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Living in Two Worlds: Comparing Chemical Engineering Students to Other Engineers and Chemists

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Abstract

Often, engineering students are treated as a homogeneous population in post-secondary education. This paper explores the differences between chemical engineering students and chemistry majors as well as students of other engineering disciplines. The data used were drawn from the nationally-representative Sustainability and Gender in Engineering (SaGE) survey. This survey collected responses from 6,772 students in first-year English classes during Fall 2011. The survey included topics covering students' experiences in their last high school science classes, beliefs about engineering and sustainability, as well as their demographics and prior academic performance.

According to students' responses on their likelihood of entering a particular major, 123 students were identified as chemical engineering students, 691 students were identified as some “other” engineering students, and 251 students were identified as chemistry majors. We compared responses of the chemical engineering students with these two disparate groups respectively to identify differences in high school experiences, attitudes, and backgrounds using t-tests for linear variables, Wilcoxon rank-sum tests for Likert-type questions, and chi-square tests for dichotomous variables.

Chemical engineering students show uniqueness in their career goals when compared to both engineers as well as chemistry majors. For example, they differ significantly from other engineers in their prior chemistry experiences, problem solving strategies, and their science identity. Chemical engineers are almost indistinguishable from chemistry students in their high school science experiences and academic preparedness except for indicators of their physics and math identities. These findings have implications for student recruitment and matriculation into chemical engineering and the instruction of these students.

Introduction

In traditional analyses of students' career choice, students in various engineering disciplines are often treated as a singular group rather than as members of individual disciplines. While a few studies have looked at the differences between engineering students and physical scientists[1–3], few have examined the specific differences between students who chose chemistry or chemical engineering. High school students have not been fully exposed to science practice, let alone engineering practice, so the specific choice of chemical engineering over chemistry may only be a partly-informed decision. Additionally, the coursework to prepare for a specific STEM career is often undifferentiated in high school. Students entering college may not be prepared to make an informed choice between engineering and science majors. Instead, students choose engineering or science based on the perceived fit with their intentions and several irrational factors.[4] These findings add to the motivation to explore the underlying differences in students who choose chemical engineering over chemistry.

Comparison Between Chemical Engineering Students and Other Engineering Students

Our previous work comparing chemical engineers with other engineering groups show that chemical engineers are distinct from other engineering disciplines on several measures.[5] Chemical engineering students report particularly high expectations towards solving societal problems in their careers than other engineering students. This expectation includes a more frequent desire to address sustainability-related issues (e.g. disease, climate change, energy and water supply). Chemical engineering students also put more emphasis on developing a deep understanding (of natural phenomena, in everyday life, using scientific questioning and evidence). Not surprisingly, chemical engineering students usually take a second course in chemistry in high school and do better than other future engineering students. Finally, chemical engineering students were particularly confident in their abilities to perform tasks related to their scientific and course activities (write a lab report, interpret experimental results, apply knowledge to an assignment/test, get good grades). Students who choose chemical engineering over other engineering disciplines come from marginally high socio-economic status.

In addition to other factors, chemical engineering students showed a stronger interest and prior performance in science than other engineers. In light of these findings, this paper explores this emergent connection between science, specifically chemistry, and chemical engineering majors. In a recent paper, Zhang and colleagues found that, upon leaving, chemical engineering students transferred most frequently to the physical sciences and that students leaving the physical sciences to engineering more often chose chemical engineering than any other engineering subfield.[6] This study examined the differences between chemical engineers and other engineering students, science students, and non-science students. The data from this study were limited to transcript information from the Southeastern University and College Coalition for Engineering Education (SUCCEED). The authors did find general differences between engineers and scientists in representation of women, higher SAT math and verbal scores for engineers, longer time to graduation for engineers, and taking more credit hours before graduation. However, because of its design, this study did not explore students' career interests and attitudes, especially at the beginning of their college careers, which is the focus of the current paper. Further study of students' interests and attitudes about engineering disciplines is vital to the recruitment and retention of engineering students.

Several studies have shown that students will develop a strong connection with their chosen major when the perceived identity of a professional in that field aligns with a students' self-identity.[7–12] Since chemical engineering students show similar identity traits to physical scientists, the differences between students who choose chemical engineering over chemistry may have important implications for how students are recruited into chemical engineering and how those students should be instructed.

Methods

The data used in this study were drawn from a subsection of the Sustainability and Gender in Engineering (SaGE) survey (http://www.clemson.edu/~gpotvin/SaGE.pdf), which is a large-scale study of students in introductory English courses enrolled in colleges across the U.S. (NSF GSE 1036617). A stratified, random sample of all two-year and four-year institutions across the U.S.

was taken from a comprehensive list of the National Center for Education Statistics (NCES). This list was then divided by institution type (two-year or four-year) and by institution size (small, medium, or large) into six lists. Each list was randomized and then recruiters contacted schools on each list. The stratification accounted for the size of the institution and prevented over-sampling of smaller, but numerous, colleges around the country. This methodology utilizes a cross-sectional approach relying on the natural variation in students' experiences and backgrounds. In total, fifty schools agreed to participate in the survey with 6,772 eventual individual respondents. Students reported that they came from homes in at least 2,533 different ZIP codes across the U.S. of the total student population that completed the demographic portion of the survey, of which 54.7% were female. The survey was administered in required introductory English courses to capture a sample representative of both STEM and non- STEM majors. The survey instrument focused on student backgrounds, pedagogical factors in physical science classrooms, classroom achievement, and student attitudes toward STEM and sustainability. In this project, sustainability is defined broadly as meeting the "needs of the present without compromising the ability of future generations to meet their own needs."[13] The intent of the study was to focus on factors that increased enrollment in engineering majors and to explore the connections between engineering and sustainability-related topics in students' experiences.

The survey included 47 Likert, Likert-type, multiple choice, and categorical questions about student career goals, high school science experiences, prior math and science enrollment and achievement (including types of courses taken, the level of courses, the year in which courses were taken in high school, final grades, and AP test scores), student attitudes about sustainability, and demographic information.

Multiple aspects of validity and reliability of the instrument was assessed. An open-ended hypothesis-generation survey was collected from 82 first-year engineering and 41 non-engineering students, as well as 83 high school science teachers (recruited via the listserv of the National Science Teachers' Association). Lending to content validity, these hypotheses were included in the survey. Questions were further refined based on feedback from assessors and the results of pilot testing in a first-year freshman engineering course. An in-person pilot of the survey and focus groups were conducted with first-year freshmen engineering students. Thus, each item of the survey was further examined for face and content validity.

One question utilized in this analysis asked students to "Please rate the current likelihood of your choosing a career in the following:". The various 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 a Likert-type scale from 0 ("not at all likely") to 4 ("extremely likely"). In the current analysis, students that responded as "extremely likely" to choose a career in chemical engineering were grouped together, and students who responded "extremely likely" to chemistry were grouped together for a comparative analysis. The reason for this choice was to identify students with the most unambiguous intentions of majoring in chemical engineering on the one hand and chemistry on the other. The options of chemical engineering or chemistry as a major were considered mutually exclusive in this comparison.

According to the classification outlined above, 123 students in the sample were categorized as chemical engineering students (29.3% of which were female) and 250 students were categorized as chemistry students (49.8% of which were female). The chemical engineering students were comprised of 72% freshman, 21% sophomores, and 7% upperclassman. Similarly, the chemistry students were comprised of 73% freshman, 16% sophomores, and 11% upperclassman. This distribution is not surprising given the fact that they survey was administered in a required introductory English course.

For the questions with linear responses (SAT scores), a Welch's t-test was used to compare the mean responses of chemical engineering with chemistry students.[14] A chi-square test was utilized for dichotomous variables to assess whether there is a statistically significant difference in the responses of the two groups.[15] A Wilcoxon rank-sum test was used for all Likert-type questions.[16] For all tests performed in this analysis, the maximum probability of Type-I error (e.g. a false positive result) that was permitted was 5%. Note that only survey items pertaining to student preparation, background, and attitudes was analyzed in this paper. All analyses were conducted using the statistical software system R.[17]

Results /Discussion

The results of the various t-tests and Wilcoxon rank-sum tests are summarized in Table 1, and the results of the chi-square tests are summarized in Table 2. Only tests relating to the research question that were statistically significant are reported; in total, one linear, 21 non-parametric, and eight dichotomous variables showed significant differences. For each variable in Table 1, the mean and standard error are given for both groups of students. The larger mean is listed in bold. Similarly, Table 2 gives the results from the chi-square tests. The percentages of each group answering affirmatively to each factor are listed, followed by the statistical significance. The higher percentage is listed in bold. Tests for related variables are grouped together in Table 1: first, career goals (highlighted in grey); second, attitudes about science (white); third, physics identity (grey); fourth, attitudes about technology (white); fifth, science/engineering hobbies (grey); sixth, SAT math scores (white). In Table 2 the questions are also grouped together: first, sustainability factors in career goals (grey); second, influences on career choice (white); third, attitudes about mathematics (grey).

As indicated in Tables 1 and 2, chemical engineering students show several substantial differences with students in chemistry. In order to understand the uniqueness of chemical engineering students and consider how to specifically design pedagogy for these students, it is instructive to consider the meaning of the related blocks of factors that were found to be significant.

Table 1: Wilcoxon rank-sum outcomes for Likert-type variables and t-test outcomes for linearized variables.

Variable	Chemical Engineering Students (Mean ± Std. Error) N=123	Chemistry Students (Mean ± Std. Error) N=250	Level of Significance (*: p< 0.05, **: p< 0.01, ***: p<0.001)§
Career Goals			
Helping others (scale: 0-not at all important; 4-very important)	3.13 ± 0.12	**3.60 ± 0.36**	***
Having job security	**3.68 ± 0.06**	3.34 ± 0.29	***
Working with people	2.70 ± 0.35	**3.07 ± 0.03**	*
Inventing/designing things	**2.80 ± 0.32**	1.82 ± 0.68	***
Doing hands-on work	3.00 ± 0.33	**3.37 ± 0.04**	**
Attitudes About Science			
In biology worked on labs or projects (scale: 0-never; 4-daily)	2.36 ± 0.30	**2.67 ± 0.01**	*
In chemistry concepts/ideas were introduced before formulas/equations (scale: 0-never; 4-daily)	3.11 ± 0.34	**3.45 ± 0.01**	*
In physics spent time doing small group activities (scale: 0-never; 4-daily)	2.42 ± 0.42	**2.87 ± 0.03**	*
Hope to develop expertise in one specific field (scale: 0-strongly disagree; 4-strongly agree)	2.26 ± 0.44	**2.77 ± 0.07**	**
I live in the moment (scale: 0-strongly disagree; 4-strongly agree)	2.16 ± 0.36	**2.53 ± 0.01**	*
Physics Identity			
I see myself as a physics person (scale: 0-strongly disagree; 4- strongly agree)	**2.41 ± 0.12**	1.71 ± 0.61	**
My parents/ relatives/ friends see me as a physics person (scale: 0-strongly disagree; 4- strongly agree)	**2.40 ± 0.11**	1.72 ± 0.59	**

Variable	Chemical Engineering Students (Mean ± Std. Error) N=123	Chemistry Students (Mean ± Std. Error) N=250	Level of Significance (*: p< 0.05, **: p< 0.01, ***: p<0.001)[§]
My physics teacher sees me as a physics person (scale: 0-strongly disagree; 4- strongly agree)	**2.42 ± 0.02**	1.92 ± 0.48	*
I am interested in learning more about physics (scale: 0-strongly disagree; 4-strongly agree)	**2.87 ± 0.16**	2.14 ± 0.59	**
I am confident that I can understand physics in class (scale: 0-strongly disagree; 4- strongly agree)	**2.96 ± 0.07**	2.43 ± 0.46	*
I am confident that I can understand physics outside of class (scale: 0-strongly disagree; 4- strongly agree)	**2.72 ± 0.02**	2.24 ± 0.47	*
Others ask me for help in physics (scale: 0-strongly disagree; 4- strongly agree)	**2.78 ± 0.17**	2.01 ± 0.61	**
Attitudes About Technology			
I use technology more than my peers (scale: 0-strongly disagree; 4-strongly agree)	**2.78 ± 0.10**	2.01 ± 0.44	**
The benefits of new technologies greatly outweigh the risks (scale: 0- strongly disagree; 4-strongly agree)	**2.94 ± 0.03**	2.57 ± 0.35	*
Science/Engineering Hobbies			
Frequency of tinkering with things (scale: 0-never in my life; 4- more than six times in my life)	**2.56 ± 0.05**	2.01 ± 0.51	*
Frequency of participating in science/engineering hobbies (scale: 0-never in my life; 4- more than six times in my life)	**1.84 ± 0.06**	1.29 ± 0.49	*

Variable	Chemical Engineering Students (Mean ± Std. Error) N=123	Chemistry Students (Mean ± Std. Error) N=250	Level of Significance (*: p< 0.05, **: p< 0.01, ***: p<0.001)§
SAT Math scores (Scale 200-800)	**677 ± 24**	571 ± 85	***

§The level of statistical significance is coded in the final column: * represents a statistical significance less than 0.05 but greater than or equal to 0.01, ** represents a statistical significance less than 0.01 but greater than or equal to 0.001, and *** represents a statistical significance less than 0.001.

Table 2: Chi-square test outcomes for dichotomous variables.

Variable	Percent of Chemical Engineering Students Indicating (N=123)	Percent of Chemistry Students Indicating (N=250)	Level of Significance (*: p < 0.05, **: p < 0.01, ***: p<0.001)§
Sustainability Factors in Career Goals			
Want to address energy in career	**34%**	13%	***
Want to address disease in career	12%	**53%**	***
Want to address climate change in career	**11%**	6%	**
Want to address water supply in career	**16%**	9%	***
Influences on Career Choice			
In high school spoke with male engineer/scientist visitors	**14%**	8%	**
Math teacher contributed to selection of career path	**11%**	6%	*
Physics teacher contributed to selection of career path	**10%**	5%	*
Attitudes about Mathematics			
Math was a series of courses that I had to pass	19%	**39%**	*

§The level of statistical significance is coded in the final column: * represents a statistical significance less than 0.05 but greater than or equal to 0.01, ** represents a statistical significance less than 0.01 but greater than or equal to 0.001, and *** represents a statistical significance less than 0.001.

Many high school classroom practices and student attitudes were not found to be different, as well as a number of variables related to students' high school science course lengths, class sizes, frequency of meetings and activities. Similarly, students were questioned about their performance in their high school courses with no significant differences between chemical engineers and chemistry students. These results suggest that, while such factors may have a significant impact on the recruitment of students into engineering or science, no differential effects could be found for chemical engineering majors over chemistry majors.

Students' prior experiences in chemistry courses did not differ between chemical engineers and chemistry majors. However, major differences were discovered when comparing student beliefs and attitudes about their future career goals. Chemical engineering students desired having job security ($p<0.01$) and to invent or design things in their careers ($p<0.001$) while chemistry students had a stronger desire to help others ($p<0.001$), work with people ($p<0.05$), and do hands on work ($p<0.01$). Students perceive that choosing a chemistry career over a chemical engineering career will allow them to have a stronger personal impact and connection in the work force. These results are not, in fact, surprising given what others have found about the differences in communities of practice between engineers and scientists.[18] Speaking with a male scientist or engineer had a significant correlation with choosing chemical engineering ($p<0.01$). The effect of the gender of the scientist or engineer is unknown. The significant difference for a male engineering or scientist may be due to low reporting of meeting with a female engineer or scientist because the field of engineering is particularly predominated by men. Another possible explanation is that a male influence had a significant impact on the students who chose engineering – most of which were male. Another marginal influence on students' choice of engineering was their math and/or physics teachers ($p<0.05$). Finally, students choosing either chemistry or chemical engineering had different sustainability topics that they wished to address in their careers. Chemistry students reported that they wanted to address disease ($p<0.001$) in their careers while chemical engineers indicated that they would prefer to address energy ($p<0.001$), climate change ($p<0.01$), and water supply ($p<0.001$). Incorporating these specific topic into high school curricula or highlighting ways in which engineers address these specific sustainability topics may recruit more students into chemical engineering over chemistry.

Some marginal effects were identified for students majoring in chemistry in terms of science classroom practice. They more often worked on labs and projects, were given the concepts before equations, and worked on small group activities (all $p<0.05$). These students also had a stronger desire to be an expert in a single field ($p<0.01$) and were less rigid than their chemical engineering counterparts in their attitudes ($p<0.05$). Chemistry students' confidence in a science classroom or laboratory may explain why some students who would succeed in chemical engineering choose chemistry as their major.

Chemical engineering students showed a significantly higher interest and confidence in their physics abilities than chemistry students. They reported that family and friends ($p<0.01$) and their teacher ($p<0.05$) saw them as "physics people" to a greater degree than chemists. Chemical engineers also stated that they were more interested in physics ($p<0.01$) and confident in their abilities to understand physics ($p<0.01$). Finally, others asked chemical engineering majors for help in physics significantly more than chemistry students ($p<0.001$).

One interesting finding is the difference in attitudes about technology. Chemical engineers have a more positive attitude about technology ($p<0.05$) and utilize technology more often than their peers ($p<0.01$). They also reported a greater frequency of tinkering with things ($p<0.01$) and participating in science or engineering hobbies outside of class ($p<0.05$). This positive view of technology may highlight students' interest in engineering specifically. These students may view engineering as a way to use technology in their careers to benefit the world around them. Including descriptions of technologies that are utilized in the chemical engineering profession is a possible way to validate such students' interests and help them see how the engineering theory taught in traditional engineering classrooms connects to the “real world.”

Chemical engineering students display significantly higher SAT math scores than chemistry students ($p<0.001$). This finding, along with students' higher interest in physics and positive attitudes about the subject, may explain the influence of math and science teachers on career choice. Traditionally strong students who perform well in math and science may be steered toward an engineering career track by guidance counselors and teachers. Specifically, for chemical engineers, their chemistry teachers encourage strong achievement in the field of chemistry, but their math or physics teacher may encourage the transition to chemical engineering over chemistry due to a student's performance in their classrooms.

A strength of the cross-sectional methodology used in this paper is the ability to draw conclusions from a nationally-representative sample college students. Also, we were able to test hypotheses related to factors and events that occurred naturally in students' experiences, rather than being restricted to student variables that could be manipulated in an intervention setting. A notable weakness of this methodology is the ability to draw only correlational, not causal, conclusions. The correlational results reported here are strong, in many cases, but further work is necessary to investigate the causal relationships underlying the results reported here. For example, students may want to address energy in their careers because of their choice of chemical engineering as a major, or they may choose chemical engineering because of their desire to address energy in their careers.

Conclusions

Our previous work found that chemical engineering students show, in many ways, more similarities to physical scientists than other engineering students.[5] This earlier analysis was conducted in an effort to understand the similarities and differences between these two groups. Chemical engineering students are a distinct group in and of themselves. They are not only significantly different from other engineering disciplines, but, as we have shown in this paper, they are also distinct from chemists.

We have shown that chemical engineering students have different career goals and interests, beliefs about technology, abilities in physics and math, and influences on their career choices than chemistry students. One the one hand, chemical engineers show stronger interest in solving societal problems in their careers, interest and competence in science, and more positive chemistry experiences that distinguish them from other engineers and suggest some similarities to chemists. On the other hand these same chemical engineering students have a stronger interest and competence in physics and math, more economically and personally motivated career goals, more positive attitudes about technology and its possible applications, and not as fully developed laboratory skills than chemists which are more representative of an engineering approach to the world. These findings along with previous work about chemical engineering students begins to give an overall picture of the types of students sitting in freshman chemical engineering courses or general engineering courses intending to major in chemical engineering.

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