79	-0.204	0.0108
	Accessibility	3.40	3.15	0.246	0.0186
	Helpfulness (PA)	4.42	4.30	0.126	0.0397
	Money (PA)	2.87	3.04	-0.170	0.0276
	Caring (GA)	4.19	3.98	0.206	0.0082
	Creativity	3.82	4.00	-0.179	0.0171
	Design Efficacy	3.70	4.06	-0.358	0.0000*
	Parental Influence	1.54	1.50	0.044	0.5552
	Mentorship	1.98	1.94	0.073	0.3870

* p-value < 0.002
PA is Personal Agency; GA is Global Agency
Specific items are listed in the Appendix

The responses from both engineering majors were pooled together, and the entire sample was used to test differences between upper- and lower-division students. All factors were tested using a t-test, and the mean of each group, difference in means, and p-values are listed in Table 4. Only three factors showed significant differences between upper- and lower-division engineers: math interest, physics recognition by others, and engineering global agency related to caring about others. Lower-division students answered more positively with respect to math interest and global agency related to caring about others, while physics recognition by others was greater for upper-division students.

Table 4 T-tests by division on all engineering students (significant differences were found)

Domain	Construct	Mean			P-value
		Lower	Upper	Difference	
Math	Performance/Competence	4.24	4.10	0.139	0.0174
	Interest	4.18	3.76	0.420	0.0000*
	Recognition by Others	4.35	4.33	0.018	0.7813
	Recognition by Self	4.06	3.98	0.076	0.3064
	Efficacy	4.09	4.13	-0.044	0.5053
Physics	Performance/Competence	3.72	3.88	-0.164	0.0202
	Interest	3.78	3.63	0.151	0.1097
	Recognition by Others	3.60	3.91	-0.302	0.0009*
	Recognition by Self	3.44	3.66	-0.214	0.0129
Engineering	Performance/Competence	4.27	4.26	0.011	0.8221
	Interest	3.43	3.34	0.096	0.0499
	Recognition by Others	4.34	4.39	-0.048	0.5190
	Recognition by Self	4.22	4.39	-0.173	0.0099
	Communication Skills	3.73	3.71	0.019	0.7692
	Accessibility	3.50	3.26	0.248	0.0069
	Helpfulness (PA)	4.45	4.35	0.101	0.0419
	Money (PA)	2.93	2.97	-0.034	0.5818
	Caring (GA)	4.32	4.07	0.255	0.0000*
	Creativity	3.93	3.93	0.004	0.9513
	Design Efficacy	3.76	3.91	-0.151	0.0308
	Parental Influence	1.49	1.52	-0.028	0.6354
	Mentorship	2.05	1.94	0.109	0.1201

* p-value < 0.002
PA is Personal Agency; GA is Global Agency
Specific items are listed in the Appendix

Qualitative Responses

Student responses to the open ended item "Is there anything else you wish to share about your experience in engineering?" provide additional insight to interpret the quantitative findings. Though many lower-division students who responded expressed a life-long interest in science and/or excitement in beginning their college engineering careers, the general sentiment among upper-division students was that although engineering was "hard but worth it," several provided suggestions for the program that would have added value to their college careers. With respect to the demands of the curriculum, one student stated, "The course load is brutal. I sacrifice many aspects of my life to do well in my classes." With respect to the suggestions for areas of improvement, many upper-division students wished the curriculum was presented in a more hands-on fashion, included more labs to complement the courses, involved more collaboration, and exposed them to more real-world applications of the material covered in class.

Both upper- and lower-division students commented on the need to expose people to engineering earlier in school and in life. Both upper- and lower-division students also commented on the lack of diversity, leaving comments such as "Engineering, as is, is a profession that attempts to be exclusionary discipline [sic]. An attempt should be made to expose underrepresented communities to engineering on a personal level and portray engineering as less of a difficult science but a fun one."

Discussion

Perhaps most surprisingly, no statistically significant differences were found for the engineering identity scales: engineering performance/competence, interest, recognition by others, and recognition by self. These were new scales created by simple substitution of "engineer" or "engineering" in previously validated math and physics identity scales. As mentioned, the reliability of these new scales was above 0.70, yet expected differences between upper- and lower-division students were not observed. One possible reason is because of the extremely low p-value of 0.002 required to claim significant differences based on a Bonferroni correction to account for the large number of t-tests performed. Some factors in the overall comparison shown in Table 4, such as engineering recognition by self and engineering accessibility to minority racial and gender groups, exhibited p-values (0.0099 and 0.0069, respectively) that might have been considered significant using a different threshold or correction. Other, less conservative, methods of determining a p-value might have determined other factors to have significantly different responses. Additionally, if we separated first-, second-, third and fourth-year students, we may have observed more changes in engineering identity, possibly between the first and second year when attrition is highest.

However, these results are still useful in considering what types of questions will better discriminate between stronger or weaker engineering identity. In the analysis between lower-division ME and CE students, no factors were statistically significantly different. It is possible this is because of typically low exposure to engineering among high school students and first-year students focusing on math and science requirements. Or perhaps many of these students have similar optimistic views of engineering as entering students. Many of the lower-division respondents were freshmen only two weeks into their first semester of engineering. Thus, with limited exposure to engineering, lower-division students might be more likely to respond similarly between majors, especially given the perceived similarities between mechanical and civil engineering, when compared to other branches of engineering, in the earlier years; both lower-division curricula involve similar, often overlapping, engineering and science courses. These results indicate that the pooled lower-division responses in the analysis covered in Table 4 were less likely to be affected by major.

Analysis of upper-division students in ME and CE yielded several other notable results. For instance, the mechanical engineers showed a distinctly higher physics identity through higher means on all four physics identity factors. This finding is in line with a similar study on disciplinary differences in engineering students' aspirations and self-perceptions.[10] Since this survey was only given at one university, this difference might be related to the difference in coursework or department cultures between mechanical and civil engineers. It is also impossible to conclude whether ME students exhibit a particularly high physics identity or if CE students exhibit a low physics identity. It is possible that the strong physics identity would not be significantly different between the different engineering disciplines if the data included responses from several institutions. All of these are important questions to be explored in future work. This strong physics identity in the upper-division mechanical engineers is a possible reason a significant difference in physics recognition by others was found in the analysis comparing all upper-division students to all lower-division students, shown in Table 4.

Comparisons between the upper- and lower-division students exhibited a higher math interest, and global agency related to caring about others for lower-division students. The higher mean interest in math in lower-division students could be related to a higher exposure to math in high school. High school curriculum often includes several years of math and several years of various sciences, only one of which is physics, which is often not required. As students progress through the curriculum by completing math requirements and taking more engineering courses, interest in math as a standalone subject might decrease. Lower division students are also more likely to be currently enrolled in math courses at the time of the survey, which was administered early in the semester prior to any exams.

Another discriminating factor was global agency related to caring for others. A higher mean response to this factor in the lower-division students could indicate that lower-division students have different reasons for joining engineering than upper-division students have for persisting in engineering. The lower-division students might be more likely to be optimistic about the use of engineering in their lives and in society, which might change over time with more exposure to difficult and often grueling degree plans. This is further evidenced by the various comments about curriculum difficulty made by the upper-division students in the open response question.

One limitation of this data set is the high representation of freshmen and seniors in the sample. Many of the upper-division classes that took this survey were fourth year lab classes and first year introductory classes. If the same survey was divided by year—freshman, sophomore, junior, senior—instead of by upper- and lower-division, a more obvious trend in engineering identity could potentially be found. The apparent optimism and excitement from the freshmen and the feeling of general accomplishment of the seniors could have resulted in a similarly high rating of engineering identity from the lower- and upper-division students. It is possible that with more fine-grained analysis, we might observe that sophomores and juniors, who have more experience with engineering but are not about to graduate, tend to become part of a "slump" where they feel less confident in the major, especially since the hardest engineering courses are often taken during this time.

Future work involving this survey and data will include analyses beyond a simple t-test. We will run regression models on the current data to explore the possible effects of major, year, gender, and race on engineering identity. The survey will also be repeated, enabling longitudinal study. A weakness of the current data set is that it samples only students currently enrolled in an engineering major. Over time, we will be able to track students who leave engineering and use their early responses to understand the relationship, if any, between engineering, math and physics identity, and persistence in engineering. The survey will also be administered at additional institutions and across a more diverse sample of engineering disciplines.

Conclusion and Implications for Future Research

Though this survey aimed to measure engineering identity directly, and the new scales exhibited high reliability, no significant difference between upper- and lower-division students was observed. However, lower-division students were found to have a higher math interest, and global agency relating to caring about others while upper-division students have a higher physics recognition by others. These findings suggest that lower-division students have different motivations for joining engineering than upper-division students have for staying in engineering. This study also found that though lower-division mechanical and civil engineers exhibited no significant difference in responses, upper-division mechanical engineers at this institution go on to develop a greater overall physics identity and opinions of their design efficacies than do upper-division civil engineers. Future work will explore whether these differences persist across a broader range of disciplines and institutions. Further data analysis will be conducted on this sample to disentangle the potential effects of gender and race on the findings. Finally, the survey will be given to the same students next year to monitor longitudinal retention rates and changes in engineering identity.

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Appendix

Table 5 List of each significant factor found in any of the three t-test analyses, corresponding items within each factor, and scales used to collect data for each item as written within survey

Factor	Survey Items	Response Scale
Physics Performance/ Competence	To what extent do you disagree or agree with the following statements?[5(adapted)] (a) I am confident that I can understand physics outside of class (b) I can overcome setbacks in physics (c) I am confident that I can understand physics in class (d) I can do well on exams in physics (e) I can understand concepts I have studied in physics (f) Others ask me for help in physics	"1" for Strongly Disagree to"5" for Strongly Agree
Physics Interest	To what extent do you disagree or agree with the following statements?[5] (a) I enjoy learning physics (b) I am interested in learning more about physics	"1" for Strongly Disagree to"5" for Strongly Agree
Physics Recognition by Others	Do the following see you as a physics person?[7(adapted)] (a) Parents (b) Relatives (c) Friends	"1" for No, Not at all to"5" for Yes, Very much
Physics Recognition by Self	Do the following see you as a physics person?[7(adapted)] (a) Yourself (b) Physics instructor	"1" for No, Not at all to"5" for Yes, Very much
Design Efficacy	How confident are you in your ability to do the following[(new scale)] (a) Design a product or process on your own (b) Design a product or process in a team	"1" for Not at all Confident to"5" for Very Confident
Math Interest	To what extent do you disagree or agree with the following statements:[5] (a) I enjoy learning math (b) I am interested in learning more about math	"1" for Strongly Disagree to"5" for Strongly Agree
Engineering Caring (GA)	In your opinion, to what extent are the following associated with the field of engineering?[5(adapted)] (a) Saving lives (b) Caring for communities (c) Protecting the environment	"1" for Not at all to"5" for Very Much so

Table 6 List of newly created engineering identity and creativity scales

Factor	Survey Items	Response Scale
Engineering Performance/ Competence	To what extent do you disagree or agree with the following statements?[5(adapted)] (a) I am confident that I can understand engineering outside of class (b) I can overcome setbacks in engineering (c) I am confident that I can understand engineering in class (d) I can do well on exams in engineering (e) I can understand concepts I have studied in engineering	"1" for Strongly Disagree to"5" for Strongly Agree
Engineering Interest	We are interested in knowing why you are studying engineering. Please indicate below the extent to which the following reasons apply to you:[11] (a) I feel good when I am doing engineering (b) I like to build stuff (c) I think engineering is fun (d) I think engineering is interesting (e) I like to figure out how things work	"1" for Not a Reason, "2" Minimal Reason, "3" Moderate Reason,"4" for Major Reason
Engineering Recognition by Others	Do the following see you as an engineer?[7(adapted)] (a) Parents (b) Relatives (c) Friends	"1" for No, Not at all to"5" for Yes, Very much
Engineering Recognition by Self	Do the following see you as an engineer?[7(adapted)] (a) Yourself (b) Engineer instructor	"1" for No, Not at all to"5" for Yes, Very much
Creativity	To what extent do you disagree or agree with the following statements?[(new scale)] (a) I like to think creatively (out-of-the-box) (b) I like to solve problems in novel ways (c) I like open ended-problems	"1" for Strongly Disagree to"5" for Strongly Agree