FACTORS CONTRIBUTING TO THE UNDER-REPRESENTATION OF WOMEN IN PHYSICS-BASED ENGINEERING FIELDS

Julie Anne Schuck
Michele Fish

Cornell University
Ithaca, New York

INTRODUCTION

Throughout the U.S., women represent 9 to 20% of the physics-based engineering majors and 30 to 40% of the non-physics-based engineering majors. This research study is aimed at understanding the small percentage of women in the physics-based fields and the apparent bias away from physics. We collected information from undergraduate women at eight universities regarding their choice of an engineering major and their perceptions of the engineering curriculum. This paper presents some of the findings.

Definition of physics-based engineering fields

Physics-based engineering (PBE) fields require undergraduate engineering students to take more than ten physics-based courses for the completion of a major in that field. Physics-based courses require a physics course as a prerequisite or focus on mechanics, electricity, magnetism, optics, or wave phenomena. (These are the topics of introductory physics courses.) Through an examination of course catalogs for the eight universities in this study, the following engineering fields have been classified.

TABLE 1: Classification of engineering fields by physics-based course requirements

Non-PBE fields (< 6 courses)	Mid-range fields (6-10 courses)		PBE fields (> 10 courses)
Chemical Eng.	Petroleum Eng.	Eng. Science	Nuclear Eng.
Industrial / OR	Ceramic Eng.	Structural Eng.	Eng. Physics
Environmental	Biological Eng.	Marine/Naval	Electrical Eng.
Agricultural Eng.	Mining Eng.	Textile Eng.	Aerospace Eng.
Geological Eng.	Construction Eng.	Geophysics	Mechanical Eng.
Atmosphere/Ocean	Metallurgical	Civil Eng.	
	Computer	Architectural Eng.	
		Materials Science	
		Applied Math	

Evidence of under-representation of women

Women are under-represented in engineering in general. However, they are even more under-represented in the PBE fields. The following table displays the representation of women in undergraduate engineering for the United States and the eight U.S. universities in this study. Enrollment percentages from the twelve largest fields have been organized from PBE to Non-PBE fields (refer to Table 1). Notice the increase in percentages in the bottom part of the table.

TABLE 2 : Representation of Women in Engineering at 8 U.S. Universities Based on Undergraduate Enrollment Figures (1995)

	US[1]	East MC	South HC	MidW C	MidW C	MidW HC	Mtn HC	Mtn VC	West VC
Total	19%	23%	25%	16%	23%	26%	24%	20%	23%
Electrical	13%	15%	13%	8%	13%	19%	19%*	13%	13%
Aerospace	16%		16%	14%	22%	10%		21%	26%
Mechanical	12%	18%	15%	6%	18%	17%	19%*	13%	14%
Eng. Sci.	22%	9%		29%		11%	11%	28%	22%
Civil	21%	35%†	26%	19%	21%	10%	19%*	22%	
Materials Science	21%	27%	19%	10%	24%	32%	23%		
Computer	16%	13%	8%	7%		11%	21%	14%	18%
Biological	35%								39%
Chemical	33%	32%	35%	32%	37%	35%	36%	36%	28%
Industrial	29%	39%	34%	28%	31%	39%			
Agricultural	28%	44%		19%	39%				
Environmental	35%	35%†				36%			

MC, HC, VC, C = Most, Highly, Very Competitive Admissions Standards
*University lumps Elect, Mech, Struct disciplines under "Engineering" field
†University lumps Structural & Environmental disciplines under Civil

Focus of study

To develop some understanding of the under-representation of women in PBE fields, we organized this study around three questions.

1. What influences encourage a female to choose a PBE field?
2. What influences discourage a female from choosing a PBE field?
3. What affects students' attitudes toward physics?

For this study, we collected information from sophomore women in engineering at eight U.S. universities. An engineering sample was targeted to identify students who had an interest and ability for engineering. A sophomore sample was targeted to identify students who had chosen a major, who had taken at least one introductory physics course, and who would have a better recall of their pre-college experiences and freshman courses (than older students/engineers). A female sample was chosen to compare two different groups of women since much work regarding science/engineering has already been done comparing men and women. Comparisons between the PBE majors and the non-PBE majors will be used to identify what influences a female to choose or not choose a PBE major and what differences exist regarding the perception of physics.

Participants of the study

The eight U.S. universities selected for this study are characteristic of the institutions where the majority of undergraduates are likely to receive their engineering education. They range in admission competitiveness[2] and geographic region (refer to Table 2). A questionnaire was mailed to every sophomore woman in engineering at these universities. The questionnaire yielded response from 499 students. Of these, 135 participated in focus group interviews at each university. Of the larger sample, 142 and 214 students are identified as PBE and non-PBE majors, respectively. For the focus group interviews, 67 and 56 students are PBE and non-PBE majors, respectively. Detailed descriptions of the research methods and instruments will be published elsewhere.[3]

FINDINGS

Analysis of the data

Most of the information from the questionnaires could be represented as categorical frequencies and therefore was statistically analyzed using the Chi-square test. Written comments and the transcribed interviews were subjected to a process of iterative coding. Code names, which represent main points suggested in the data, are used to organize the findings. Most of the codes fall into the larger themes of engineering environment, course curriculum, physics, and influences on choice of major. Aspects of engineering and/or physics mentioned only by non-PBE majors but not by PBE majors (or vice versa) are considered significant.

Perceptions of physics

The questionnaire data shows a significant difference on "physics attitude" between the PBE and non-PBE majors. In high school, 13% of the PBE majors disliked physics whereas 27% of the non-PBE majors disliked physics ($p<0.001$). At the time they responded to the questionnaire (Spring '96, sophomore year), 35% and 55% of the PBE and non-PBE majors, respectively, disliked physics ($p<0.001$). Students indicated on average that their college physics courses have the most influence on their feelings about physics. (Other considerations were HS course, physics text, hobbies, parents, peers, and society.) Compared to 36% of the non-PBE majors, only 19% of the PBE majors find physics dull or uninteresting ($p<0.001$). PBE majors are more likely to regard physics as very practical or usable (96% vs. 89%, $p=0.002$). Both groups agree, on average, that physics is challenging, a mix of theory and application, and useful to many in addition to scientists and engineers.

In order to understand students' dislike of physics, we turn to information collected from the group interviews. Students who dislike physics tend to blame a negative experience in a HS course, the lack of preparation in a HS course, a poor physics grade, or the irrelevance of physics to their major or job. In addition, the two issues raised most often are the inability to grasp physics concepts and the teaching style of college courses. Notably, these two comments were all made by non-PBE majors. We currently do not have enough information to understand why these students aren't "grasping" the concepts, but we are in the process of collecting additional information which should provide clues. We do, however, have comments regarding the teaching of physics. The students expressed concerns about the emphasis placed on theory (derivations) compared to examples during lectures, the relevance of labs and demos to lecture, the pace of the lecture and course, and the accessibility and enthusiasm of the professor. All of these concerns are covered in more depth elsewhere.[3]

During the group interviews, students were asked which engineering majors they would never consider and why. Although other engineering fields are also being avoided, we will focus on the PBE majors. The most expressed reason for avoiding a PBE major is its resemblance to an introductory physics course. Other reasons for avoidance include the perceived difficulty of the major and a retreat from technology. Aerospace engineering has its own problems with the recent lay-offs in the field.

Comparison between PBE and non-PBE majors

Information collected from the questionnaire is presented in the following table. All significant differences between the two groups are included. A sample of the findings which are not significantly different is also included.

TABLE 3: Comparison of women in PBE majors against those in non-PBE majors

	PBE N=142	Non-PBE N=214	significant difference
Have brother(s)	59%	64%	No
Have father with Sci/Eng career	57%	36%	$p < 0.001$
Have mother with Sci/Eng career	15%	11%	No
Participated in HS sports	73%	75%	No
Participated in outside-of-school science activity	54%	48%	No
In top 25% of HS class	97%	96%	No
Took technical design course in HS	31%	19%	$p= 0.01$
Took apart/ fixed/ built	55%	41%	$p= 0.01$
Said hobbies affect feelings on physics	61%	46%	$p= 0.01$
Affect of low representation of women in engineering	31% like 10% dislike	42% like 4% dislike	$p= 0.02$
Influences on choice of major			
Math/Science aptitude	96%	97%	No
Positive experience in HS course	80%	81%	No
Negative experience in college course	42%	47%	No
Always wanted to be an engineer	46%	34%	$p= 0.04$
Strong versatile degree	84%	92%	$p= 0.03$

The verbatim data from the interviews and written comments support the statistical findings. PBE majors (especially electrical) are more likely to indicate the presence of an engineering role model. PBE majors (especially mechanical) are more likely to remember building and fixing things. In addition, PBE majors are the only ones to complain of lacking this "hobby" experience while their classmates seem to have it. PBE majors are more likely to express an interest in the subject matter of their field (computers, circuits, space shuttle, building, design, ...). Whereas non-PBE majors tend to express an appreciation for the technical background of an engineering degree but plan to go on to medical, law, or business school. The majority of women in this study (though not all) actually prefer or at least don't care about the low percentage of women. It is viewed as a challenge to succeed or as recognition of academic talent.

DISCUSSION

Women who have chosen a PBE major have a more favorable attitude toward the subject of physics than women choosing non-PBE majors. This supports our initial assumption of a bias away from physics. We find that this difference in attitude is most likely due to a lack of understanding of physics concepts and/or a lack of appreciation for teaching style on the part of the non-PBE majors. Of course, these two factors may be related since an adjustment in teaching method could possibly improve a student's ability to understand the material.[4-8] We also find the students' experiences in their college physics courses have a strong influence on their attitude toward physics. This indicates that the introductory physics courses required of all engineering students can be used to foster a favorable attitude toward physics. In this study, more of the PBE majors than the non-PBE majors had opportunities to develop an interest for engineering. More PBE majors were exposed to an engineering role model. More PBE majors were able to get hands-on experience through their own fixing/ building at home or through a technical design course in high school.

This study has shown that to increase the representation of women in PBE fields we need to expose more women to the engineering field and to increase the number of women who have confidence in their ability to understand physics.

During middle and high school, girls should meet someone who is an engineer (male or female) and participate in hands-on activities. By hands-on, we mean projects that engage students to think about the design and to physically build the project. The same sort of engagement could be applied to taking something apart. Since about 50% of our sample was never exposed to such, we encourage colleges to include hands-on projects in the freshmen engineering curriculum and to bring in practicing engineers as guest speakers. These ideas have already been implemented by many universities and women in engineering organizations.

Next, we need to address the learning of concepts in physics. Other studies have shown that "failure" in physics/engineering can be attributed to weak math skills,[9] poor study habits,[10] conflict between learning style and teaching style,[4,5] and/or conflict between alternate conceptions and correct physics conceptions.[6-8] We are currently in the process of collecting additional information that should provide clues to which of these four possibilities has the greatest effect on our sample. In the mean time, we can offer the following suggestions for college teaching which reflect our own data and current research in the area.

We observe mixed opinions on students' preferences for theoretical derivations or relevant examples. Hence, professors should strive for variety in lectures not only in content but also in teaching mode. Allowing time for students to think and participate during lectures benefits active learners and may alleviate the perception of a fast-paced course. Students complain about the lack of relevance between lecture and labs and demos. Perhaps homework problems, followed by exam questions, which pertain to the lab could be assigned in addition to the traditional text problems, forcing students to apply lecture material to lab results. Too often demonstrations are saved for the end of lecture when students put away their notes. Demonstrations should be done early in the lecture. Students should be given ample time to think and write down what they saw and why they think it happened. Then the professor should explain what happened. Students complain about the lack of approachable and enthusiastic professors. Professors can appear more enthusiastic and approachable if they can learn students' names (when possible), hold non-conflicting office hours, drop in on labs/recitations, and take students' questions seriously.

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