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Machines versus Compassion: Comparing male and female students in biology-based engineering discipline

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MACHINES VERSUS COMPASSION: COMPARING MALE AND FEMALE STUDENTS IN BIOLOGY-BASED ENGINEERING DISCIPLINES

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ABSTRACT. *Biology-based engineering disciplines have been the most successful at recruiting women into engineering. An analysis of gender differences in student experiences in such disciplines helps illuminate ways to combat the under-representation of women in engineering. This article examines the academic backgrounds, expressed interests, and student experiences of 424 women and men in biology-based engineering programs throughout the country. Gender similarities in the broad engineering activities of design, building, and analysis were found. Gender differences were identified in the applications of these activities. Male students were significantly more interested in the applications in the areas of agriculture, automation, and irrigation, while female students were significantly more interested in the areas of biochemical engineering, biomedicine, and social responsibility. These results suggest that recruiting and retention of women in biology-based engineering disciplines can be promoted by selecting appropriate application areas without sacrificing emphasis on overall engineering skills.*

Keywords. *Biology-based engineering sub-disciplines, Student interests survey, Women in engineering.*

The gender disparity in science and engineering programs nationwide has been of critical concern to educators and scholars alike. Unlike other historically male-dominated occupations such as law and medicine that have seen gains in achieving gender equity, science, math, and engineering (SME) fields have remained peculiarly imbalanced in terms of gender. In fact, the percentage of engineering bachelors degrees earned by women has decreased from 21.2% in 1999 to 18.1% in 2007 (ASEE, 2008). Statistics show that in spite of talent, ability, and opportunity, women are choosing not to pursue programs in fields such as computer science and engineering (BEST, 2004b; Darke et al., 2002; Rochefort et al., 2004; GAO, 2004). Interestingly, women are entering biological and agricultural engineering programs in greater numbers. This trend might illuminate how and why women might be successfully recruited into and remain in engineering educational programs and careers. This article examines the nature of this trend and explores its significance to the gender disparity in SME fields.

Since the early 1990s, the "pipeline theory" has been the dominant conceptual framework used to describe the SME gender disparity (Darke et al., 2002; Xie and Shauman, 2003). According to this theory, the gender gap in science and engineering exists because few women take science and math in school and/or are lost at various leakage points in the pipeline from school to work. The pipeline theory, however, has proved to be inadequate in explaining the lack of success in improving gender equity in engineering for several reasons (Clewell and Campbell, 2002; CEOSE, 2004; Correll, 2004; Xie and Shauman, 1997, 2003). First, whereas women in the past did not graduate from high school with the necessary math and science prerequisites to enter engineering (AAUW, 1992), women now take as many high school science classes, and their achievement levels are roughly the same level as men (AAUW, 2004; BEST, 2000, 2004a; Clewell and Campbell, 2002; CEOSE, 2004; Freeman, 2004; GAO, 2004; Jackson 2004; Long et al., 2001; CAWMSET, 2000; Thom, 2001). Thus, the idea that women are not in science and engineering fields because they do not start out in the "pipeline" is empirically false.

Second, a large body of empirical literature suggests that even though women now acquire as many years of education as men do, they major in different subjects, choose different occupations, and accumulate less overall labor market experience (Badgett and Folbre, 2003). Women have made great strides in entering once male-dominated fields such as law, veterinary medicine, biological sciences, and medicine. Yet engineering remains a male-dominated field (BEST, 2004a; Darke et al., 2002; Rochefort et al., 2004; GAO, 2004; Long et al., 2001; Tietjen, 2004). The pipeline theory cannot account for these occupational choices.

Third, at this time, the rate of leakage from the pipeline appears to be similar for male and female students. Indeed, female students are slightly more likely than male students to complete an engineering degree and less likely to switch to non-engineering programs. Thus, although women are less

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likely than men to enter science and engineering, women who enter science and engineering fields are likely to do well and graduate (Adelman, 1998; Huang et al., 2000; NSN, 2000; Seymour and Hewitt, 1997). They are not lost in significant numbers due to leakage, as the pipeline theory would suggest.

If the pipeline theory fails to account for the pervasive gender imbalance in SME (Seymour and Hewitt, 1997), then how do we explain why these fields remain less responsive to forces that have otherwise successfully affected gender equity in other professions? One place to look is in the set of motivations and interests that lead women and men to choose different educational and career pathways. For example, Seymour and Hewitt (1997) note that in comparison to men, women are more likely to explain their choice of SME majors in altruistic terms. Pinker (2002) and Pressley and McCormick (1995) also point to a large body of research that indicates that "on average, women are more interested in dealing with people and men with things." This difference explains in part the great surge of women into anthropology, sociology, psychology, law, and medicine. It may also help explain why fewer women express interest in engineering, math, and the hard sciences.

The importance of interest, motivation, and educational choice is demonstrated by Pinker (2002), who quotes Patti Hausman, a social scientist speaking at the National Academy of Engineering Convention in 2002:

"The question of why more women don't choose careers in engineering has a rather obvious answer: Because they don't want to. Wherever you go, you will find females far less likely than males to see what is so fascinating about ohms, carburetors, or quarks. Reinventing the curriculum will not make me more interested in learning how my dishwasher works" (p. 352).

Indeed, although some people claim that women avoid SME careers because they lack confidence in their math skills, a 2003 study found that "young women value working with and for people," and "they don't perceive engineering as a profession that meets that need" (Eccles, 2003).

Instead of engineering, both Eccles (2003) and Spears et al. (2004) found that young women who are strong in math tend to seek careers in the biological sciences. Recent statistics show that although 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 (AAUW, 2004) and just 20% in engineering (Tietjen, 2004). Since biology-based engineering disciplines, the biological sciences, and medicine share many common themes, there is reason to believe that women could be successfully recruited into biology-based engineering disciplines (BBE). This article analyzes results from a recent survey of BBE students to shed light on how the students themselves perceive their recruitment into and experience within engineering programs.

This article is particularly concerned with the question of whether gender differences exist in the interests and attitudes of BBE students. 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, or a curriculum that is equally appealing to men and women (AAUW, 2004; BEST, 2004a; CEOSE, 2004; NAE, 2002). To date, little research has been done to explore whether students agree with such tactics and, more importantly, if gender differences even exist in educational interests. With low enrollment of women in engineering and overall engineering enrollment stable or dropping, an understanding of student interests is a critical component of both recruitment and retention. Further, noting that significant changes are being made to the structure of biology-based engineering curricula nationwide, a window of opportunity currently exists to integrate this information into the curricula.

Objective

This study examines data collected from students in biology-based engineering programs attending American universities using an on-line survey from the fall of 2005 through the spring of 2006.

The goal of this research was to develop an understanding of the students enrolled in biology-based engineering disciplines. To achieve this goal, four objectives were met. They included developing an understanding of the students':

- Backgrounds, including gender and home community.
- Motivations for entering engineering.
- Academic preparation and comfort level in course subjects.
- Interests within biology-based engineering.

In addition, this research probes the students' decisions related to engineering (their major and specialty), their perceptions of school-related influences on their career decisions, the importance of external non-school influences, and their motivations for studying engineering.

Methods

Survey Data Set

A total of 424 students from ten U.S. universities (table 1) participated in the on-line survey. External validity refers to the extent to which the results of a sample population can be generalized to other populations. A rule of thumb for determining the size of a quantitative study is to make the sample as large as possible with a minimum of 100 respondents in a survey (Gall et al., 2003). In the U.S., estimates of the number of engineering degrees awarded range from 60,639 in 2002 (NSB, 2006) to 222,335 in 2004 (Wadwha, 2006). Leedy and Ormrod (2005) suggested that if the population is in excess of 5,000, then a sample size of 400 is adequate, since sampling error is less than 5% if the sample is over 384.

Table 1. Respondents by university.

	Responses	
Institution	Number	Percent
Iowa State University	37	8.8%
Louisiana State University	94	22.3%
Mississippi State University	26	6.2%
Ohio State University	25	5.9%
University of Arizona	9	2.1%
University of Arkansas	28	6.6%
University of Georgia	32	7.5%
University of Maryland	73	17.3%
University of Nebraska, Lincoln	26	6.1%
Utah State University	70	16.6%
Other Universities	2	0.4%
Total number of participants	424	

Selection of Survey Participants

This survey used a convenient sample. Participation in the survey was voluntary. The students, a combination of graduate and undergraduate students, were categorized as enrolled in biology-based engineering disciplines. Specifically, they self-identified as majoring in one of four majors (biological engineering, biomedical engineering, agriculture engineering, or environmental engineering) or an equivalent. It should be noted that many students' self-identified major did not coincide with a major offered at their university, suggesting that they identify more with their areas of specialization than their home department name.

Survey Design

The survey was released in two iterations (once per year), with minor corrections (e.g., spelling) made between the two iterations. As well, to improve the quality of the survey data, a few questions were added to the design, build, and analyze section. The survey had seven sections; four were applicable to all engineers and three specifically applicable to biological engineers. The latter group of questions contained a series of questions linked to three basic engineering activities: designing, building, and analysis. The questions within these three groups were directly related to sub-disciplines of biology-based engineering. To obtain valid and reliable data, the methods suggested by Leedy and Ormrod (2005) and Suskie (1996) were adopted. For example, multiple questions related to the same attitude/concept were written. In addition, there were no right or wrong answers.

The survey incorporated a combination of question formats, including pre-categorized demographic information and 5-point Likert scales. Table 2 shows the question types and numbers of questions in each section. The time required to complete the survey was approximately 15 to 20 min. The survey was published using SurveySuite, created and hosted by the University of Virginia. The use of an on-line format allowed students at a wide variety of locations to access the survey at their convenience.

Data Analysis

Data from the survey were exported directly from SurveySuite into a Microsoft Excel (version 11) spreadsheet. In Excel, all string data were converted into numeric data for analysis. The participants who were not enrolled in a BBE discipline, who did not identify themselves sufficiently to allow identification, or who completed the survey improperly were removed from the analysis. The Excel file was then imported into SPSS (version 14 for PC) for statistical analysis. Students who did not fill in all three areas of the design, build, and analyze (DBA) section were included in the other analyses, but were not included in the DBA analysis.

In this study, data were analyzed using the T-test and the chi-square test. Means and standard errors of means are reported where appropriate. The level of statistical significance was set at 0.05 for the data analysis. The analyses were performed by the Utah State University Office of Methodology and Data Sciences.

Table 2. Number and type of questions.

Survey Section	Question and Responses Type	No. of Questions
Demographics	Fill in blank and check appropriate box(es)	9
High school course work	Check appropriate box(es)	3
Comfort with skills used in engineering	5-point Likert scale: Strongly disagree (1) to Strongly agree (5)	14
Motivation	5-point Likert scale: Strongly disagree (1) to Strongly agree (5)	9
Interest - design	5-point Likert scale: Boring (1) to Interesting (5)	9
Interest - analyze	5-point Likert scale: Boring (1) to Interesting (5)	10
Interest - build	5-point Likert scale: Boring (1) to Interesting (5)	10
Total number of questions		64

Results and Discussion

Surveyed Population

The participating population was selected through voluntary response to an electronic survey distributed among ten universities from across the U.S. A total of 424 students responded to the survey (table 1). Participants ranged from freshmen to doctoral students. The majority of respondents were freshmen (34.9%) and sophomores (28.5%) (fig. 1a). The age range of participants also varied from younger than 18 to 34 years of age. Although a large majority of the respondents were either 18 or 19 (49.8%), students who were 20 to 23 years old composed 41.0% of the population (fig. 1b). The age group of 18 to 23 is typical for college students.

Gender and Ethnicity

Many fields in engineering and the hard sciences have not reached the critical mass where women and minorities make up at least 15% of the field. Biology-based engineering programs, however, now feature women students in sufficiently large numbers for study (NSB, 2006). Minorities of less than 15% are often referred to as tokens, or treated as representatives of their category rather than as individuals. There is also a tendency to exaggerate the extent of the differences between them and the dominant group. Thus, the personal characteristics of the individuals tend to be distorted into the stereotype of their group. Visibility tends to create high performance pressures for tokens (Kanter, 1977). By this definition, the women in biology-based engineering disciplines, although in the minority, no longer qualify as tokens. In this study, 39.2% of the respondents were female and 60.6% were male (fig. 2a).

The BBE disciplines have been less successful in recruiting ethnic and racial minorities. The respondents self-identified as 77.1% white, 0.5% Native American, 12.1% Asian American or Pacific Islander, 2.1% Hispanic, 4.3% African American, 2.6% international, and 1.4% other (fig. 2b). No significant differences were found when the ethnicities of the respondents were analyzed by gender.

Home Communities

A variety of home community types and sizes are also found among the respondents. Although a large majority came from suburban (40.1%) and rural (33.5%) areas, small urban areas (population <1,000,000) and large urban areas

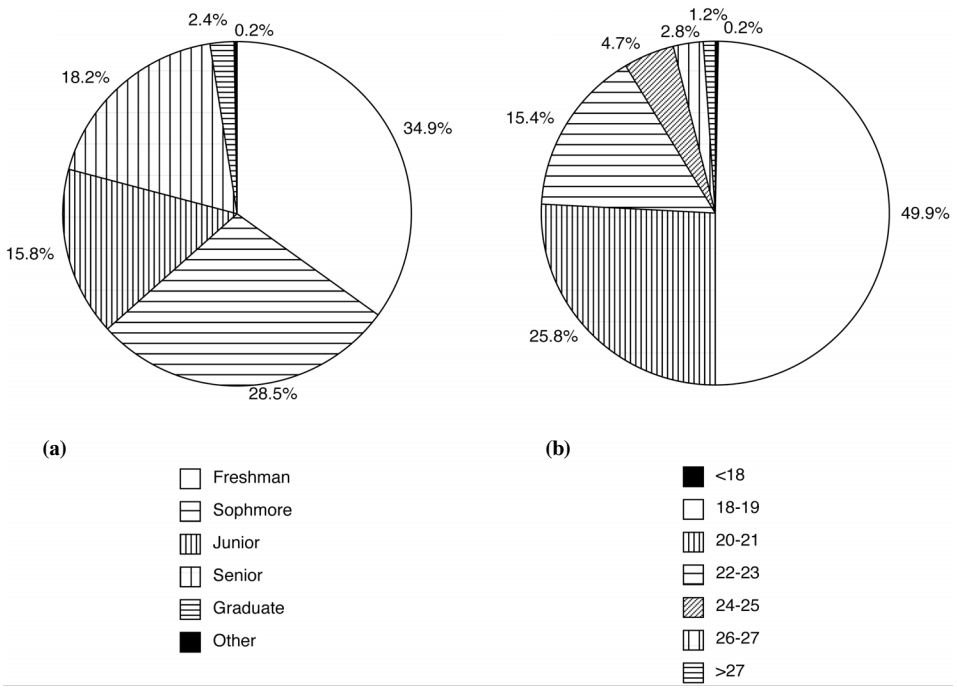

Figure 1. (a) Class rankings and (b) ages of respondents. Most respondents were in their first or second year of engineering and are under 21.

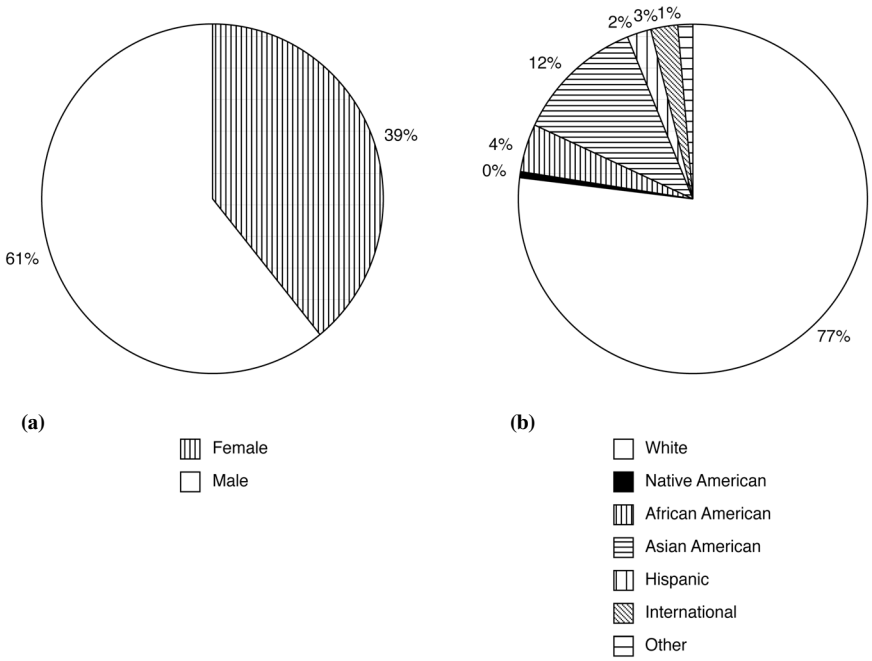

Figure 2. (a) Gender and (b) ethnicity of respondents. More participants were female due to the fact that biological/biosystems engineering has a greater percentage of females than engineering in general. Most respondents were white or Asian/Pacific islander, as is typical of engineering students.

(population >1,000,000) comprised 24.3% of the respondents' home communities (fig. 3).

In two types of communities, a significant difference in the gender distribution of students was found. More men than women were recruited from rural environments, and more women than men were recruited from small urban areas (population <1,000,000). As student recruiting follows the general movement of the population from rural to urban settings (UN, 2005), these differences in distribution are likely to have a significant impact on the percentage of women in BBE disciplines. The home community type may also have a bearing on students' attraction to or retention in sub-disciplines within the field.

Academic Preparation

Seventy-eight percent of the survey's respondents indicated that they had chosen to enter engineering (either in general or with a specific engineering discipline in mind)

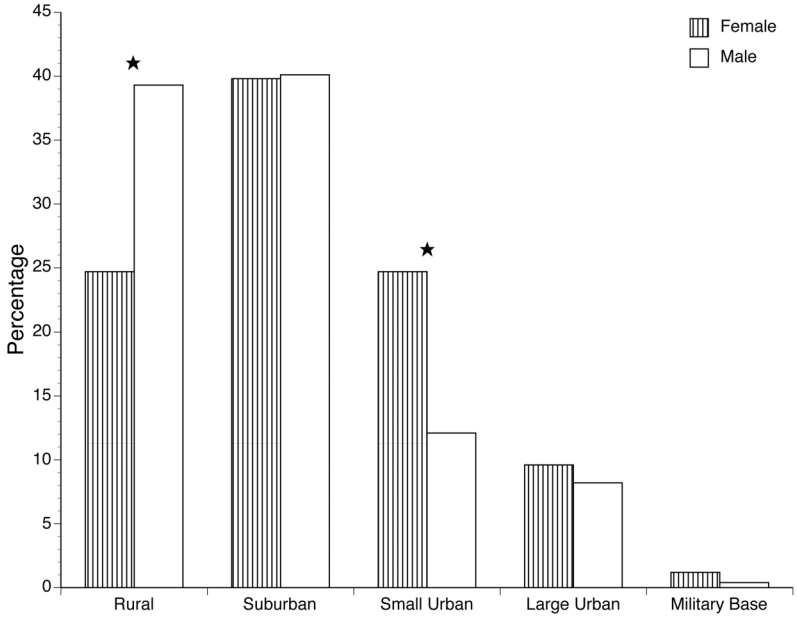

Figure 3. Community type of the respondents. Most respondents were from suburban and rural areas. Significant gender differences (indicated with stars) in home community size were found for rural (more likely for men) and small urban (more likely for women) communities.

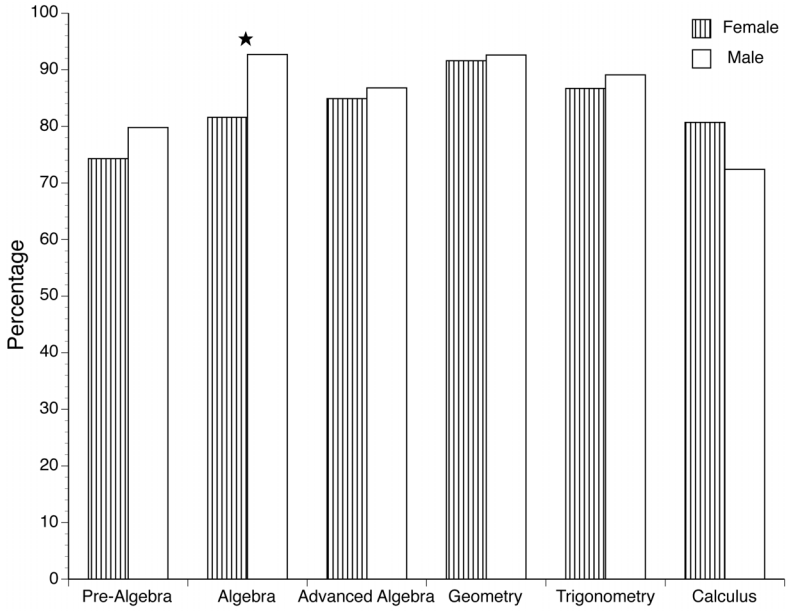

Figure 4. Math taken in high school by gender. With the exception of calculus, men took slightly more mathematics than women overall. However, the only statistically significant gender difference (indicated with a star) was for algebra.

prior to entering the university. Quite unsurprisingly, therefore, most of them had obtained significant high school preparation in mathematics and science.

Of the respondents, 77.3% reported having completed high school coursework in pre-algebra, 88.2% having taken algebra, 86.1% having taken advanced algebra, 92.2% having taken geometry, 88.2% having taken trigonometry, and 75.7% having taken calculus. The only significant gender difference was the number who had taken algebra, with 81.6% of women and 92.7% of men having taken the course. The gender breakdown of the students in the courses is shown in figure 4.

There were no significant differences between women and men in their levels of preparation in the sciences. Of the respondents, 73.3% reported having taken physical science in high school, 95.5% reported having taken biology, 95.3% reported having taken chemistry, 82.3% reported having taken physics, and 30.5% reported having taken computer science (fig. 5).

Over the last 10 to 15 years, a number of national pre-engineering experiences have been initiated for inclusion in the high schools. These include Project Lead the Way (initiated in 1997), US First (initiated in 1992), and Infinity (initiated in 1999). The oldest national program considered was JETS (1950). Finally, Engineering State is a regional program hosted in some states. Although there were no significant differences between the men and women, this is likely due to the low number of students in the sample who

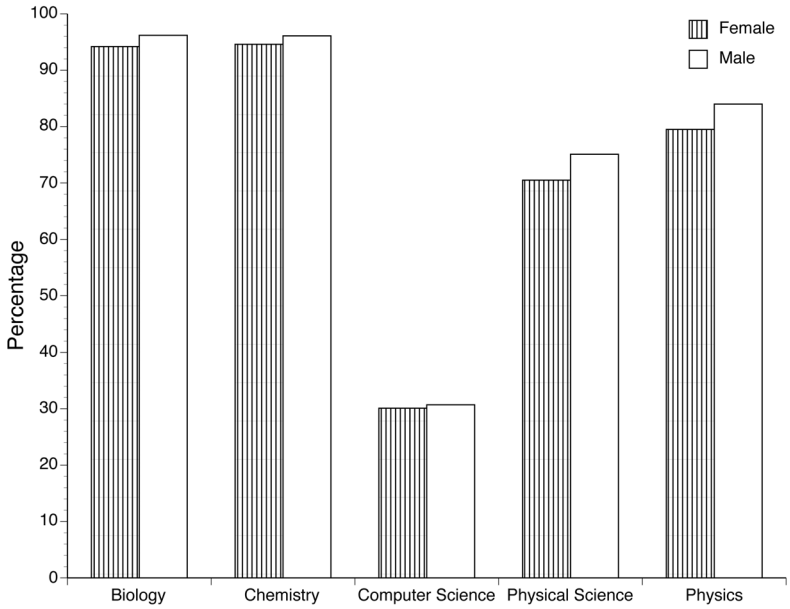

Figure 5. Science taken in high school by gender. Despite some gender differences in the amount of science taken, there were no statistically significant gender differences.

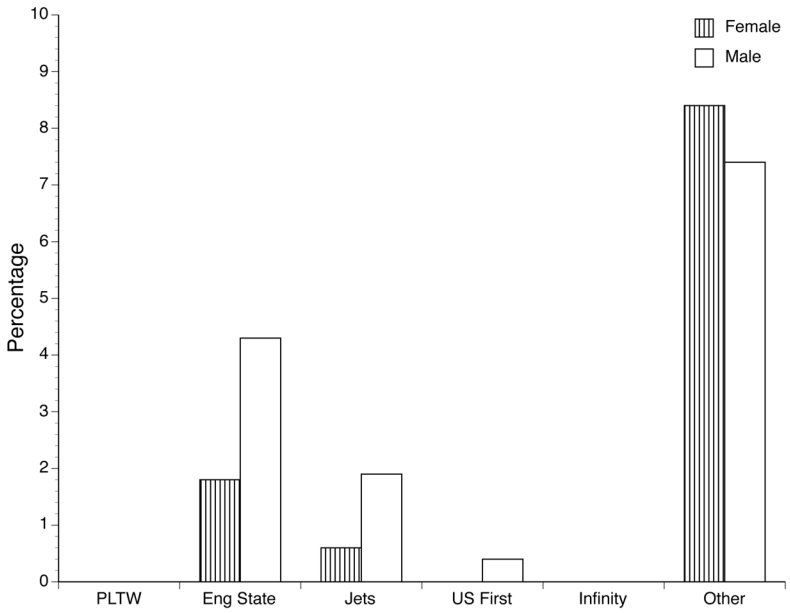

Figure 6. Pre-engineering experiences in high school by gender. Few of the respondents were involved in pre-engineering experiences, and none of the gender differences were statistically significant.

had taken part in these programs. Given the growth of the pre-engineering programs, however, the numbers of participants is likely to increase (fig. 6).

In summation, these results correlate with the literature in that the men and women in our sample had similar high school backgrounds in mathematics and science. This finding indicates that the female respondents in this study were as adequately prepared as the male respondents to pursue careers in biology-based engineering disciplines.

One important factor to note is the high percentage of students in our sample who had taken biology and chemistry in high school. This finding suggests that these classes may be the most effective classes to use for recruiting. Since these courses are also part of the pipeline for biology, veterinary science, and medicine, BBE disciplines may be able to tap into them for recruiting additional women into the field.

Motivations for Engineering

Every engineer has his or her own reason or combination of reasons for their interest in engineering. One block of survey questions was directed at identifying these reasons by asking students to indicate the level of agreement with statements of the form "I am interested in engineering because engineers...". The responses and associated mean values on a response scale ranging from 1 to 5 were to build things (3.82), design things (4.21), support families (4.10), pay for hobbies (3.74), use neat equipment (3.95), help others (4.25), continuously learn (4.39), work with interesting

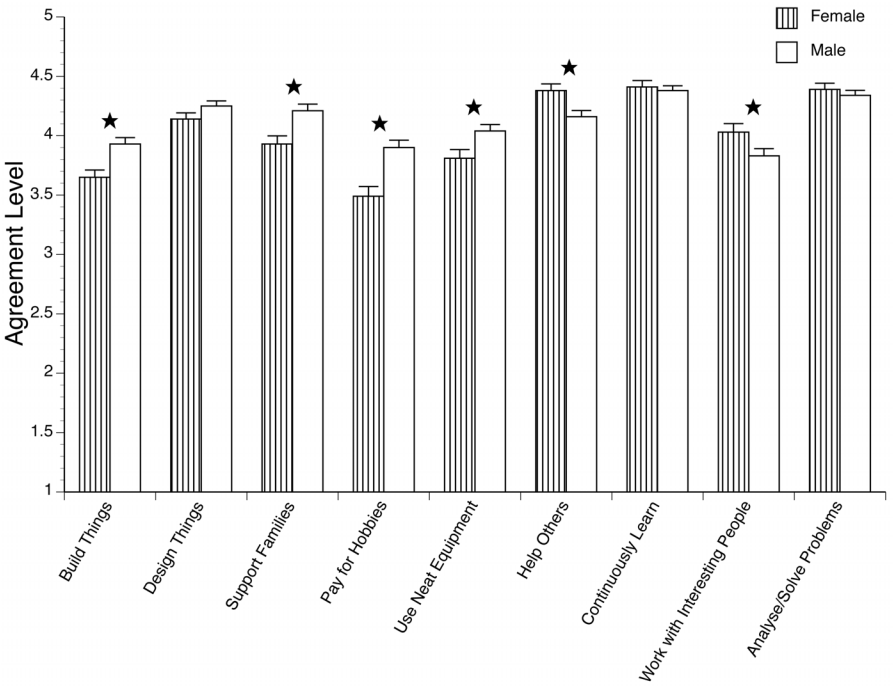

Figure 7. Motivations for becoming an engineer. Students were asked to indicate their level of agreement with the statement "I am interested in engineering because engineers...". In general, preferences were consistent with traditional gender roles, with men motivated by manipulating things and financial support, and women motivated by helping others and working with people. Statistically significant differences between men and women are indicated with stars, and error bars indicate standard errors.

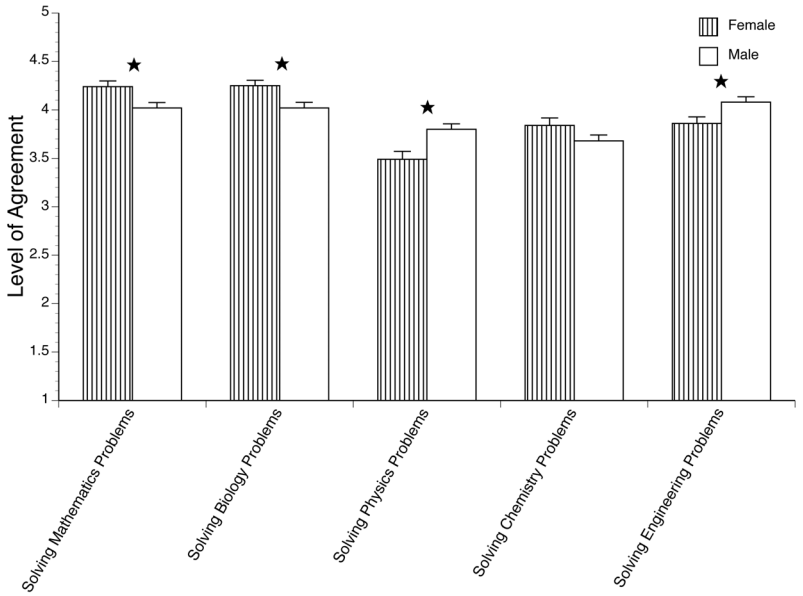

Figure 8. Student comfort in science, mathematics, and engineering. Students were asked to indicate their level of agreement with a statement of the form "I am comfortable...". Statistically significant differences between men and women are indicated with stars, and error bars indicate standard errors.

people (3.91), and analyze/solve problems (4.36). Men were significantly more interested in building things, supporting families, and using neat equipment. Women were significantly more interested in helping others and working with interesting people (fig. 7).

These results suggest several updates to the materials used to recruit more women into BBE. The first of these is emphasizing the interactions between students and between students and faculty. The second is emphasizing the benefits of BBE to society on a human level. As figure 7 suggests, these changes are unlikely to have a negative impact on recruiting men into BBE programs.

Student Comfort with Course Material

It is important to note the difference between academic preparation in a discipline and comfort in learning the material and solving problems in the same discipline. Survey respondents were asked to indicate their level of agreement

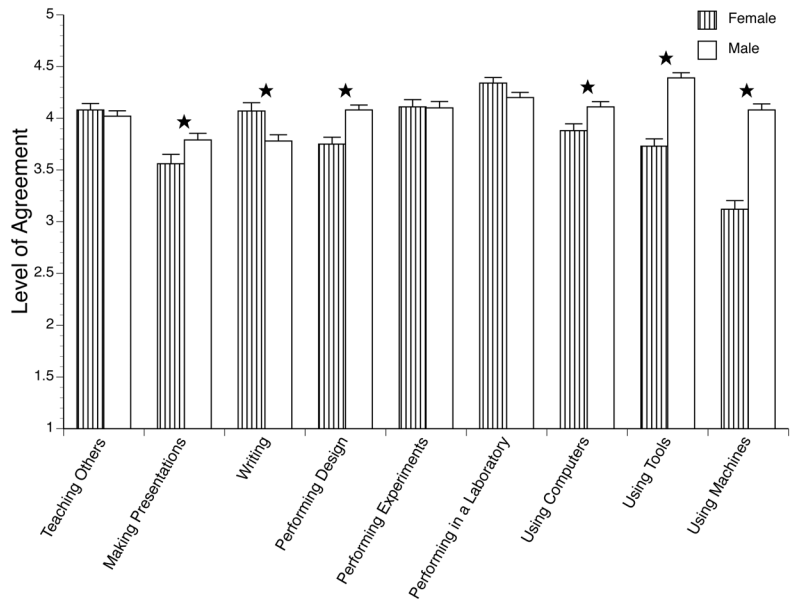

Figure 9. Student comfort in other engineering actions. Students were asked to indicate their level of agreement with a statement of the form "I am comfortable...". Statistically significant differences between men and women are indicated with stars, and error bars indicate standard errors.

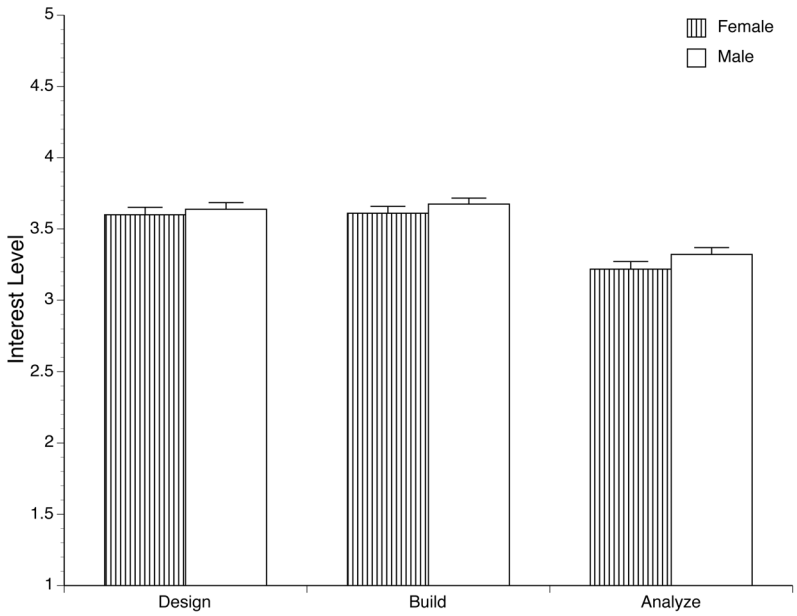

Figure 10. Build, design, and analyze comparisons to mean by gender. The mean is the average score of all participants for all questions in the category. No statistically significant differences were found between men and women. Error bars indicate standard errors.

to statements of the format "I am comfortable...". Two groups of topics were considered: solving problems related to coursework, and performing various actions associated with engineering. In general, BBE students surveyed indicated that they were comfortable learning new material related to their coursework, with means ranging from 3.68 (physics) to 4.11 (mathematics and biology), with engineering (3.99) and chemistry (3.74) in the middle. These means suggest general agreement with the statement. Significant gender differences were found for mathematics (female > male), biology (female > male), physics (male > female), and engineering (male > female) (fig. 8).

The comfort questions related to actions performed in engineering were aimed at identifying topics on which we can build on existing confidence and topics where courses need to build confidence. In communication skills, students exhibited general comfort, with mean values of 4.05, 3.70, and 3.90 for teaching others, making presentations, and writing, respectively. Significant gender differences were identified for making presentations (male > female) and writing (female > male). When examining comfort at performing design, performing experiments, and working in a laboratory, the means were 3.95, 4.10, and 4.26, respectively. The only significant gender difference occurred with performing design (male > female), although the values indicate general comfort in this area for both men and women. The final group of questions examined comfort with using things like computers, tools, and machines. In all three

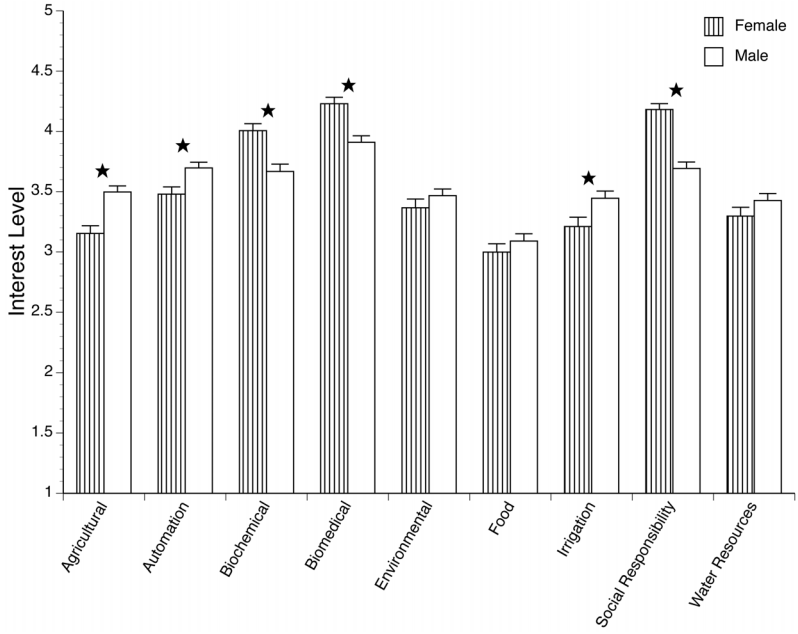

Figure 11. Engineering interests in comparison to mean by gender. The mean is the average score of all participants for all questions. Statistically significant differences between men and women are indicated with stars.

of these areas, men were significantly more comfortable than women. The overall mean values were 4.02, 4.13, and 3.70 for computers, tools, and machines, respectively (fig. 9).

The BBE Interests Matrix

A critical question is whether these gender differences are linked to the practice of engineering or to the biology-based engineering sub-disciplines in which they are practiced. To examine this question, a matrix of 29 questions was asked of the students. In responding to these questions, students indicated their level of interest in designing, building, or analyzing projects in one or more of the sub-disciplines specific to biology-based engineering.

Fundamental Engineering Activities

When the 29 questions were analyzed based on the fundamental engineering activities of building (9 questions), designing (10 questions), and analyzing (10 questions), no gender difference was found (fig. 10). That is, 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.

Activities by BBE Discipline

When these questions were analyzed based on nine different sub-disciplines of biological and agricultural engineering (agricultural engineering, biochemical engineering, biomedical engineering, environmental/ecological engineering, food engineering, irrigation engineering, machine systems/automation engineering, social responsibility applications, and water resources engineering), a statistically significant difference appeared between male and female interest levels in a T-test for equal means in six sub-disciplines. These sub-disciplines were agricultural engineering (male > female), biochemical engineering (biotechnology/bioprocessing) (female > male), biomedical engineering (female > male), irrigation engineering (male > female), and social responsibility applications (female > male) (fig. 11).

If one considers mean values less than 3.25 as indicative of low interest, then students were generally uninterested in food engineering (women and men), irrigation engineering (women), and agricultural engineering (women). The students were interested (mean greater than 3.75) in biomedical engineering (women and men), biochemical engineering (women), and social responsibility applications (women).

BBE Interests by Name

As a point of comparison, BBE students were asked to indicate their interests from a check list of sub-disciplines and career paths. The students were allowed to check multiple items on the list. Their interests were (in order of percentage indicating interest) biomedical engineering (65.3%), biological/bio-systems engineering (56.8%), biochemical engineering (biotechnology/bio-processing) (28.3%), pre-professional (pre-medical, pre-veterinary, pre-dental) (26.5), environmental/ecological engineering (22.2%), agricultural engineering (18.2%), water resources engineering (11.6%), machine systems/automation engineering (10.6%), food engineering (7.7%), engineering/technology education (7.9%), and irrigation engineering (5.2%).

It should be noted that two sub-disciplines were chosen far more often than the others: biomedical engineering and biological/bio-systems engineering. In addition, a relatively large number of BBE students were interested in pursuing a non-engineering professional degree. Significant differences in interests between men and women were identified for agricultural engineering (male > female), machine systems/automation engineering (male > female), and biomedical engineering (female > male) (fig. 12).

When the results from this question were compared with the BBE interest matrix (table 3), biomedical, biological/bio-systems, and biochemical were consistent in being high-interest areas. Food and irrigation engineering were of low interest. Two sub-disciplines exhibited differences between

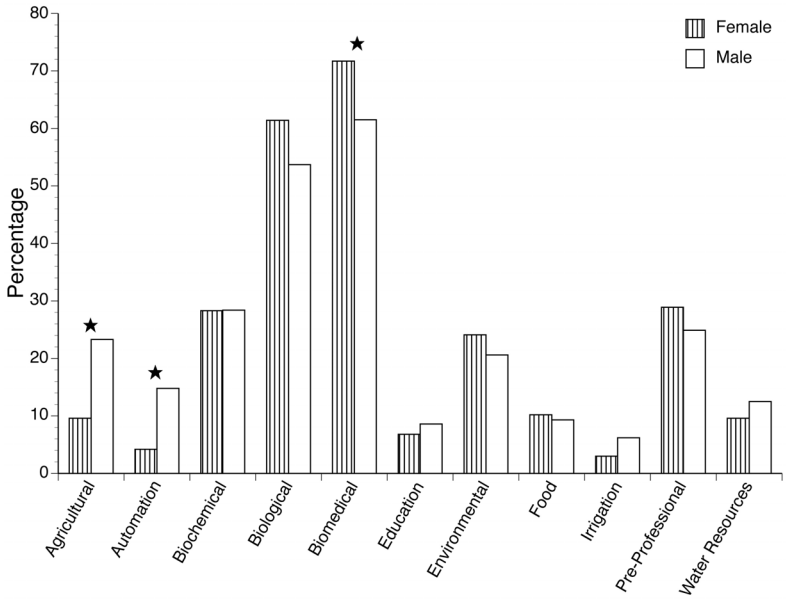

Figure 12. Self-identified sub-discipline interest areas of students in biology-based engineering by gender. Statistically significant differences between men and women are indicated with stars.

Table 3. Comparison of BAE students' order of preference for the sub-disciplines based on the BAE interests matrix and the percentage of students expressing interest in the sub-disciplines.

Rank	BAE Interests Matrix			Percentage Expressing Interest		
	Women	Men	Overall	Women	Men	Overall
1	Biomedical Engineering	Biomedical Engineering	Biomedical Engineering	Biomedical Engineering	Biomedical Engineering	Biomedical Engineering
2	Biochemical Engineering (Biotechnology / Bioprocessing)	[a]Biological / Biosystems Engineering	[a]Biological/ Biosystems Engineering	Biological / Biosystems Engineering	Biological / Biosystems Engineering	Biological / Biosystems Engineering
3	[a]Biological / Biosystems Engineering	Machine Systems / Automation Engineering	Biochemical Engineering (Biotechnology / Bioprocessing)	Biochemical Engineering (Biotechnology / Bioprocessing)	Biochemical Engineering (Biotechnology / Bioprocessing)	Biochemical Engineering (Biotechnology / Bioprocessing)
4	Machine Systems / Automation Engineering	Biochemical Engineering (Biotechnology / Bioprocessing)	Machine Systems / Automation Engineering	Environmental / Ecological Engineering	Agricultural Engineering	Environmental / Ecological Engineering
5	Environmental / Ecological Engineering	Agricultural Engineering	Environmental / Ecological Engineering	Food Engineering	Environmental / Ecological Engineering	Agricultural Engineering
6	Water Resources Engineering	Environmental / Ecological Engineering	Water Resources Engineering	Agricultural Engineering	Machine Systems / Automation Engineering	Water Resources Engineering
7	Irrigation Engineering	Irrigation Engineering	Agricultural Engineering	Water Resources Engineering	Water Resources Engineering	Machine Systems / Automation Engineering
8	Agricultural Engineering	Water Resources Engineering	Irrigation Engineering	Machine Systems / Automation Engineering	Food Engineering	Food Engineering
9	Food Engineering	Food Engineering	Food Engineering	Irrigation Engineering	Irrigation Engineering	Irrigation Engineering

[a] Biological engineering interest level is computed as the mean value of all sub-disciplines in the matrix.

their rankings by name and by application: food engineering and machine systems/automation engineering. Food engineering was more attractive to women by name than by application. Machine systems/automation engineering was more attractive to both men and women when applications were considered than when names were considered. These two instances suggest that students are sensitive to naming practices.

Conclusions

As previous studies have refuted the pipeline theory, so too has this study. Men and women are equally prepared academically to pursue undergraduate and graduate programs in engineering. This suggests that both men and women are being "fed" into the pipeline and are likely to succeed in these engineering programs. Although this finding confirms previous studies, the common assumption that

women are somehow less prepared to go into engineering makes it worth reiterating.

Although men and women in our sample are equally prepared in terms of academic coursework, there are some gender differences in how comfortable, or confident, they feel in pursuing their coursework. Women respondents are significantly more likely to be comfortable in mathematics and biology than men, whereas men respondents are significantly more likely to be comfortable in physics and engineering than women. Although these gender differences may offset each other in the end, with women more comfortable in certain areas and men in other areas, they lend some credence to previous claims that self-assessment plays a role in career decision-making and, in related fashion, in occupational segregation by gender (Clewell and Campbell, 2002; CEOSE, 2004; Correll, 2004; Xie and Shauman, 1997, 2003).

A separate and related concern is that the men in our sample indicated a significantly higher comfort level using computers, tools, and machines. This finding is an important reminder that it is not simply women's lack of self-confidence in the areas of mathematics and physics that may dissuades them from pursuing a career in engineering, but their lack of comfort and, perhaps, lack of experience with various tools and machinery that are central to engineering education and application. This study suggests that self-assessment is critical to consider, but the areas in which self-assessment comes into play are more broad than previous studies have understood.

One of the major findings of this study is that women and men are motivated to go into engineering for different reasons. Men in our sample indicated an interest in building things, supporting families, and using neat equipment. Women were motivated by helping others and working with interesting people. These gender differences were significant and consistent with the findings of others (Eccles, 2003; Pinker, 2002; Pressley and McCormick, 1995). They indicate that the interest in engineering and the motivation to become an engineer are unique to men versus women. This may help explain not only the under-representation of women in engineering as a whole, but their concentration in such sub-fields as the biology-based engineering disciplines (Eccles, 2003). An interesting question for future study is whether these gender differences emerge in other areas of engineering. It is also worth exploring how these differences might inform curriculum development and recruitment strategy. Gender-specific recruitment materials and courses that emphasize engineering's various applications are worthy of consideration.

Perhaps equally important is the lack of significant gender differences in many areas of this study. Responses to the build, design, and analyze questions indicate that the men and women surveyed were more or less interested in pursuing the same kinds of activities associated with engineering. This finding suggests that, as educators, we need not worry about the willingness of our students to learn engineering skills and that the creation of a gender-balanced curriculum for biological and agricultural engineering disciplines can (and should) be achieved without sacrificing basic engineering skills.

Although no significant gender differences emerged in terms of generic engineering activities (i.e., design, build, and analyze), our analysis indicated key gender differences in interest in specific engineering activities. The men in our sample were more likely to have an interest in agricultural, automation, and irrigation engineering activities. In contrast, the women in our sample were more likely to have an interest in biochemical engineering, biomedical engineering, and social responsibility activities. These differences suggest several methods for improving the representation of women in BBE programs. First, we need to diversify the way in which we apply engineering. For example, the inclusion of biomedical engineering and biotechnology applications courses has the potential to improve the retention of women in engineering programs. As these materials are implemented, an emphasis should be placed on the direct human benefits of engineering practice. (As a side benefit, this will broaden the base of engineering firms that can employ our graduates.) Second, these data suggest that we include these applications in our recruiting materials.

Overall, this analysis suggests that gender is important to consider in some respects, at least in the case of BBE students. The way in which gender matters is the significance of this study. Gender does not explain any difference in academic preparation, as the pipeline theory would suggest. Rather, it explains part of the difference in how comfortable students feel in various aspects of engineering education. Gender also helps explain the various motivations for going into engineering and the various interests for pursuing a career in engineering. A fruitful question for future research to pursue is how and why these differences in motivation and interest arise, and how they might be translated into the engineering curricula and recruitment material. In general, this study suggests that the lack of success in recruiting and retaining women in engineering may be linked to the arenas in which the engineering is practiced, rather than the skills and techniques that it uses.

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