2006-1805: GENDER DIFFERENCES IN BIOLOGICAL ENGINEERING STUDENTS

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Gender Differences in Biological Engineering Students

Abstract

Do gender differences exist in the interests and attitudes of biological engineering students? Undergraduate engineering students participated in a voluntary survey designed to help understand this issue.

First, to determine whether males and females received different academic preparation, prior to entering engineering, the survey examined mathematics, science, and technical course work taken in high school. Second, in acknowledgement of entering engineering students fewer "hand's-on" mechanical skills compared to computer skills, the survey probed these areas and examined their relationship to three fundamental engineering activities (designing, building, and analyzing). Finally, the survey takes into account non-school influences such as family, geographic location, and type of community and their relationship to academic interests.

The survey incorporated a combination of question formats including pre-categorized demographic information, a 5-point Likert scale, and open-ended responses. Data from the survey was imported directly into SPSS for statistical analysis and analyzed based on gender using crosstab frequencies, prevalence ratios, and the T-test to determine whether non-parametric scores in both genders differ. By understanding gender differences in attitudes and interests in biological engineering, we can address issues in the field to improve both recruitment and retention.

Surprisingly few differences were found in the data based on gender. Based on several measures, females were equally prepared for biological and agricultural engineering when compared with males. However, differences were found in "hands-on" preparation and family background.

Introduction

Since the early 1990's the "pipeline theory" has been accepted as the dominant conceptual framework to describe the relationship between education and occupation from elementary school to initial employment [1, 2]. According to the "pipeline theory" the gender gap in science and engineering will disappear if sufficient women take science and math in school and if policies are in place to block the leakage from the pipeline at points where more women than men are lost. However, the pipeline theory has proved to be inadequate to explain the lack of success in improving gender equity in engineering for several reasons [1, 3-6].

First, in contrast to the recent past where most females did not graduate from high school with the necessary math and science prerequisites to enter engineering [7], girls now take as many high school science classes (although fewer take physics) and their achievement levels are roughly the same level as boys [3, 4, 8-16]. Yet, their enrollment and participation in engineering remains low.

Second, a large body of empirical literature suggests, that even though women now acquire as many years of education as men do at all levels, they invest in different kinds of human capital, major in different subjects, choose different occupations; and accumulate less overall labor market experience [17]. Women have made great strides in entering fields in law, veterinary medicine, the biological sciences, and medicine once dominated by men but engineering remains a male dominated field [2, 9, 12, 14, 18, 19].

Third, at this time, the rate of leakage from the pipeline appears to be similar for male and female students. Female students in engineering programs did not fall behind in the pipeline. They, actually, were slightly more likely than male students to complete an engineering degree and less likely to switch to non-engineering programs. Although women are less likely than men to enter science and engineering, women who enter science and engineering fields are likely to do well and graduate [21-24].

Despite the hundreds of projects and huge expenditures used to increase recruitment and retention of women in engineering, low enrollment with disappointing results still prevails [24]. Why is engineering less responsive to these social forces that have otherwise successfully affected gender equity in other professions?

Seymour (1997) found that the best foundation for survival and success is to have chosen one's major because of an intrinsic interest in the discipline. She also found that those with the strongest interest in their major owed their sense of direction to particular teachers, family members, role models, or mentors. Women were found to differ very sharply from men in this area of personal influence. Women were more likely to have initially chosen and switched their majors to Science, Mathematics, and Engineering (S.M.E.) disciplines because of the influence of someone that was significant to them [24]. In particular, the influence of family members is considered a major factor in the career decision making process [1, 21, 25-27].

An additional area of sharp contrast between the intrinsic interests of men and women lie not in their reasons for leaving S.M.E. majors, but in their reasons for entering them. Altruism is an intrinsic interest in the desire to enter a particular field because of a commitment to a wider moral purpose. Seymour notes that altruistic reasons for entering S.M.E. majors are predominantly expressed by women and students of color in contrast to men in general [24].

It is difficult to explain why losses in S.M.E. majors occur from a pool of disproportionately able undergraduates. Faculty (75%) find undergraduates seriously under-prepared in academic and study skills, and blame others for the high attrition rate. The author presents data to support the hypothesis that the difference in the performance scores of switchers and non-switchers are insufficient to predict which students are likely to stay and which leave. They did not find switchers and non-switchers to be two different kinds of people; they do not differ by individual attributes of performance, attitudes, or behaviors to a degree sufficient to explain why one group left, and the other group stayed. Most switching was not caused by personal inadequacy in the face of academic challenge [24].

A common deficit in pre-college education for many women was hands-on technical or laboratory experience. This deficiency was more than a handicap; it gave their male peers a psychological advantage and was a source of fears about competence and belonging for women. Requiring some technical education in high school for engineering majors might address this issue [24].

But young women are much less apt than young men to continue in quantitative disciplines, regardless of their preparation. Education statistics show that although girls and women are increasingly choosing to enter the biology-based science fields, they are, in spite of talent, ability, excellent career opportunities, and good potential salaries, choosing not to pursue learning in fields such as computer science and engineering [2, 12, 18, 28]. While women now earn more than half of the bachelor's degrees in the biological sciences, they earn just one-fifth (21%) of all bachelors degrees in physics [8] and just 20% in engineering [19].

In the engineering and scientific community, there is emerging consensus that one way to address the under representation of women is to interest women in engineering by developing a gender-balanced curriculum and integrating it into existing high school science, math, and technology education programs [4, 8, 9, 29]. A gender-balanced curriculum is one that is equally appealing to men and women.

A few recent studies credit the success in recruiting women into the biological sciences and medicine to a gender-balanced curriculum in high school. Eccles (2003) and Spears (2004) found that young women who are strong in math tend to seek careers in the biological sciences". "They value working with and for people," and "they don't perceive engineering as a profession that meets that need" [30].

Biological Engineering

Since biological engineering, the biological sciences and medicine share many common themes, there is reason to believe that women could be successful in biological engineering. Currently, very little biological engineering curriculum exists (or is widely known to exist) that is suitable for integration into high school programs. However, a pre-engineering program in biological engineering is under development by Project Lead the Way. There is a need to determine what approaches should be used in a biological engineering curriculum to encourage the participation of students of both genders.

To examine how these issues impact biological engineering, undergraduate engineering students participated in a voluntary survey designed to help understand whether gender differences exist in the interests and attitudes of biological engineering students. Current research supports the idea of promoting engineering by integrating it into existing math, science and technology education classes [8,9,10]. Yet, little has been done to see whether students agree with such tactics and, more importantly, if gender plays a role in such opinions. Significant changes being made to the structure of biological and agricultural engineering programs throughout the US, coupled with low female enrollment, and overall student enrollment in college engineering majors dropping, it is necessary to understand these differences so we can address current issues in the field and thus improve both recruitment and retention of engineering colleges nationally. There is a need for more qualitative data to address the influence of significant others on females in the choice of a college career [26].

Objectives

The first objective was to determine whether males and females received different academic preparation, prior to entering engineering. To cover this issue, the survey gathered information on the number of math, science and technical course work taken in high school.

The second objective acknowledges the fact that the interests of students entering biological engineering may be different than those 10 years ago. Hence, the survey examined their interests in three fundamental engineering activities, designing, building, and analyzing. It also probes students' decisions related to engineering, their major and specialty [17].

In the final objective, the survey takes into account non-school influences such as family, geographic location, and type of community and their perceptions of, knowledge about, and experiences with engineering.

Methods

A web-based survey, using SurveySuite software, was prepared. The use of the web format allowed the students at a wide variety of locations access the survey at their convenience. The student survey is about 15-20 minutes in length so that it can be completed in one class period or outside class. There were no right or wrong answers.

Students from seven universities across the country participated. All geographic regions of the country are represented as well as a variety of university sizes. While most participants were freshmen or sophomores, comparison with the junior and senior student data suggests that the population is a good representation of the overall biological engineering student population. Of an overall pool of 281 engineering students completing the survey, only the 178 biological and agricultural engineering students were selected for analysis.

The survey incorporated a combination of question formats including: pre-categorized demographic information and interest questions in a 5-point Likert scale. The responses to the Likert scale questions were arranged such that 1 was boring and 5 was interesting. Many of the questions relate to engineering in general, but biological engineering received more emphasis. The survey gives a strong indication as to which topics in biological engineering males and females are most interested in.

Data from the survey was imported directly into SPSS for statistical analysis. Data was analyzed based on gender, ethnic background, school name (geographic location), community type, and age. Initially, the most relevant information is gender related. The mean and standard deviation for each question were also compared by gender. A T-test was used for comparing the non-parametric scores in both genders. The prevalence ratios were calculated from the crosstab frequencies.

Population Demographics

The participating population was selected through voluntary response to an electronic survey distributed among seven universities across the United States. A majority of respondents were from the eastern half of the United States with Louisiana State University (20.7%), University of Maryland (20.7%), Louisiana Tech University (.6%), University of Georgia (17.9%) and Ohio State University (12.8%) composing 72.7 percent. Utah State University (20.7%) and the University of Arizona (5%) represented the western half of the country and 25.7 percent of the respondents. Utah State University, Ohio State and the University of Maryland are classified as northern Universities and compose 46.4 percent of the respondents. The other universities were considered southern and composed 52.5 percent of the respondents. Only 1.1 percent of the students were unidentified.

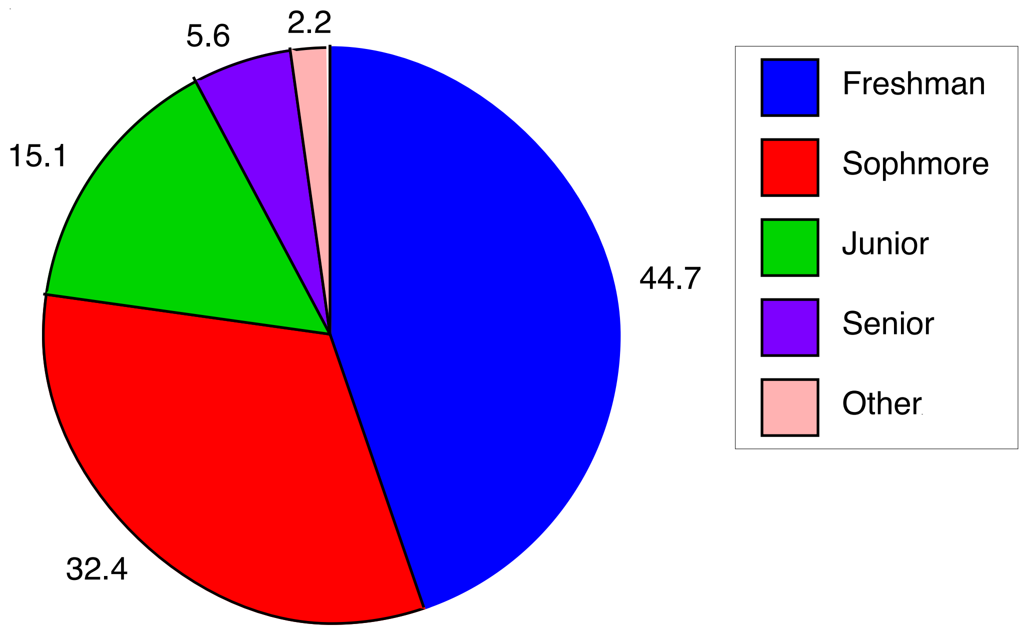

Figure 1. Class Ranking of Respondents: Most respondents were in their 1st or 2nd year of engineering

All participants were students ranging from freshmen to doctoral with self-identified biological and agricultural engineering majors under the categories of: biomedical engineering, biological engineering, agricultural engineering, environmental engineering, food engineering, irrigation, biochemical engineering/biotechnology, automation, water resources, and environmental engineering. The majority of respondents were freshmen (44.7%) and sophomores (32.4%) (see Figure 1).

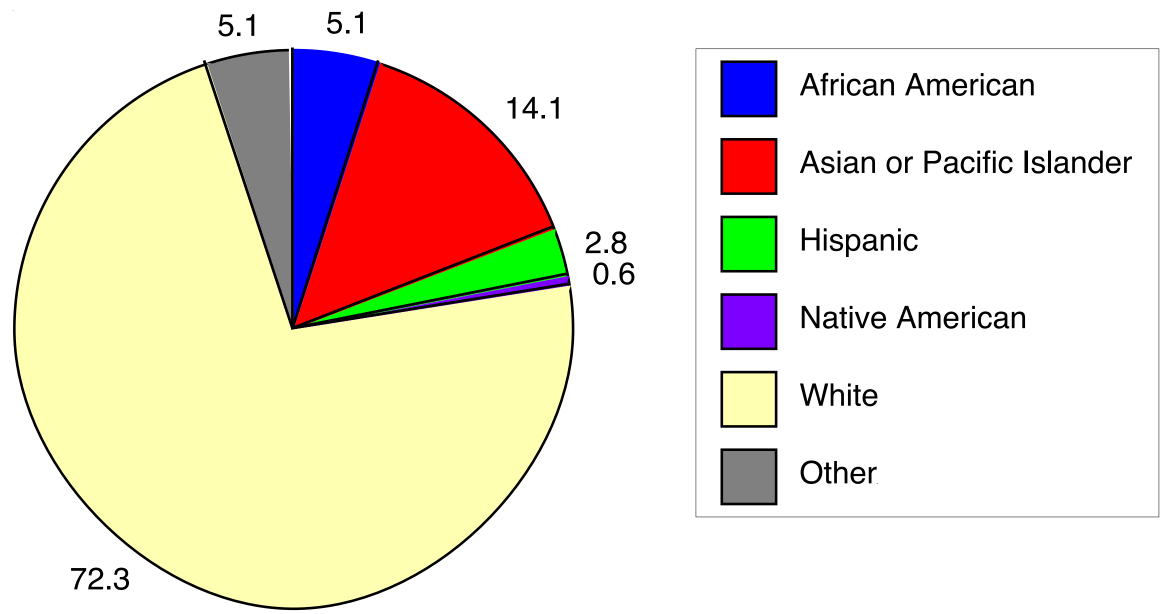

Figure 2. Ethnicity of Respondents: Most respondents were White or Asian/Pacific Islander as is typical of engineering students.

There were 72.3 percent White, .6 percent Native American, 14.1 percent Asian American or Pacific Islander, 2.8 percent Hispanic, 5.1 percent African American, and 5.1 percent other race respondents (see Figure 2). By gender, 39 percent of the respondents were female, 61 percent were male (see Figure 3).

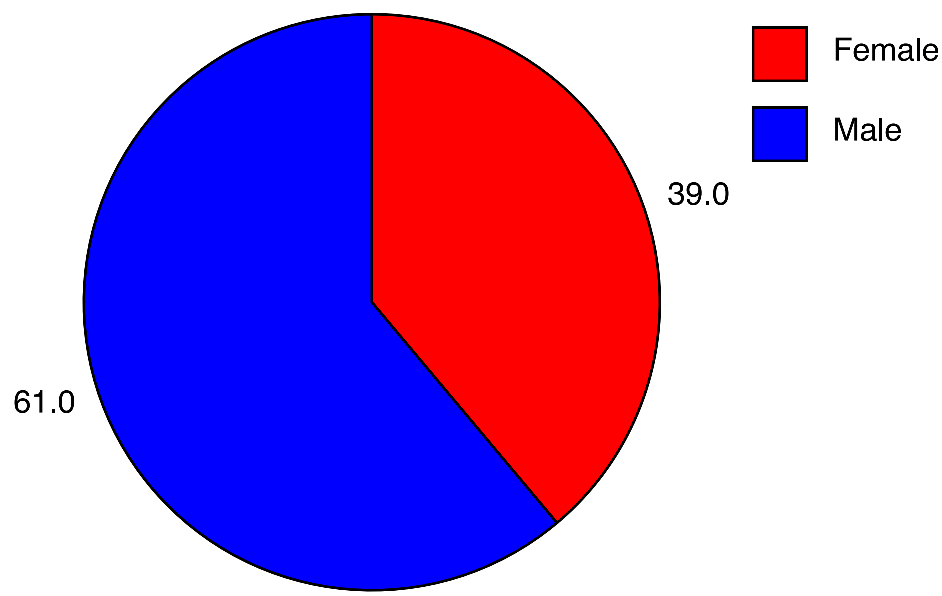

Figure 3. Gender of Respondents: More participants were female than expected due to the fact that Biological Engineering has a greater percentage of females than engineering, in general.

The age range of participants also varied from younger than 18 to 34 years of age. Though a large majority of the respondents between 18 and 19 (61.5%), students who were 20 to 23 years old composed 30.7 percent of the population. Other age groupings were significantly less (see Figure 4). The age group of 18-23 is typical for college students.

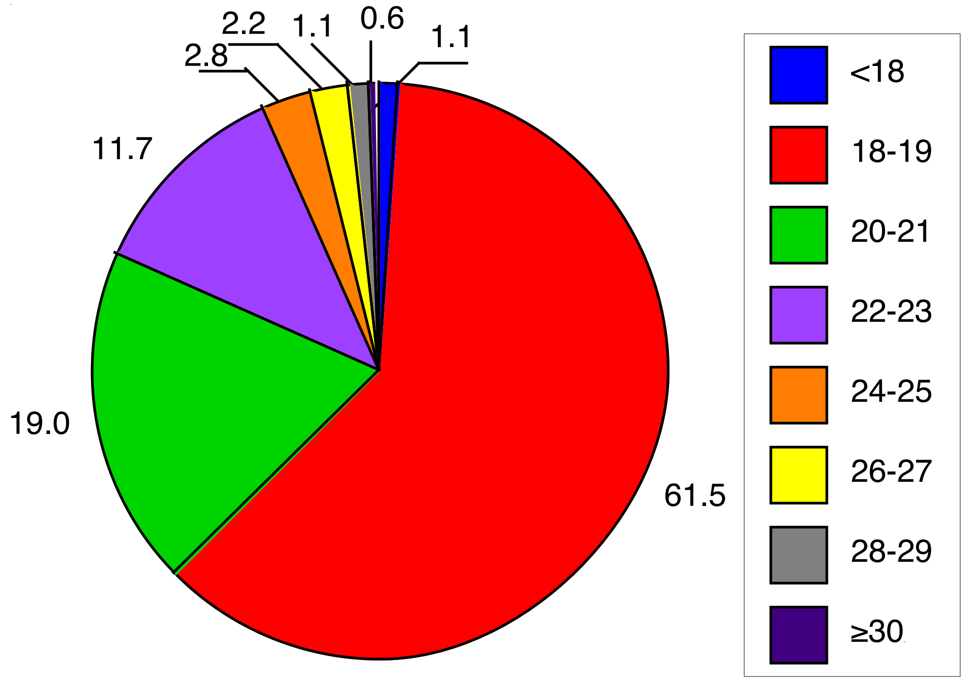

Figure 4. Age Range of Respondents: Most respondents are under 21.

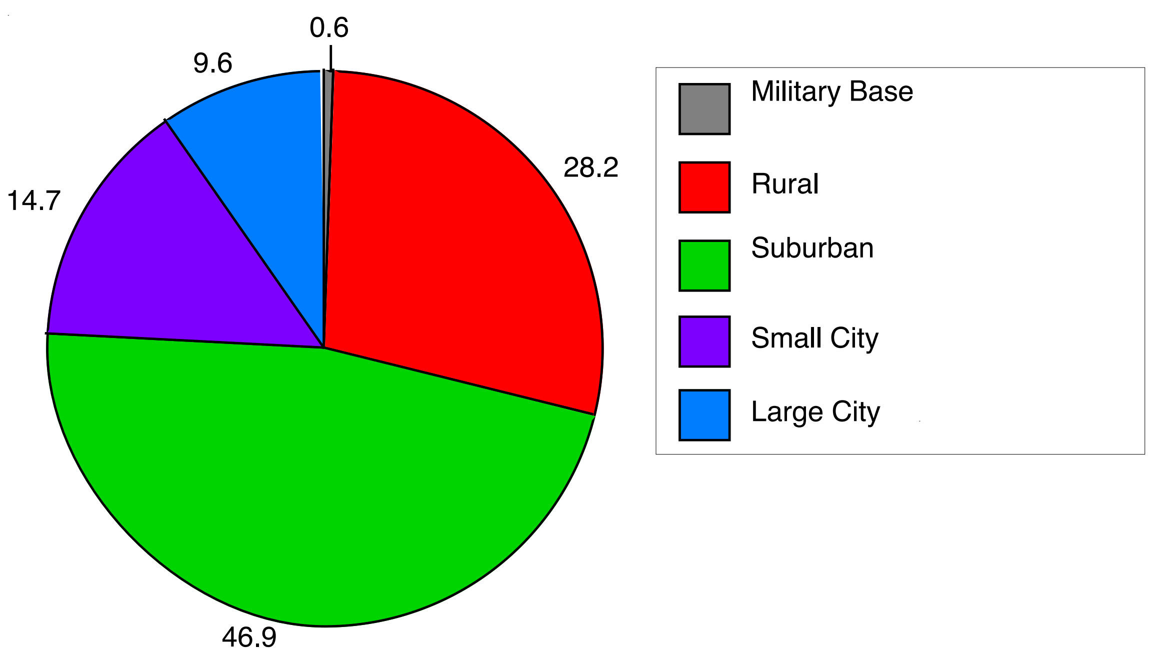

Figure 5. Community Type of the Respondents: Most respondents were from suburban and rural areas.

As well as major geographic locations, a variety of community types are also found among the respondents. Though a large majority came from suburban (46.9%) and rural (28.2%) areas, small (14.7%) and big cities (9.6%) compose 24.3 percent of the respondents living areas. Only .6 percent reported residing on a military base. (See Figure 5)

The community type of these students may also have bearing on either their retention or attraction to the field. With a majority of responses coming from suburban and rural communities, perhaps the coincidence of these environments' natural affiliation with knowledge and materials associated with biological engineering would explain the motivation of it's residents to pursue such fields of study. It could also be the environment's need for such knowledge that promotes further education in such areas. Further study among residents of such community types and their pursuance of further education within the field of biological engineering are necessary to confirm these conclusions.

Academic Preparation

To assess their academic preparation in Mathematics, Science and Technology students were asked to identify the courses they had taken while in high school.

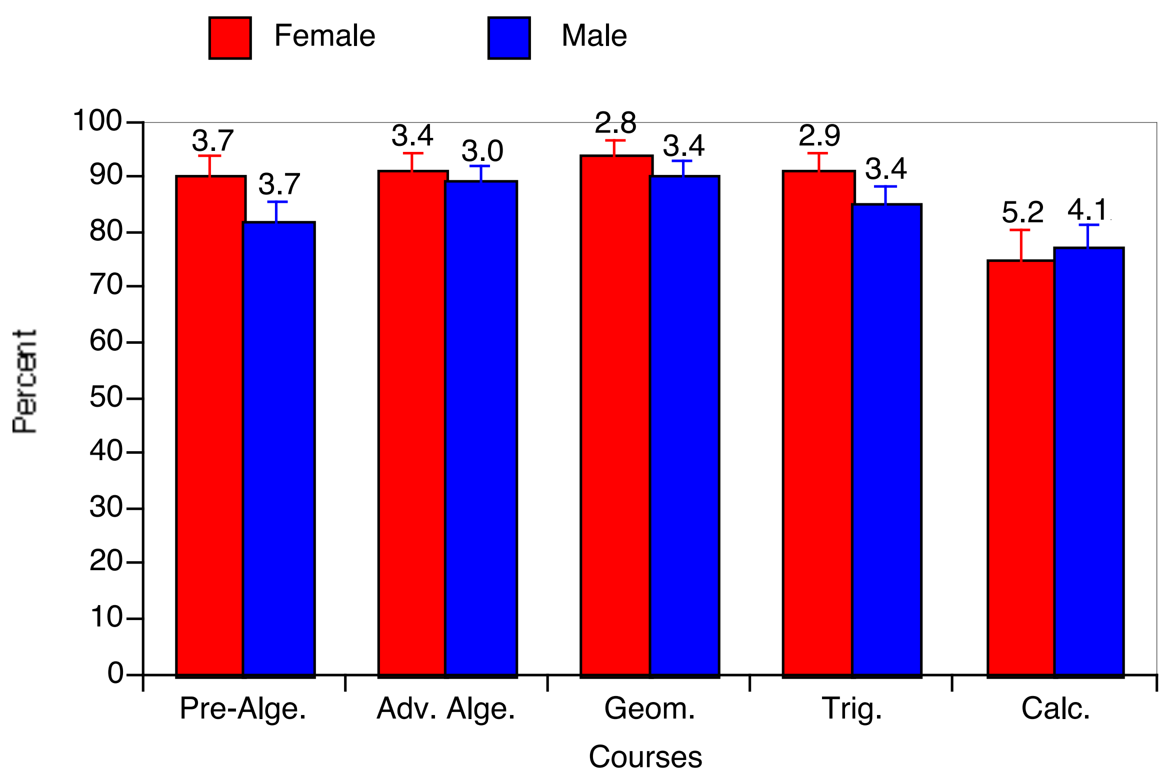

Figure 6. Math Taken in High School Arranged by Gender: With the exception of calculus, females appear to have taken slightly more mathematics than males overall. The numbers above the bars are the standard errors.

In math, 90 percent or more of the females reported having taken Pre-algebra (90%), Advanced Algebra (91%), Trigonometry (91%), and Geometry (94%), while only 75 percent reported having taken calculus. In comparison, the males reported having taken fewer courses in: Pre-algebra (82%), Advanced Algebra (89%), Trigonometry (85%), and Geometry (90%), with only Calculus (77%) being reported as slightly higher than the females (see Figure 6).

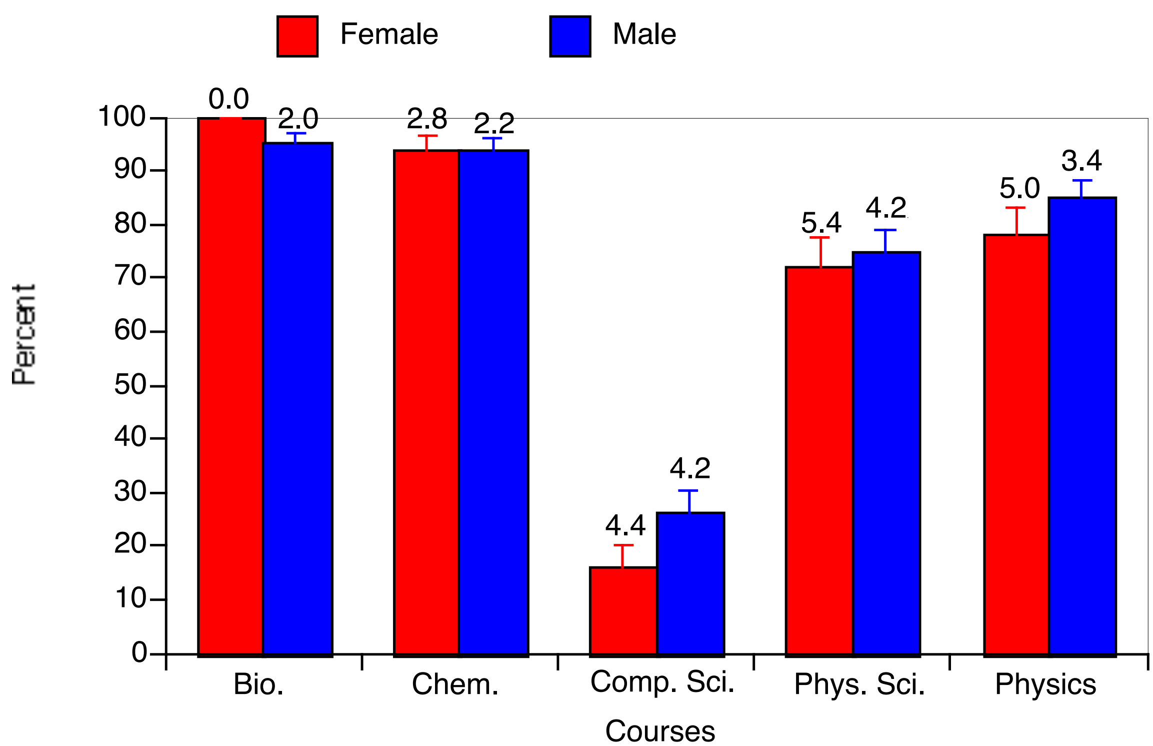

Figure 7. Science Taken in High School Arranged by Gender: There is varying difference in the amount of science taken. The numbers above the bars are the standard errors.

In science, surprisingly, all females reported having taken Biology, while only 95 percent of males did. Similar percentages of both males and females reported having taken chemistry (94% male and 94 % female) and Physical Science (75% male and 72% female). Both also reported few courses taken in Computer Science (26% male and 16% female). In Physics, 85 percent of the males reported having taken the course, while only 78 percent of females did (see Figure 7).

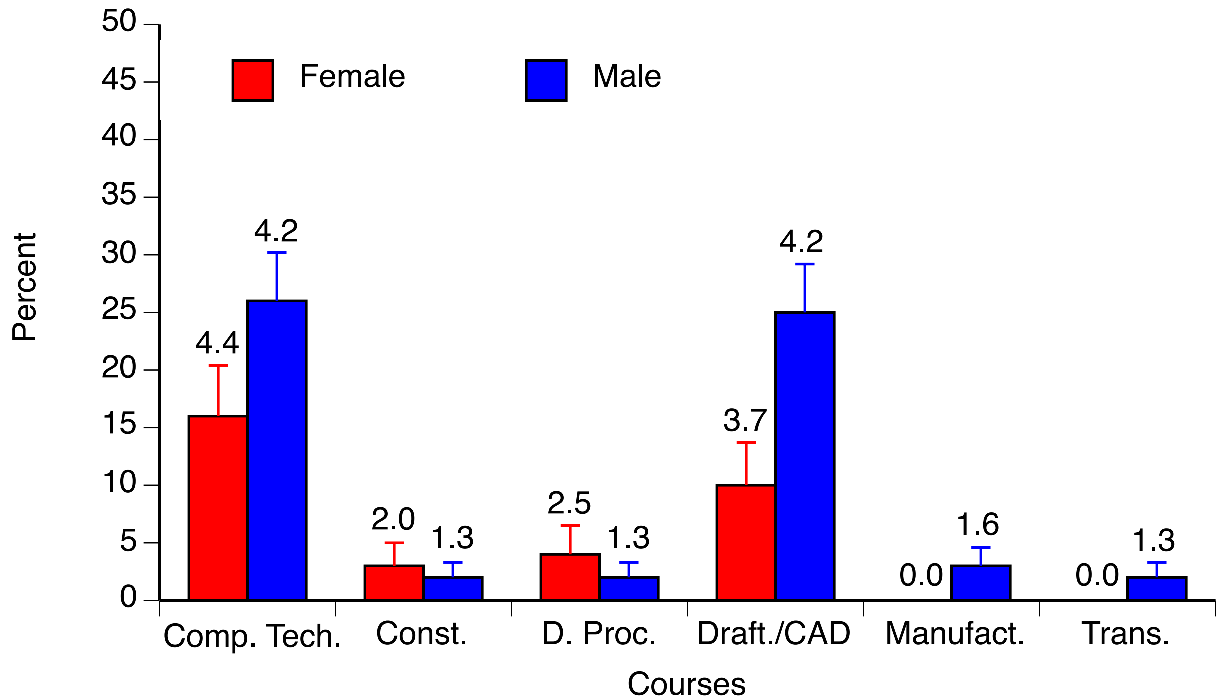

Figure 8. Technology Taken in High School Arranged by Gender: Males take more "hands on" technology education classes in high school. The numbers above the bars are the standard errors.

With regard to technology education, fewer than 27 percent of males and females reported having taken any of the technology courses listed in the survey. In fact no females reported having taken Manufacturing or Transportation courses. Additionally, low percentages of males reported having taken the same courses (Manufacturing 3% and Transportation 2%) as well as Construction (2%) and Design Processes (2%). Low percentages of females also reported having taken Construction (2%) and Design Processes (4%) as well. Both had higher percentages in Drafting/CAD (25% male and 10% female) and Computer Technology (26% male and 16% female). (See Figure 8)

In summation, these results correlate with the literature in that the females, as a whole, received adequate training in mathematics and science. Males and females had similar amounts of training in mathematics and science, with females having taken slightly more biology and slightly less calculus than the males. However, they received far less training in technology courses. The fact that both males and females in this study received little or no training in technology courses is noteworthy.

This indicates that these girls were as adequately prepared as males to pursue careers in biological engineering, questioning the validity of the pipeline theory. Yet, this does not explain why there are fewer females in the field. It is possible that, because the females that participated in this study were academically prepared, they pursued this field while other females who were not did not and hence were not a part of this study.

The gap in academic preparation falls within their exposure to technology courses. Though both males and females overall took fewer courses in technology, the fact that females took considerably less technology classes than males may be a key contributing factor to their low enrollment in college biological engineering programs and careers. In contrast, this could also mean that the less exposure females have to technology, the more likely they are to pursue biological engineering.

Since females in engineering appear to be well prepared, it would be worthwhile to suggest comparison with the academic preparation of women who pursue other fields. If the results show that females in other fields are not as academically prepared in math, science, and technology as these women, then this may be the missing link necessary to bring them not only into biological engineering, but engineering. However, if the results prove similar preparation as found in the studies of previous research, than preparation is not a factor in choosing to pursue this field.

Fundamental Engineering Activities

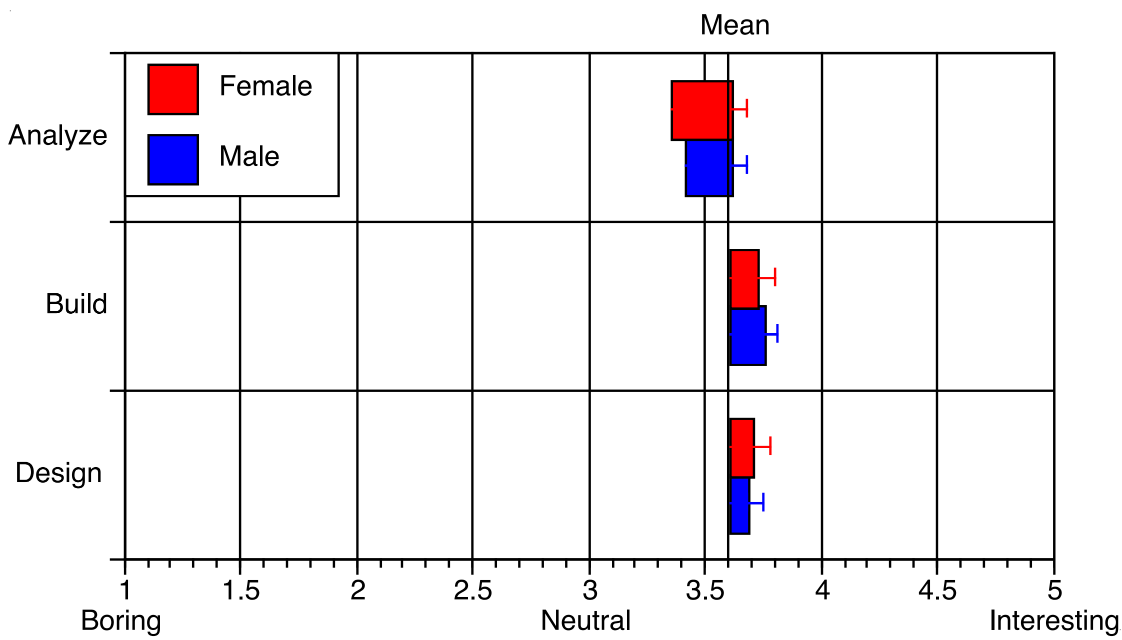

Figure 9. Build, Design and Analyze Comparisons to Mean Arranged by Gender: The mean is the average score of all participants for all questions.

Of the 29 total questions asked by the survey to examine interests in the fundamental engineering activities of build (9), design (10), and analyze (10), perhaps most striking information was the fact that there was virtually no difference between the men and women within these broad categories. No statistically significant differences were found in comparison of the interests of males and females in the conglomerate categories in a T-test for equal means. Despite an overall positive view of activities within their major (mean = 3.6), There was little deviation from it the in any category (see Figure 9).

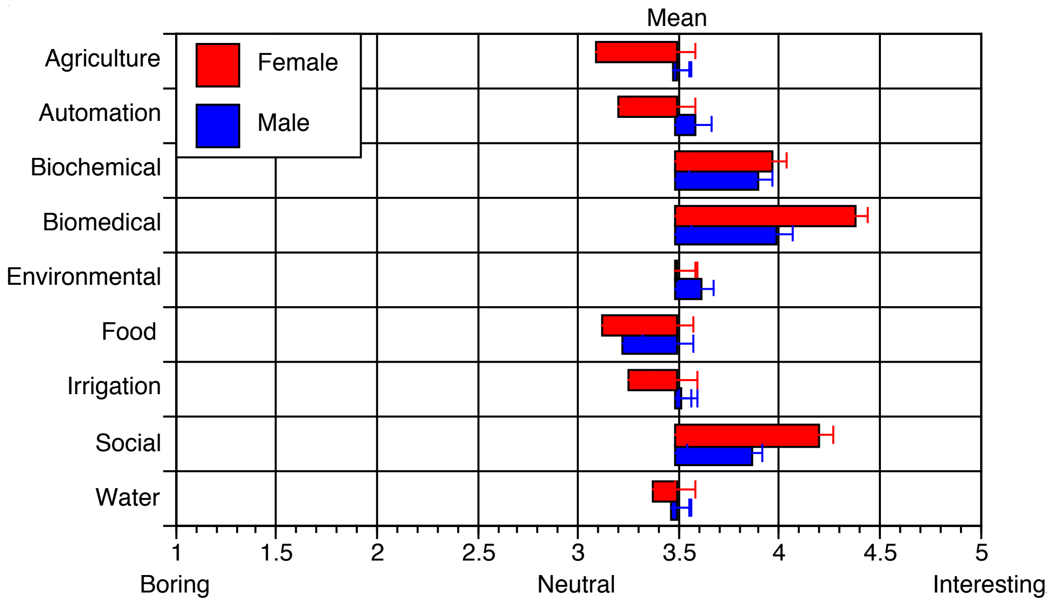

Figure 10. Engineering Interests in Comparison to Mean Arranged by Gender: The mean is the average score of all participants for all questions.

However, when the questions were divided into nine different categories of biological and agricultural engineering activities (biomedical engineering, food engineering, irrigation engineering, biochemical engineering/biotechnology, automation, agricultural engineering, water resources, envi-ronmental engineering, and social applications), a statistically significant difference appeared between male and female interest levels in a T-test for equal means in the biomedical (p=.023) category. Additional discrimination of the interest levels may occur as data currently being acquired is considered.

Although the eight of the nine subcategories failed to show statistical significance between male and female responses, the fact that both responded similarly and not too far from a slightly positive mean shows that both are at least "somewhat interested" in all of these areas. Most responses varied little from the overall mean of 3.48 , but the categories of social interest (female: 4.19, male 3.85), biomedical engineering (female: 4.37, male 3.98), and biochemical engineering (female: 3.96, male 3.89) showed much higher means and thus were relative subjects of higher interest (see Figure 10).

The general student interest in socially relevant applications is noteworthy, in that numerous previous studies have declared that women are more prone then men to be interested in these activities due to their afore mentioned altruistic nature. Instead, we find strong interest in students of both genders. However, this does not eliminate the possibility that the social application of biological engineering is what attracted the women to this field in the first place. It simply shows that men are also interested in it. Further study is necessary to determine if this and/or any of the other eight categories were contributors to their decision to pursue this field.

The only area to provide statistically significant gender preferences was in the biomedical engineering category. Difference in this field raises poignant questions regarding the exact nature of their dissimilar interest. Females (mean = 4.38) clearly favor this topic more than males (mean = 4.00). Perhaps it is here that the altruistic nature of females is displayed. If this is so, why didn't the social category show a statistical significance? Is it possible that the biomedical engineering field offers more real life application or opportunity for altruistic behaviors? Is it possible they see more value in this field than in just social events? Alternately, it is possible that the differences visible in the figures are real and the inclusion of the additional data currently being acquired will result in their statistical significance. More research needs to be done with detailed in depth questions regarding the individual characteristics of these fields as they relate to altruism in order to fully answer these questions.

The lack of significant differences between male and female responses in the build, design, and analyze activities indicates that the idea of separate gender activity preferences is incorrect. However, altering the topic of the activity (such as the inclusion of biomedical, or biochemical, or socially relevant engineering projects) has the potential to strongly impact student interest, regardless of gender. This information has the potential to provide avenues for further increasing enrollments, while not impacting the overall abilities of the biological engineering graduate.

Familial Influences

When respondents were asked whether close members of their family were engineers (sibling, parents, grandparents, aunts and uncles), 42.1 percent of males and 49.3 percent of females responded affirmatively.

One of the most interesting findings obtained from the data was the percentage of females have a female engineer in their extended family. As well, initial findings reveal that female engineering students are 3.4 times more likely to have a female relative that is an engineer than a male engineering student, but only 0.9 times more likely to have a male relative that is an engineer. This correlation is large when you consider there are very few female engineers old enough to have daughters or granddaughters that are of college age. (See Table 1) In 1970, less than 1% of engineers were women compared to 18-20% today [4, 8, 9, 12, 13, 16]. When interpreting these numbers from a family perspective, the following factors must be considered:

- Very few engineering students will have grandmothers who are engineers,
- Few engineering students will have mothers who are engineers, and
- Engineering students are more likely to have sisters or aunts who are engineers.

Thus, the number of female engineering students in the survey who have female family members who are engineers is very high indeed. The role female engineers have on the career choices of females in their extended family needs to be investigated. Table 1 summarizes the data analysis, there were 2 students not answering the question (missing data).

Table 1: Male and female familial relations to engineers.

	Female [#]	Female [%]	Male [#]	Male [%]	TOTAL [#]
Total Respondents	69	39.2%	107	60.8%	176
With a relative	34	49.3%	45	42.1%	79
Without a relative	35	50.7%	62	57.9%	97
With a female relative	11	15.9%	5	4.7%	16
With a male relative	23	33.3%	40	37.4%	63

Table 2: The prevalence ratios showing a correlation between engineering students and female or male relatives in their extended family that are engineers. Females have more family members that are engineers but it is much larger in the case of female relatives that are engineers. Categories in an extended family include: sister, brother, mother father, aunt, uncle, grandmother, and grandfather.

Prevalence Ratio	Female [%]	Male [%]	Male:Female Ratio
At least one relative that is an engineer	49.3%	42.1%	1.2
At least one female relative that is an engineer	15.9%	4.7%	3.4
At least one male relative that is an engineer	33.3%	37.4%	0.9

The fact that almost half of both males and females participating in this study reported having family members that were engineers raises the issue that family influence plays a large role in not only females, but also males choosing to pursue engineering. These results coincide with several other studies that have shown family to be the primary factor in a child's future career. Clearly, if a member of a child's extended family is an engineer, they are more likely to pursue engineering themselves, whether this relationship is causal remains a topic of future study.

Conclusions

Overall, the philosophy of the pipeline theory is likely to be an invalid explanation for the low enrollment of women in the field of biological engineering through a general lack of gender differences between men and women in 1) academic preparation, 2) interest levels in analyze, build and design activities, and 3) interest in eight of the nine major subcategories of food, irrigation, agricultural, water, biochemical, environment, automation, and social. Understanding the differences found in the biomedical area require further study to determine the specific contributing factors (e.g. whether it is altruism or not).

The only areas of particular interest lie in the non-schooling influences of community types and familial relations to engineers. In general, the majority of respondents for this survey were either from suburban or rural areas with at least one relative that was/is an engineer.

In general, it was found that 1) having familial relations with an engineer, 2) living in the afore mentioned areas, 3) having high academic preparation in math and science, and low preparation in technology based courses, and 4) high interest in social, biomedical and biochemical areas, regardless of gender, all lend higher probability to the respondents having chosen biological engineering as their major.

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