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Disciplinary Differences in Engineering Students' Aspirations and Self-Perceptions

Dr. Geoff Potvin, Clemson University
Prof. Zahra Hazari
Dr. Leidy Klotz, Clemson University
Ms. Allison Godwin, Clemson University
Dr. Robynne M. Lock, Department of Engineering and Science Education, Clemson University
Dr. Jennifer Dawn Cribbs, Western Kentucky University
Ms. Nicole Barclay, Clemson University

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Abstract

In discussions of the recruitment and retention of engineering majors, students are sometimes treated as a homogeneous group with respect to the necessary preparation for college, their career values, and their aspirations despite the diversity of opportunities and specialties across disciplines. Moreover, initiates just starting their post-secondary education in engineering may not perceive disciplines as practitioners do: they may identify and find affinity for features of an engineering specialty that may be different from actual practice.

This paper conducts a comparative analysis of students at the start of their engineering studies using data drawn from a nationally-representative survey, conducted in 2011, of 6772 students enrolled at 50 colleges and universities in the U.S. By identifying students intending to major in eight different disciplines (bio-, chemical, civil, electrical/computer, environmental, industrial/systems, materials, and mechanical engineering), we show how student goals, values and self-perceptions differ. Regression analysis is used to study how the likelihood of entering one of these eight disciplines is associated to career outcome expectations, students' self-beliefs around their science, physics, and math identities, and constructs measuring their personal and global science agency.

Results indicate that students intending to major in engineering show substantial inter-disciplinary distinctions in the investigated domains. The utility of this work is that it should help to guide more effective recruiting of students into engineering disciplines and allow for a broadening of recruitment efforts to students who would normally be overlooked for engineering careers.

Introduction

For some years, national reports have called for substantial increases in the production of STEM-trained individuals, with a particular desire for a larger and more diverse population of engineers[1-3]. The production of greater numbers of engineers in particular is seen as a critical goal to ensure the continued innovation, development, and global competitiveness of the U.S. economy. Furthermore, engineering educators have long sought to improve the teaching and learning of engineering fundamentals and skills. One avenue for such improvement is by investigating and incorporating into the content and pedagogy of K-12 and postsecondary engineering education the motivations and interests of students.

One limitation to our ability to accomplish this goal is that the self-beliefs and motivations of engineering students are not particularly well understood, especially those factors that might systematically characterize students who pursue specific engineering disciplines in college. This is particularly problematic because college initiates to an engineering major may not perceive the same aspects nor the same possibilities as experts (e.g. professional engineers, professors, etc) of pursuing such a career. That is to say, students may begin college studies in an engineering major with expectations or beliefs about their choice that is not reflected in the realities of the practice of fully-trained members of these communities[4]. While a few studies have considered the culture of engineering[5], the differences between freshman engineering and science students[6], and the learning styles and types of students in certain engineering disciplines[7-10], this remains an understudied area. One limitation of prior work has been the use of samples of limited generalizability, with analyses often sampling students from a single or geographically limited set of institutions.

Theoretical Perspectives

An emergent framework that has proven fruitful in the study of student career choice and persistence is that of role identity (or, more simply for this work, identity)[11]. Developed in a general science context[12,13] and modified for use in physics[14] and mathematics education[15], the identity framework used in this paper encompasses a set of self-beliefs held by an individual in relation to their perceptions of a specific role; for example, that of a good engineering student. As articulated in earlier studies[12-14], an individual's identity is a composite of their beliefs in four sub-domains: their interest in the subject or role, their self-beliefs about the recognition that they receive from others in the subject, their perceived competence in carrying out the tasks as part of the role, and their beliefs in their ability to perform in the role. In fact, previous work[14,16] has shown that the performance and competence domains are not statistically independent and, instead, load together in factor analyses. Thus, there are three statistically distinct aspects of one's identity in a subject: interest, recognition, and performance/competence.

Another framework with a long and venerated history of use in understanding engineering student career choice is the social cognitive career theory[17,18]. This framework, implementing the social cognitive theories of Bandura[19] in the domain of career choice, uses two affective constructs in particular: self-efficacy beliefs (which has some overlap with the identity constructs explained above) and outcome expectations (which are the anticipated results, both positive and negative, associated to a particular choice action). SCCT has been well tested on engineering students[20] amongst others, and outcome expectations have been found to have a close relationship to students' self-efficacy beliefs and, hence, their career choices.

The final theoretical perspective of use in this paper is that of agential beliefs. For purposes of this discussion, the agential beliefs can be thought of as an individual's belief in their ability to make choices and see them manifested in the real world. More specific to the context of STEM education, critical science and critical physics agency[21-23] has been conceptualized as encompassing an individual's beliefs about how they see science (or physics, engineering, etc) as facilitating their ability to accomplish the goals they set for themselves and impact the world around them. Part of this framework also includes an individual learning to analyze science, and the world, critically as well as becoming familiar with the tools and practices of their field (e.g. learning to “do” engineering). The development of such perspectives may lend to an individual's growing professional identity and attachment to their practice, whether as an engineer, scientist, or otherwise.

Methodology

In order to explore the aspects of student beliefs and aspirations encompassed in their identities, their science agency, and their career outcome expectations in different engineering disciplines, this paper analyzes data drawn from the Sustainability and Gender in Engineering (SaGE) Survey (NSF Grant Number 1036617). This survey, focused on the high school experiences related to sustainability that influence students, particularly women, to consider careers in engineering, was conducted in the fall semester of 2011 by surveying students enrolled in regular college freshman English courses. The participating schools, which includes both 2- and 4-year institutions, were recruited from a stratified random sample of a comprehensive list of all institutions in the U.S. available from the National Center for Education Statistics. The stratification of the sample was based on two factors: to control for the relative population of students at 2- and 4-year institutions, and to account for the variance in size of institution around the country (this avoided under-representing the numerous, but small, liberal arts colleges by comparison to very large public institutions). In total, 50 schools were recruited for participation. By surveying regular college English classes, a prototypical "required" course for students of all majors, it was possible to gather data from a nationally-representative sample of students that includes engineering majors, other STEM majors, and non-STEM majors alike. In total 6772 students returned surveys, with representation from 100% of the 50 recruited schools. Figure 1 provides an indication of the national representativeness of the student sample: students' reported *home* ZIP codes are plotted (note that multiple students reporting the same home ZIP code appear as a single point on the map).

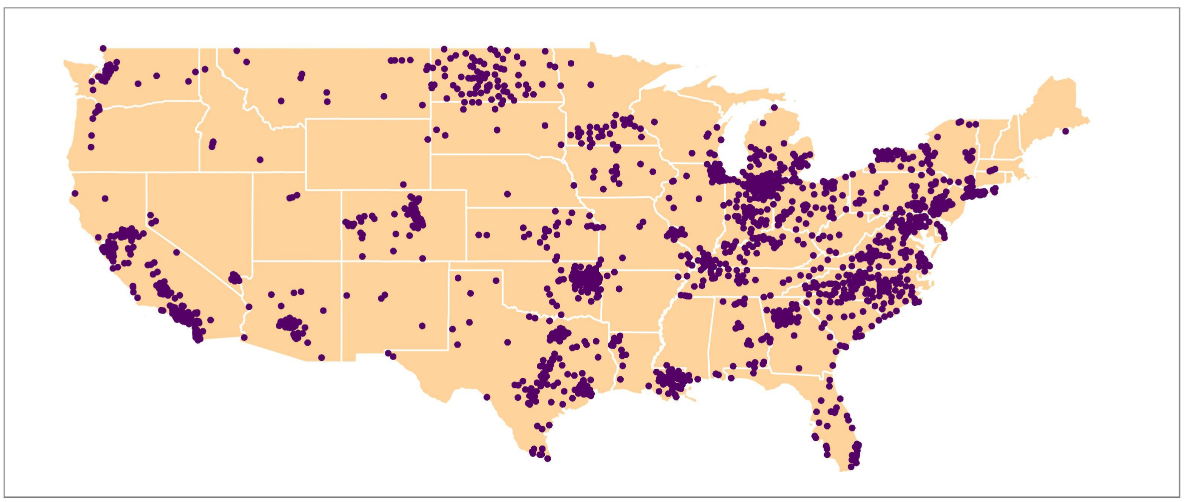

Figure 1: Map of respondents' home ZIP codes (continental U.S. displayed only). Multiple responses with the same ZIP code are represented by a single dot.

The survey included items that probed students educational experiences before college, with a focus on high school math and science (physics, chemistry, and biology) classes, their attitudes and beliefs about sustainability, the nature of science, the ability of science & technology to impact the world, their self-beliefs about their identities in math, physics, and science in general, their career intentions and outcome expectations, and demographic information. Of interest to the current paper, students were asked to indicate the likelihood of them choosing a career in a wide variety of STEM fields, including eight separate engineering disciplines: bioengineering, chemical engineering, civil engineering, electrical/computer engineering, environmental engineering, industrial/systems engineering, materials engineering, and mechanical engineering.

Each response was a five-point Likert-type scale anchored from “0 – Not at all likely” to “4 – Extremely likely”. Students who indicated a “3” or “4” as their response to a particular engineering discipline were separated out for further analysis. In all, 814 different individuals responded with a “4” in at least one engineering discipline, and a total of 1319 individuals responded with a “3” or greater in at least one engineering discipline *and* did not indicate a greater likelihood of them pursuing another, non-engineering career (e.g. a science discipline). The distribution of responses towards the career intentions questions for the 1319 individuals studied in this paper is indicated in Figure 2. From this figure, it can be seen that, despite the sample selection process, a large variance exists in each of the engineering career responses: in 6 of 8 cases, the response “0 – not at all” is still the most common response. This indicates that most of the individuals considered here intend on one or a small number of disciplines. Electrical/computer engineering and mechanical engineering are the two most popular disciplines and so have a plurality of individuals who responded with a “3”.

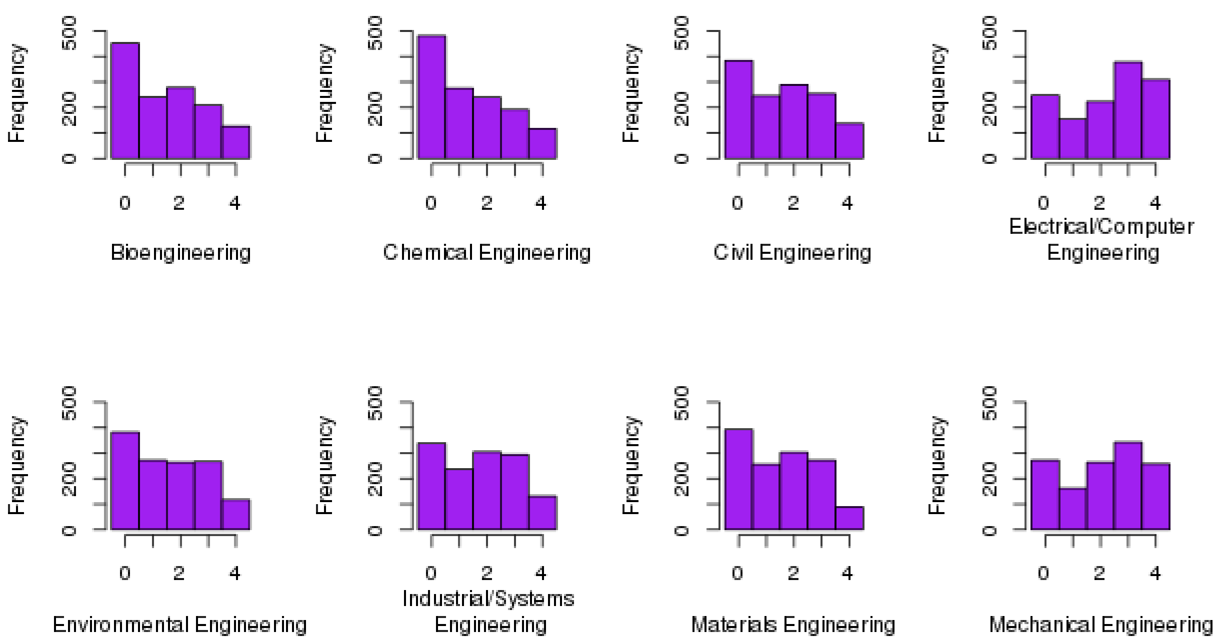

Figure 2: Distribution of student responses towards the eight engineering disciplines investigated. For each major, responses are anchored from “0 – Not at all likely” to “4 – Extremely likely”. In all cases, N=1319.

In addition to the career intention questions, individuals were probed on several items that measure the interest, recognition, and performance/competence subcomponents of identity, in three domains: physics, mathematics, and science (general). These items were combined (following earlier quantitative work in this domain[14]) to form nine composites, which are proxies for these identity measures. Several questions also probed students' beliefs about the nature of science and engineering and the ability of science & technology to impact the world. Using exploratory factor analysis, some of these items were combined into a pair of measures of agency: global science agency (beliefs in the ability of science & engineering to change the world in a global sense) and personal science agency (beliefs in science & engineering to change one's life). Also, students were asked about several career outcome expectations including: the importance of making money, having job opportunities, having personal/family time, solving societal problems, etc.

A series of multiple linear regression models[24] were constructed on the above-mentioned factors, for the 1319 individuals identified as having a strong intention of pursuing an engineering career. For each factor, all eight engineering career intention variables (i.e. the Likert-type variables indicated in Figure 2) were simultaneously inserted as predictors. The advantage of this approach is that the students who were identified as likely engineers were compared to *each another*, so the results facilitate a comparison of relative differences between students of various engineering disciplines, rather than a comparison of engineers versus non-engineers, for example. All data processing, statistical analyses, and figures in this paper were created using the **R** statistical language and software system[25] and the ggplot2 package[26]. Throughout this analysis, the α level, the maximum allowed probability of a false positive (Type I error), has been set at 0.01 or 1%.

Results

The results of the regression analyses are summarized in Table 1. Each row represents a separate regression model; however, it is more instructive to interpret the table by column. Each column represents the factors upon which each engineering discipline were found to be significantly different than other engineers.

Major: Factor:	Bio	Chem	Civil	ECE	Env	Ind/ Sys	Mat	Mech	Adj R^2 (N)
Science Identity – Recognition	+0.131 ***	.	+0.115 **	.	.	.	.	.	0.03(1239)
Science Identity – Interest	+0.239 ***	.	.	.	.	.	.	.	0.11(1012)
Science Identity – Performance/Competence	+0.181 ***	+0.156 ***	.	.	-0.101 **	.	.	.	0.09(993)
Physics Identity – Recognition	+0.130 **	+0.125 **	.	.	.	.	.	.	0.10(815)
Physics Identity – Interest	.	+0.123 **	+0.136 **	+0.110 **	-0.106 **	.	.	+0.126 **	0.10(837)
Physics Identity – Performance/Competence	.	+0.127 **	+0.138 **	.	-0.148 ***	.	.	.	0.09(775)
Math Identity – Recognition	.	+0.130 **	+0.190 ***	-0.106 **	-0.159 ***	-0.124 **	.	+0.136 ***	0.06(903)
Math Identity – Interest	.	+0.118 **	+0.174 ***	+0.106 **	-0.157 ***	.	.	+0.124 **	0.07(891)
Math Identity – Performance/Competence	.	+0.164 ***	+0.147 **	.	-0.203 ***	.	.	.	0.06(839)
Personal Science Agency	+0.236 ***	.	.	.	.	-0.143 ***	.	.	0.10(928)
Global Science Agency	+0.177 ***	.	.	+0.140 ***	-0.103 **	.	.	.	0.05(905)
Outcome Expectation – Helping others	+0.109 **	.	.	.	+0.109 ***	.	.	.	0.02(1226)
Outcome Expectation – Supervising others	.	.	+0.104 **	.	.	.	.	.	0.02(1225)
Outcome Expectation – Inventing/designing things	.	.	.	+0.123 ***	.	.	+0.138 ***	+0.121 ***	0.07(1225)
Outcome Expectation – Developing new knowledge and skills	.	.	.	+0.078 **	.	.	.	.	0.01(1225)
Outcome Expectation – Having lots of personal and family time	.	-0.131 ***	.	.	.	.	.	.	0.01(1228)
Outcome Expectation – Solving societal problems	.	.	.	.	+0.143 ***	.	.	.	0.03(1230)
Outcome Expectation – Doing hands on work	.	.	.	.	.	.	+0.109 **	+0.120 ***	0.02(1223)
Outcome Expectation – Applying math and science	+0.142 ***	+0.174 ***	+0.106 **	.	-0.119 ***	-0.118 **	.	+0.173 ***	0.11(1230)

*Table 1: Summary of regression models; each row represents a separate model. The quoted figures in each cell are β, the normalized effect sizes. "." represents a non-significant result, "**" represents a significance of $p<0.01$, "***" a significance of $p<0.001$.*

Seven outcome expectation variables, which were tested in the regression analysis, showed no significant effects and so are not show in Table 1. In particular, the variables “making money”, “having job security and opportunity”, “becoming well known”, “working with people”, “having an easy job”, “being in an exciting environment”, and “making use of my talents and abilities” had no significant dependence on engineering discipline. The first two of these factors in particular are often cited as reasons why students may choose engineering careers; however, these results indicate that these outcome expectations are not significantly different for students across engineering disciplines.

In order to synthesize the results in Table 1 and facilitate an interpretation of collective results for the different groups of engineering students, they have been organized by engineering discipline below:

- **Bioengineering –** students who indicated a high likelihood of pursuing a career in bioengineering showed several significant differences in comparison to the “average” engineer. In particular, they reported markedly higher general science identities (all three sub-constructs of recognition, interest, and performance/competence), higher physics identities (recognition component) and higher indicators of both personal and global science agency. In terms of the outcome expectations considered, bioengineering students had higher career expectations towards helping others and the desire to apply math and science. These findings collectively position bioengineers as being somewhat akin to pure scientists with strong beliefs in the ability of science & technology to change both their lives and improve the world around them.
- **Chemical Engineering –** chemical engineering students also exhibit higher indicators of science identity (recognition component), physics identity (interest and performance/competence components), and math identity (all three components). Interestingly, they report a lower than average desire to have lots of personal and family time but, like bioengineers, expect a higher desire to apply math and science in their careers. These results suggest chemical engineers have more affinity to science and math through their self-identification as well as their career expectations, echoing other work in this area [Current Authors, *in press*, 2013 –citation redacted].
- **Civil Engineering –** civil engineers are also well separated from their peers. Showing higher than average science (recognition), physics (interest and performance/competence), and math identities (all three components), they also report a higher desire to supervise others in their careers (the only group that is significantly distinguished on this factor) and a higher desire to apply math and science. This group appear to reflect values somewhat similar to bio- and chemical engineers, although they stand alone in their increased desire to supervise others in their careers.
- **Electrical/Computer Engineering –** this group is a somewhat complicated case, possibly due to the inclusion of both electrical and computer engineering careers in the same category of response. The combined group have slightly higher physics identities (interest component) as might be expected but show mixed self-beliefs about their math identities (lower recognition component but higher interest component). They have a higher degree of global science agency and greater expectations to invent/design things and develop new knowledge and skills. The outcome expectations of this discipline

appear to be somewhat confirmatory of what might be expected of ECE students.

- **Environmental Engineering** – individuals who report a high likelihood of pursuing a career in environmental engineering are well-distinguished from their peers on several indicators. They report *lower* general science identities (performance/competence component), physics identities (interest and performance/competence components), math identities (all three components) and desire to apply math & science in their careers. Somewhat surprisingly, environmental engineers tend to show a lower degree of global science agency, which might reflect diminished expectations for the likelihood of science & technology to change the globe's environmental prospects. More expectedly, they report a higher desire to help others and solve societal problems.
- **Industrial/Systems Engineering –** industrial/systems engineering students have only marginally distinct identities (lower recognition component of their math identities) but also exhibit lower degrees of personal science agency and lower desire to apply math and science in their careers. These findings suggest that industrial/systems engineering students, while not particularly well-distinguished from the "average", may place value on other factors not considered in the SaGE survey in their career interests.
- **Materials Engineering –** students who express a strong desire to pursue a materials engineering career are relatively undistinguished from the mean. They differ significantly from other engineers in only two outcome expectations: the desire to invent/design things and to do hands on work. While the lack of significant findings in this case may be due to the relatively small size of this group (only 89 individuals indicate this career as "4 - Extremely likely", with a further 272 responding with a "3"), this may also indicate that materials engineering students might be thought of as "typical" in their career interests and self-beliefs.
- **Mechanical Engineering –** mechanical engineering students distinguish themselves on several indicators, including their physics identities (higher interest), math identities (higher recognition and interest components) , as well as the desire to apply math and science in their careers. Perhaps unsurprisingly, they also report greater desires to invent/design things and to do hands on work in their careers.

Discussion

Some general conclusions can be drawn from these results. Firstly, they provide clear evidence that different engineering disciplines should not be assumed to be homogeneous in self-beliefs and career intentions. As mentioned previously, while some expectation outcomes that are frequently referenced with respect to engineering – namely, making money and having job security – were found not to vary significantly between different disciplines, several of these indicators distinguished between groups quite well. Similarly, the general science, physics and math identity constructs are very useful in predicting disciplinary association, with bio-, chemical, and civil engineers showing particularly strong attitudes in these domains, and environmental engineers showing particularly low attitudes, compared to the collective average.

Another interesting observation that becomes clear in Table 1 is the distinction between older, more established disciplines – chemical, civil, electrical/computer, and mechanical engineering – and the other groups. Students in the former block of majors tend to exhibit particularly high degrees of math and physics identity – especially in the interest sub-construct. This may indicate that students who choose these four disciplines display attitudes traditionally identified as being "like" engineers, and so get directed towards these career choices. On the other hand, groups like bio- or environmental engineers do not exhibit these attitudes to the same degree, which may be related to the fact that these students intend on majoring in disciplines which are not as well established, and so allow greater opportunity for different motivations or aspirations. It is noteworthy to recognize that these disciplines currently have greater diversity (e.g., with respect to gender representation) in their student body.

One discipline that stands very clearly distinct from others are students with environmental engineering career intentions. It is interesting to note that environmental engineers have lower identities than most other engineering groups though they desire to help others and solve societal problems to a significantly greater degree than their peers. Despite having some overlap in content and scope with chemical and civil engineering, this group, amongst the newest discipline studied in this work, exhibits very different aspirations. This suggests that the environmental engineering community may particularly benefit from recruiting potential students outside traditional boundaries.

In the future, it would be very useful to extend this work to understand what experiences, prior to college, impact student attitudes reported here. This would give clear explanation for *how* students get directed towards one or other engineering discipline, a critical piece of information in the improvement of the recruitment and retention of the next generation of engineers. Another use of this work is to begin the long process to incorporate some of these findings into the curricula of engineering programs. For example, bioengineering students may show positive gains if curricula can be structured around issues that connect to these students' particularly high beliefs about personal and global science agency – the potential for science & engineering to change their lives, and the lives of others.

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