Y B ME?: An analysis of the status of women in mechanical engineering and the Women's Technology Program as a potential long-term solution

by

Christina Chestnut

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ABSTRACT

The issue of the lack of women in the fields of science and engineering has recently received new attention by the scientific and women's studies communities alike. In fields such as Mechanical Engineering there continues to be a marked lack of women, especially when looking at higher levels of academia. One solution that has been suggested is to provide young women with a pre-collegiate introduction to engineering and also to give them opportunities to be in contact with women in the field. The Women's Technology Program (WTP), a summer program for girls who have just finished their junior year of high school, was originally created to help solve this problem in the Electrical Engineering and Computer Science department at MIT. Due to its apparent success in the four years of its existence, it was felt that the development of such a program in the Mechanical Engineering department at MIT might be a worthwhile effort. The WTP in ME will contain an overview of many of the topics of mechanical engineering, with an emphasis on critical thinking and problem solving, two skills that are invaluable to engineers and are rarely taught below the university level.

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Cynthia Skier, you were willing to give me a chance two summers ago in your still-budding Women's Technology Program. You have been so great in helping out the new program and with providing me information for this thesis. Thanks for your never-ending support.

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Contents

Introduction

At the moment, there are very few women in mechanical engineering, from undergraduate students, to graduate students, to faculty, and to industry. There are various theories for why this should be the case, and these reduce either to an essentialist view of women and their "natural-born aptitudes" or to the discrimination against women and their socialization not to be engineers. The fire of this essentialist/social constructionist debate was recently refueled by remarks made in January 2005 by the president of Harvard University, Lawrence H. Summers, in his speech for the National Bureau of Economic Research Conference on Diversifying the Science and Engineering Workforce. The basis of his speech was the following:

> Twenty or twenty-five years ago, we started to see very substantial increases in the number of women who were in graduate school in this field [professional programs]. Now the people who went to graduate school when that started are forty, forty-five, fifty years old. If you look at the top cohort in our activity, it is not only nothing like fifty-fifty, it is nothing like what we thought it was when we started having a third of the women, a third of the law school class being female, twenty or twenty-five years ago. And the relatively few women who are in the highest ranking places are disproportionately either unmarried or without children, with the emphasis differing depending on just who you talk to.[1]

These observations are reiterated in commentary by the former Dean of Undergraduate Education and now head of the Science, Technology, Society Department of MIT, Rosalind Williams from her 2002 book *Retooling: A Historian Confronts Technological Change*:

> Most women are no longer explicitly told that they have to make a choice between family and work (or, more precisely, between a balanced human life and professional success as defined in today's marketplace), but they get the message anyway. The various women's committees now operating at MIT have spent a lot of time negotiating access to salary data, to ensure

[1] Lawrence H. Summers. "Remarks at NBER Conference on Diversifying the Science & Engineering Workforce." National Bureau of Economics Research. Cambridge, MA. 14 January 2005.

> that men and women are being paid equally. The pay disparities they have found, however, are minor compared to this disparity: in the School of Engineering, approximately half of the women faculty members have children, while four out of five of the men do.
> Women do not drop out of engineering, as they go on in life, because they are worried about being paid less or getting less in benefits. They drop out because the more they look at the world they are headed for, the less they want to live there.[2]

The speech outlined Summers' reasons for the above-quoted observation, that of the lack of women seen in the professional, science, and engineering fields. He assigned much of the reasoning for the lack of women in science and engineering to their essential inaptitude for and "natural desires against" such matters:

> So my best guess...of what's behind all of this is that the largest phenomenon, by far, is the general clash between people's legitimate family desires and employers' current desire for high power and high intensity, that in the special case of science and engineering, there are issues of intrinsic aptitude, and particularly of the variability of aptitude, and that those considerations are reinforced by what are in fact lesser factors involving socialization and continuing discrimination.[3]

In light of these statements, it seems almost impossible that there would not be a backlash. This has come in the form of speeches, conferences, papers, studies, and any other form of rebuttal imaginable. In some ways, it seems that Summers should be thanked for raising the consciousness of a problem that many thought had been solved or thought was well on its way.

The Women's Technology Program, a four-week summer program for high school-aged women run and taught by women students at the Massachusetts Institute of Technology (MIT), has simply brought the essentialist/social constructionist battle into the realm of study and practice. The idea behind the program is to inspire young women

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[2] Rosalind Williams, *Retooling: A Historian Confronts Technological Change.* Cambridge, MA: The MIT Press (2002) 202-203.
[3] Lawrence H. Summers. "Remarks at NBER Conference on Diversifying the Science & Engineering Workforce." National Bureau of Economics Research. Cambridge, MA. 14 January 2005.

who may have a general interest in math and the sciences to consider engineering by showing them, in an all-girls environment, what it really is. The point is not to force women to go into a field which they do not desire to study, but, as is the goal of feminism in general, to make sure that these women are making an educated choice on what they want to do. Uninformed decisions, or those made in the face of discrimination and outside pressure, cause many women to be lost them to the so-called "soft" sciences of chemistry and biology and to the humanities simply because they see no role models in engineering have lost the motivation to be seemingly the only women in their field.

What follows here is an analysis of the status of women in mechanical engineering today, both as undergraduate students, graduate students, and faculty members at MIT and as graduate students and faculty members at large. There is a description of the current Women's Technology Program in the Electrical Engineering and Computer Science Department at MIT and the outline of the pilot program in the Mechanical Engineering Department. A sample lesson plan for one of the days of study is included as well as a plan for the future of the Women's Technology Program as a whole.

Mechanical Engineering Today

There are currently almost 100 women undergraduate students majoring in Course II (strict mechanical engineering major) in the Mechanical Engineering Department at MIT. This figure would be encouraging if it represented a growth from recent time past, however, as can be seen in Figure 1 below, this number (approximately 30% of the Mechanical Engineering undergraduate population) is almost unchanged from the last five years.

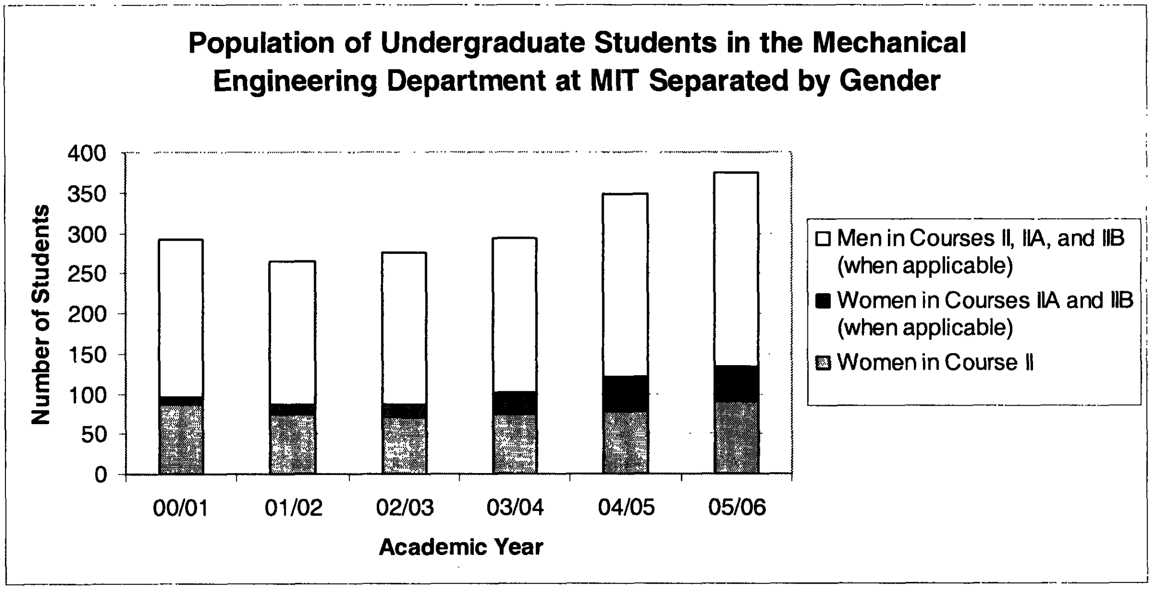

Figure 1: Population of undergraduates in the Mechanical Engineering Department at MIT separated by gender. Course IIB was no longer offered as a degree after academic year 2002/2003. Course IIA, although always offered, only received accreditation during academic year 2003/2004. These numbers are taken from fifth week surveys by the registrar.[4,5]

The change that can be seen from this data, however, is the number of women students who have entered the IIA program. This program within the mechanical engineering department is one in which certain core requirements of the original mechanical engineering major are kept, but the student must also take courses which form a separate concentration. The most popular "track" for the concentration is biomedical engineering and pre-medical, with 35% of the IIA students pursuing these areas.[6] These areas are seen as predominantly female:

> National figures...support the preference of women for branches of engineering that focus on environmental and biological problems. There is a similar lopsidedness in enrollments in the School of Science [at MIT],

[4] "Number of Students by Course and Year." 10 May 2006. <http://web.mit.edu/registrar/www/stats/yreportfinal.html>
[5] "Number of Women Students by Course and Year." 10 May 2006. <http://web.mit.edu/registrar/www/stats/womenfinal.html>
[6] "ME at MIT: Course 2A." 10 May 2006. <http://www-me.mit.edu/UGradProgram/Course2A.htm>

> where women overwhelmingly prefer biology, environmental science, and neuroscience to physics or math.[7]

The question is then truly what is a preferential choice in terms of careers and interests, and what is a choice made by the presence of subtle and insidious bias and discrimination; for, such programs as IIA may simply be ways of making an otherwise abstruse subject as mechanical engineering more accessible to everyone because the program is flexible to the needs and desires of the student.

There is much more depressing news from the world of graduate school. In the 2004 application pool to the mechanical engineering graduate department, there were 633 total applications, of which only 87 were women (13.7%).[8] These women tended to fare worse in the admissions than their male counterparts (37 women admitted out of 192 total, which is 19.3% for women versus 28.4% for men)[9], and 22 of those women registered in the fall of 2005 (out of 106 total who registered, 20.8%).[10] As can be seen below in Figure 2, however, the population of graduate student women still remains at approximately 15%, which is lower than the 20% figure of the registered incoming female students.

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[7] Rosalind Williams, *Retooling: A Historian Confronts Technological Change,* Cambridge, MA: The MIT Press (2002) 207.
[8] "Mechanical Engineering at MIT – Admissions Statistics." 10 May 2006 <http://www-me.mit.edu/GradProgram/GradStatistics.htm>
[9] Ibid.
[10] Ibid.

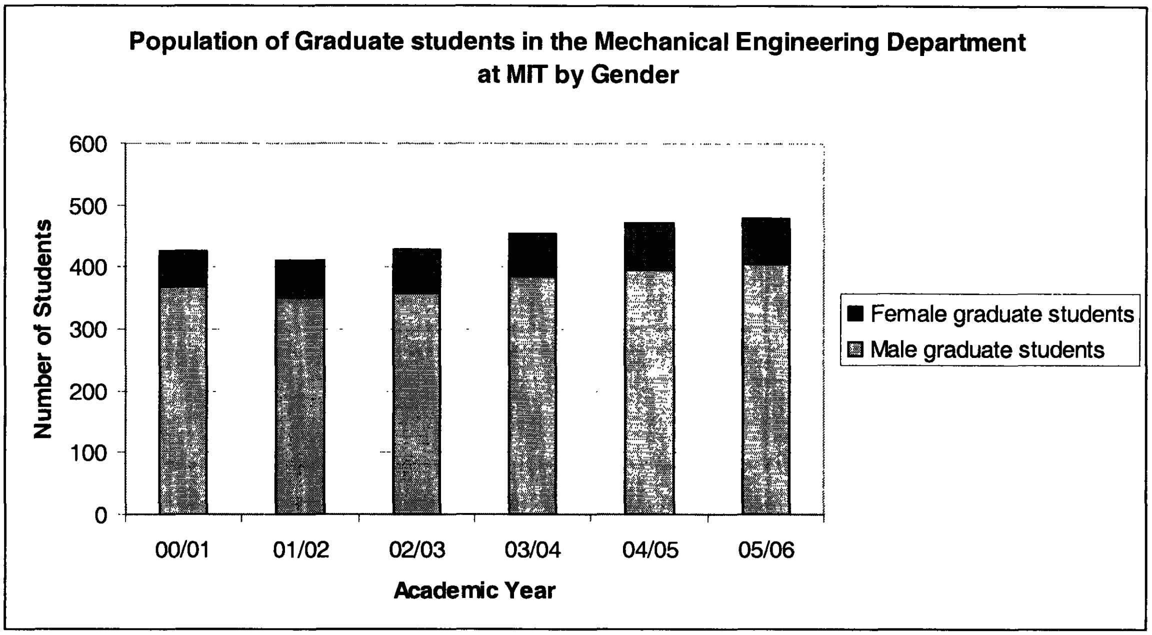

Figure 2: Population of graduate students in the mechanical engineering department at MIT by gender. These numbers were taken from fifth-week surveys done by the registrar in the fall of the academic years indicated.[11,12]

Considering the ideas presented in the introduction, the information in Figure 2 is rather expected. A more interesting question, therefore, comes not from Figure 2 but from Figure 3 (seen below), in which is presented the population of female graduate students in the MIT Mechanical Engineering Department as divided by degree program (either Master's degree or PhD).

[11] "Number of Students by Course and Year." 10 May 2006. <http://web.mit.edu/registrar/www/stats/yreportfinal.html>

[12] "Number of Women Students by Course and Year." 10 May 2006. <http://web.mit.edu/registrar/www/stats/womenfinal.html>

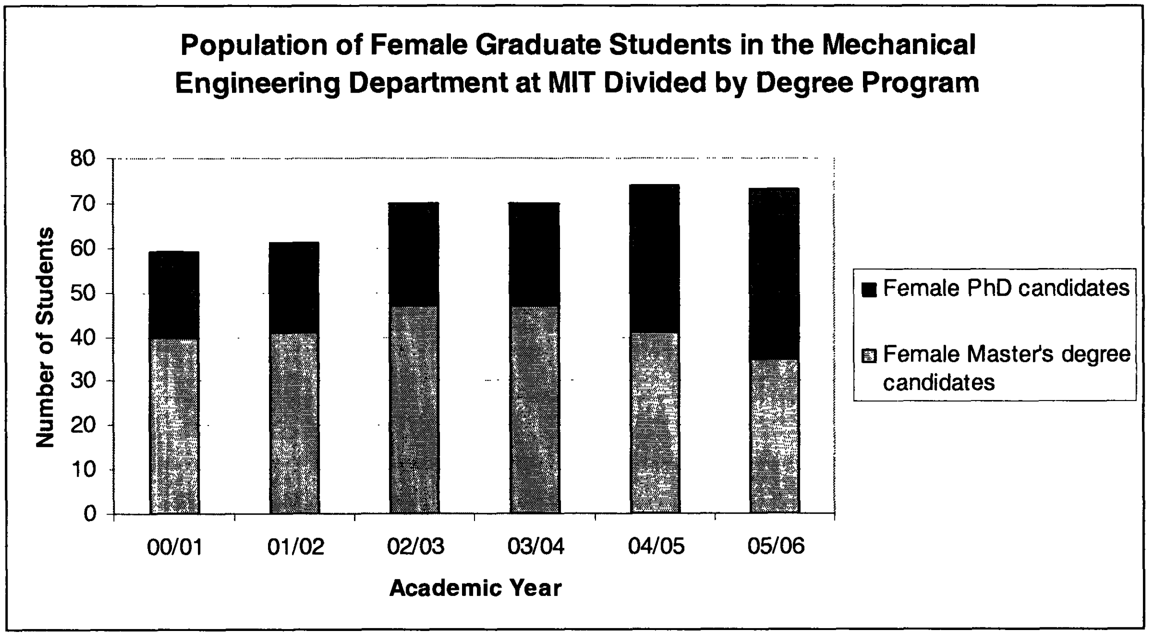

Figure 3: Population of female graduate students in the mechanical engineering department at MIT divided by degree program.[13,14]

As the population of the graduate program has grown over the past six years, so has the number of women, approximately proportionally. The number of women students in the Master's program, however, has remained approximately constant at 40 students, while the PhD program is much smaller, and has, in fact, been growing. Why is it that the PhD program, which has approximately as many students as the Master's program (around 200 each), has had so many fewer female students?

One theory is the marginalization of women in higher levels of academia. A study published in *Nature* magazine in May of 1997 showed that there is, in fact, a great deal of sexism that occurs in the peer-review process (specifically in that of the Swedish Medical Research Council). The two researchers performing the study catalogued all of the applicants to this council for one year, and then they created a system of scoring to

[13] "Number of Students by Course and Year." 10 May 2006. <http://web.mit.edu/registrar/www/stats/yreportfinal.html>
[14] "Number of Women Students by Course and Year." 10 May 2006. <http://web.mit.edu/registrar/www/stats/womenfinal.html>

objectively evaluate the productivity of each candidate. A multiple-regression analysis was then performed in order to rule out the interdependence of different productivity variables.

> According to the multiple-regression model..., female applicants started from a basic competence level of 2.09 competence points [on a scale from 0 to 4]...and were given an extra 0.0033 competence points by the reviewers for every impact point they had accumulated. Independent of scientific productivity, however, male applicants received an extra 0.21 points for competence. So, for a female scientist to be awarded the same competence score as a male colleague, she needed to exceed his scientific productivity by 64 impact points....This represents approximately three extra papers in *Nature* or *Science*..., or 20 extra papers in...an excellent specialist journal....Considering that the mean total impact of this cohort of applicants was 40 points, a female applicant had to be 2.5 times more productive than the average male applicant to receive the same competence score as he.[15]

Unlikely this is only the case for the Swedish Medical Research Council.

In a larger context of women in academia, out of the nine female faculty members in the mechanical engineering department at MIT, only two of them are full professors. The other seven are assistant professors, an entry-level, non-tenured position. This is as related to the total number of faculty (91), with 62 fully tenured professors and only 11 assistant professors. Women are, therefore, very much underrepresented in the tenured faculty and are largely overrepresented in the more tenuous position of non-tenured faculty.

The untenured female faculty in the Mechanical Engineering Department were hired over the last few years in an initiative to improve the situation in the Department when it was found to be the most unfriendly toward hiring female faculty in the 2002 Report of the School of Engineering done in response to the study done by Nancy

[15] Christine Wennerås and Agnes Wold. "Nepotism and sexism in peer-review." *Nature* v.387(22 May 1997): 342.

Hopkins, a professor of biology at MIT, in 1999 noting the discrimination against women in the school of science.

> In Mechanical Engineering, however, while women have been hired onto the faculty, only one of the five ever hired up until 2001 is still at MIT [as of 2002]. The first woman was hired by the department in 1987 and is now a full professor with an endowed, 5 year, chair in the department. All of the other four women hired between 1987 and 2000 have left MIT. Mechanical Engineering hired another woman faculty member in 2001.[16]

In addition, in the MIT School of Engineering in general, marginalization of faculty has been seen in many ways:

> In our interviews with women faculty, we heard of women not being included in research activities (e.g., participation in group research grants or PhD thesis committees) and in departmental activities (e.g., women never being invited to give a presentation at annual departmental retreats; lack of representation on influential committees). Some women noted that they were asked to teach lower level undergraduate subjects rather than specialized graduate subjects relating to their own research. Some were asked to change their teaching assignments more often than their male peers.[17]

Additionally, there is one area in the Mechanical Engineering faculty that is completely lacking in women, and that is the Product Realization area.[18] This is rather frightening, considering the fact that out of all of the undergraduate course requirements at MIT, the most come from the field of design and manufacturing (all within the generalized field of Product Realization). When this is considered in conjunction with Rosalind Williams' observations, the result is stunning: "the fact that an increasing number of women participate in engineering is both fine and irrelevant, if the cult of

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[16] Boyce, Chisolm, et al. *Report on School of Engineering*. 2002 <http://web.mit.edu/faculty/reports/pdf/soe.pdf> p. 12
[17] Ibid, 4.
[18] "Mechanical Engineering at MIT – People." 10 May 2006. <http://www-me.mit.edu/People/Data/Faculty.html>

innovation defines a distinctive technological arena where men and masculinity dominate."[19]

In the wider world, similar observations to these can be seen. In a report done by Dr. Donna J. Nelson of the University of Oklahoma in 2005, the number of women receiving PhD degrees and those in faculty positions of various levels were tabulated, to alarming results, seen in Table 1 below.

Table 1: Female PhD's by Year of PhD Attainment[20]

Discipline	1983-1992	1993-2002
Chemistry	22.8%	31.3%
Math	20.5%	27.2%
Computer Science	17.9%	20.5%
Astronomy	12.7%	20.6%
Physics	9.0%	13.3%
Chemical Engineering	14.4%	22.3%
Civil Engineering	10.2%	18.7%
Electrical Engineering	6.4%	11.5%
Mechanical Engineering	6.0%	10.4%
Economics	22.4%	29.3%
Political Science	31.0%	36.6%
Sociology	51.1%	58.9%
Psychology	55.0%	66.1%
Biological Sciences	36.5%	44.7%

Although the rates of PhD attainment have risen considerably in the last twenty years, the rates for women in the field of mechanical engineering is still the lowest in the chart, with engineering being the segment in which the fewest women by percentage are earning PhD's at all.

The data pertaining to faculty positions nationwide are also astounding. Seen below in Table 2, the numbers of professors, especially in the engineering disciplines

[19] Rosalind Williams. *Retooling: A Historian Confronts Technological Change*. Cambridge, MA: The MIT Press (2002), 210.
[20] Donna J. Nelson and Diana C. Rogers. "A National Analysis of Diversity in Science and Engineering Faculties at Research Universities." 2005. <http://www.now.org/issues/diverse/diversity_report.pdf>

decrease as the level of tenure increases. This is therefore a problem with the system overall, not just at MIT.

Table 2: Female Science and Engineering Faculty by Rank[21]

Discipline	Assistant Professor	Associate Professor	"Full" Professor	All Ranks
Chemistry	4.1%	3.0%	5.1%	12.1%
Math	2.8%	2.4%	3.1%	8.3%
Computer Science	2.8%	3.8%	4.0%	10.6%
Astronomy	3.4%	2.6%	6.5%	12.6%
Physics	1.5%	1.4%	3.8%	6.6%
Chemical Engineering	3.8%	4.0%	2.7%	10.5%
Civil Engineering	4.8%	3.2%	1.8%	9.8%
Electrical Engineering	1.8%	2.5%	2.2%	6.5%
Mechanical Engineering	2.5%	2.3%	1.8%	6.7%
Economics	4.3%	3.0%	4.2%	11.5%
Political Science	8.6%	8.2%	6.7%	23.5%
Sociology	12.6%	11.0%	12.2%	35.8%
Psychology	9.6%	8.4%	15.4%	33.5%
Biological Sciences	6.3%	5.4%	8.5%	20.2%

All of these data point to a very alarming pyramidal trend: as one rises higher on the ladder of academia, the number of women decreases dramatically, both as a percentage and in actual numbers. The real questions then become why has this happen, why is this still happening, and what can one do to alter this trend.

The Women's Technology Program

The Women's Technology Program (WTP) in the Electrical Engineering and Computer Science (EECS) Department at MIT is a summer program for high school girls who have just completed the eleventh grade. The mission of the program is "to spark high school girls' interest in future study of engineering and computer science."[22] The WTP was originally created as a thesis project for EECS graduate student Douglas Ricket. He saw the need for women in his experiences a graduate student and teaching

[21] Ibid.
[22] "MIT Women's Technology Program." 10 May 2006 <http://wtp.mit.edu>

assistant (TA) at MIT: "In the summer of 2001 I taught electronics to a high school group of 30 boys and only 1 girl, and as TA for 6.034 [Artificial Intelligence] in fall 2001, all 9 instructors were male and only 6 of my 50 students were women."[23]

The WTP has, to date, been very successful, from the numbers and also from the perspectives of the students. Of the students who chose to go to MIT after participating in the WTP, the most popular major was EECS (7 students), with mechanical engineering being second (3 students).[24] Overall (including students who chose to attend other universities than MIT), there are 21 students majoring in electrical engineering and/or computer science, and 12 students majoring in some form of engineering (excluding electrical engineering).[25] This trend suggests that perhaps there is a need for a program specializing in mechanical engineering to serve the students who want a more broad understanding of engineering in general before deciding on a specific field. In addition, the students in the EECS program had to do a design project that involved creating electro-magnetic motors in the Pappalardo Lab, and many of them enjoyed this section greatly (for a number of them, this was their favorite part). This seemingly new-found like for design and building also leads one to believe that many of these girls had simply never been exposed to that kind of activity before, and so introducing the students to this as an entire program seemed like a good idea. The goal is to have the girls who participate learn something new about themselves and to discover new careers and opportunities that they had never understood before.

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[23] Douglas Ricket. "The Women's Technology Program: EECS Outreach for High School Students." Diss. Massachusetts Instituted of Technology (2002): 7.
[24] From follow-up surveys given to the former students by Cynthia Skier, the WTP program director.
[25] Ibid. Out of a total number of 67 students for which data was available.

There has been such a great interest in the Women's Technology Program – there are hundreds of applications every year – that it seemed like a good idea to try and expand the program. Growing too much larger in the area of electrical engineering and computer science seemed like it might expand beyond its means, especially in terms of staffing, but expanding into a new field looked very promising, especially considering the interest showed in the subject matter by the students within the EECS program. Currently the EECS WTP is under the direction of Cynthia Skier, who is an administrator in the EECS department, and she has been acting as a consultant to the new program. She has agreed to be the behind-the-scenes director for the WTP in ME, but Barbara Hughey has been working as the advisor and director to the creation of the WTP in ME.

The Women's Technology Program in Mechanical Engineering is meant to give young women who are inspired by or maybe simply intrigued by the prospect of creating things the opportunity to learn about mechanical engineering in an all-female environment, which may encourage the girls to speak up, question, and learn more than in a situation that is dominated by their male peers. The broad but not shallow curriculum will also allow the students to be introduced and to understand many concepts in engineering that many young men have already been shown or simply absorbed through their interactions with older men in such venues as the tool-shed or garage. The all-female environment will allow the students to see and work with women who are in academia and who may serve as their role models for moving forward in engineering.

Program Overview

The program will have two main components – educational and social. The educational part is comprised of two classes – one called Y B ME? (Why be M.E.?) and one that will be called the math class. The Y B ME? class is essentially an overview of many of the topics that are found in mechanical engineering with enough depth to make it possible for the students to use what they have learned in a capstone project. The math class contains some theory supporting the Y B ME class, but it also features many experiments to verify the theory in practice. The math class will comprise one "period" of the day (one and one-half hours), and the M.E. class will be double that.

The residential (social) part of the program is something that is already largely in place from the EECS version of the WTP. The two programs will be sharing the same space in the McCormick dormitory (although they will be on separate floors), and they will be sharing some of the same residential staff. This will enable there to be some interconnection between the two groups, although the students will not be taking the same classes, and there is no plan to integrate the program to the point of course selection.

The non-residential social aspects of the WTP in ME will be similar to those of the WTP in EECS, although they will include more mandatory field trips. The mechanical engineering version of the WTP has a great emphasis on the hands-on experience along with applied learning, such as facility tours, both within academia and without.

Curriculum Outline

The curriculum is designed to introduce the students to as wide a variety of mechanical engineering topics as possible without overburdening the students with too much high-level information. The courses are meant to be overviews that nonetheless give enough depth to spark interest and have the students feel that they have learned a great deal. The main topics that will be covered are the following:

- Problem-solving in general, with emphasis on trade-offs and decision-making
- Basic physics (electricity, mechanics, energy)
- Mechanics of materials
- Thermodynamics/fluid mechanics
- Manufacturing
- Big things and small things (e.g. MEMS and bridges)
- Design and drawing
- Matlab

These topics will be addressed both from the mathematical side and from an engineering perspective so that the theory can be matched with experimentation. The emphasis on physicality is very important, for many of the students will come here without having done any hands-on experimentation, and the tangible aspect is critical to the engineering experience.

There will be several ways in which the real-life aspects of engineering will be demonstrated in this course. Professors and graduate students in the department who are performing research that pertains to the above-mentioned topic list are being asked to give lab tours or guest lectures to show the students the applications of the topics they are surveying. In addition, there will be a field trip to the Otis Elevator Company test facility in order to show the students what a real-life engineering facility is like.

There will be capstone projects in both the ME class and the math class. The math project will include the use of Matlab to evaluate the economic, temporal, and feasibility tradeoffs for a given design problem. The project in Y B ME? will be to build hovercrafts in two teams. The teams will each have a variety of tasks to accomplish with the hovercrafts they build, such as to go forward the fastest, fly the highest above the ground, have the best maneuverability, and carry the heaviest weight.

Math Syllabus

The math course syllabus was developed this past winter to accommodate the perceived needs of both the Y B ME class and the students as they are entering the program. It is divided into twelve one and one-half hour lectures, with the remaining five lecture periods being devoted to the final projects. An outline of the dates and lecture topics is shown in Table 3 below, with full explanations in the subsections below that.

Table 3: Outline of the math class syllabus for the WTP in ME.

Date	Lecture Number	Title
Monday, June 26	1	Word Problems
Tuesday, June 27	2	Review of Pre-calculus
Wednesday, June 28	3	Current, Voltage, and Resistance
Thursday, June 29	4	Ohm's Law/Intro to Physics
Friday, June 30	5	Math of Physics
Monday, July 3	6	Math of Manufacturing
Wednesday, July 5	7	Intro to Systems of Equations
Thursday, July 6	8	Conversion of Systems to Matrices
Friday, July 7	9	Intro to Matrices
Monday, July 10	10	Matlab Syntax
Tuesday, July 11	11	Matlab to Solve Systems
Wednesday, July 12	12	Practice with Matlab

Monday, June 26 (Lecture 1) – Word Problems

This is the first day of their classes. The students will be learning problem-solving techniques using several problems that we give them. There will also be a discussion of the analysis of the information given in a problem, such as the quality of the data given, and whether there is too much or too little information in a problem. They will also be introduced (hopefully re-introduced) to the idea of estimation and ways to figure out if the answer they find at the end of a problem is reasonable.

A second big topic of this lecture will be a discussion of units. The students will be given a very extensive list of units and their meanings along with a physical idea of what the quantity measures. They will be required to use dimensional analysis in the problems they are given, either to get the answer or to figure out a reasonable approximation of the answer.

Tuesday, June 27 (Lecture 2) – Review of Pre-calculus

In this lecture, the main focus is a review of the concepts that they should have learned in pre-calculus, which include exponents and e, logarithms, trigonometry and graphs of all of these types of functions. These are very important topics, for they form the basis of the concepts that the students will be learning with reference to calculus and all of the physics and graphical analysis that they will do.

Wednesday, June 28 (Lecture 3) – Current, Voltage, Resistance

The basis of mechanical engineering includes not only the physical concepts of how bodies move, but it also includes the fundamentals of electrical engineering. At the highest levels of mechanical engineering and electrical engineering, the subjects are highly interconnected. Since Ohm's Law, which relates the current and voltage in a circuit by a constant of proportionality known as resistance, is the most basic law in electrical engineering, it seemed to be a good place to start. This lecture will cover the basics of voltage, current, and resistance, giving many intuitive examples, such as the water analogy for voltage.

Thursday, June 29 (Lecture 4) – Ohm's Law/Intro to Physics

Since the concepts of current, voltage, and resistance are relatively complicated for those new to the subject, the actual description of Ohm's Law will be today instead of the day before. After Ohm's Law has been verified experimentally through experimentation with small experiments and the Vernier software (to look at voltage-current curves), the students will be introduced to the basic concepts of physics. These will include an outline of Newton's three laws (inertia, F=ma, and balance of forces), a discussion of different kinds of forces and free body diagrams with some simple problems for homework.

Friday, June 30 (Lecture 5) – Math of Physics

This lecture will be a conclusion to the one from the day before. Any information that is not covered will be finished here, and the students will also do a Ball Drop Experiment.[26] This is a fairly simple experiment that will help to solidify the ideas of basic two-dimensional mechanics (focusing on trajectories) while at the same time familiarizing the girls with the Vernier software and how to use the Excel to graph data and fit it with trend lines. These data will be used again later to show the students how to graph with Matlab.

Monday, July 3 (Lecture 6) – Math of Manufacturing

The focus of this lecture will be on the various ways of manufacturing and how the layout of factories affects their output productivity. There has been extensive research into how the size of storage between operations and the different types of layouts, such as job shop versus streamlined manufacturing, affects the output productivity of various manufacturing systems. This is not exactly applicable to the

[26] See Appendix A

manufacturing facility that the students will be visiting, but it is highly relevant to manufacturing in general and will give them something to look for when they are at the Otis Elevator facility.

Manufacturability is also an important consideration in design, therefore talking about mass-production of goods will be a good start to their thinking about creating things to be built on a larger scale than that which will be covered in the design portion of this course. In addition, the ideas of waste streams, end-of-life, and environmental impact are very relevant to how things are manufactured today, and so they should, at least, be touched on once during the course.

Wednesday, July 5 (Lecture 7) – Intro to Systems of Equations

Today the students will review systems of equations and how they can be put together from a given word-problem or physical situation. This is also an introduction to modeling (as in, deducing what part of a problem is important, relevant, and should be discussed and utilized as something to be solved). It will involve the review of problems similar to the ones covered in the first lecture, only this time the solutions will be more formalized and process will be encouraged (so that the students will be able to follow in the upcoming lectures on matrices. The samples problems will come from the realm of mechanics of materials to help reinforce the topic, which will be the one presented in the Y B ME? class.

Thursday, July 6 (Lecture 8) – Conversion of Systems to Matrices

This will be an introduction to how matrices are created from systems of equations. The conversion will involve lining up the variables such that the coefficients can be considered separately. The coefficients (for now) will only be 2x1 matrices so that matrix multiplication need not be known in order to discuss these problems. The example problems and homework from today's lecture will be taken from the subject of static fluid mechanics, for that will be the featured focus of the Y B ME? lecture.

Friday, July 7 (Lecture 9) – Intro to Matrices

In this lecture, we will be working on the basics of matrix algebra (addition/subtraction, multiplication, inverses, determinants, etc.) and matrix properties (non-commutativity of many operations, etc.). In addition, the meaning of vector solutions will be discussed: for instance, if a 2x1 matrix is found to be a solution, the students will be shown that the first entry represents the result of the first variable and the second entry corresponds to that of the second variable. Now the students should be able to take problems all the way from words, to systems, to matrices, to solutions.

If it is desired, some examples can come from the Discrete Math class from the 2005 WTP in EECS. The instructor, Corey Kemper, used examples from her work in imaging to show how matrix algebra works visually. For instance, a multiplication of a matrix by a constant number greater than 1 corresponds to a darkening of the image. This was a really interesting way of showing how matrices work from a completely different perspective, which may be very effective in solidifying the difficult new concepts relating to matrices.

Monday, July 10 (Lecture 10) – Matlab Syntax

Today's focus will be on how to use Matlab in general. The students will be taught how the program works and some basic command-line and script-writing skills along with the syntax of Matlab. They will be introduced to some of the concepts of computer programming, such as variable declarations and appropriate punctuation, for it is necessary even when writing very short and easy scripts. Graphing will also be demonstrated, for they will need it the next day. If the students grasp these concepts easily, there is the possibility of teaching the students how to write functions as well.

Tuesday, July 11 (Lecture 11) – Matlab to Solve Systems

Most of this lecture will be dedicated to problem-solving and additional individual or pair work on the solution of problems with Matlab. The students will be introduced to both the Help menu in Matlab and to the demos available both through the program and also at the Mathworks website. These demos are very good, and it will begin to enable the girls to be more self-sufficient. It will allow those with further abilities to delve deeper into Matlab and to see how powerful and filled with possibilities it is.

Today the students will also be asked to re-analyze their data from the Ball Drop Experiment in Matlab. This will give them yet another tool with which to look at data which has different strengths and weaknesses from Excel. Again, this is not only to help show them how new tools work, but it will also help to educate the girls in how to decide what the most appropriate method is for doing their own data analysis.

Wednesday, July 12 (Lecture 12) – Practice with Matlab

This is the last day of official lectures in the Math class. The girls will be introduced to their final project, which will focus on design choices and trade-offs when analyzed with various costs are associated with aspects of the design project. For example, the design may call for a body made of metal. If aluminum is chosen as this metal, then it will be easier to machine, and therefore cost less than steel in terms of manpower required and, potentially, in terms of environmental impact (less cutting fluid used and disposed of) to complete the project. On the other hand, aluminum is much more expensive to start out with than steel. The students will then have to associate cost structures based on their research into reasonable values for such things as machining costs and cost of goods. Other areas to investigate include how the number of goods to be produced affects these costs as well, for then the possibility of automation comes as a viable option. Matlab can (and should) be used as a tool throughout this project for solving the simultaneous equations that the girls will write to describe their design and manufacturing situations.

This project will hopefully shed some light on the challenges of being a designer or an engineer. It will also attempt to incorporate much of what the students have been taught during the summer and serve to reinforce the very important concept of tradeoffs. It will also be a way to show the students various online search engines such as Matweb for finding material data and get them to think critically and originally about how to define the solution to the problem. These girls are used to there being only one right answer, but that will not be possible here, and that is something that should be emphasized a great deal in this project: as long as the solution that is found can be defended with data and logical analysis, it is correct (although it can also be shown that some solutions are, in fact, better than others given particular constraints).

Conclusions and Future Plans

There is the possibility of taking the Women's Technology Program to a higher level than simply departmental: it may be relocated into the School of Engineering, becoming a unified program with different sections for the each field of study within the School of Engineering that wishes to be involved. This way the program could be expanded to cover even more topics, and there would be a larger pool of human resources from which to draw the staff of the program (Because there are so few female graduate students in both the Electrical Engineering and Computer Science and the Mechanical Engineering Department it is often difficult to find enough who are willing – and able within their research constraints – to teach the classes.).

The Women's Technology Program, while still not old enough to have impacted entire lives of young women considering careers in science and engineering, has proved to be motivational to its students and successful in exciting them about topics that they had not seen previously. After attending the program, one young woman wrote:

> Before I attended WTP, I always thought that CS or Engineering were for guys and was always intimidated even to learn about it. However, after having attended the program, I am much more confident that even girls can study such fields and that we can succeed in it if we put our heart to it.[27]

This is just one of many testimonials to what the Women's Technology Program has done in the short-term and in only one field. With the trials of time and with the addition of more segments of the program, it should become easier for young women (and men) to see that anyone can achieve in the field of engineering. In the words of Rosalind Williams:

> Gender discrimination and gender bias are deeply interconnected. The cultural identity of science and engineering as masculine results from, and feeds back into, the overwhelming prevalence of men in their practice. As gender discrimination is gradually addressed, gender bias should also change. That is the point of increasing diversity in any human institution: not only to ensure equal access to the advantages it offers, but also to redefine the institution so that its identity reflects the full range of human needs and concerns. One reason to open up engineering to women is to be

[27] From follow-up surveys given to the former students by Cynthia Skier, the WTP program director.

fair to women. Another reason, ultimately more important, is to transform engineering so that it better serves the needs of humanity.[28]

As engineers, we must understand our differences and use our various skills to solve the problems of humanity. This goes beyond gender to all forms of diversity. Any variances from person to person have the possibility of adding new and potentially useful perspectives to a given problem. Stifling these perspectives and opportunities for growth and change will end up causing more suffering than solutions.

There is no reason for sex-based bias and discrimination. In the words of Ruth Schwartz Cowan:

> Our reproductive systems...the biological bases of gender dichotomies, are the only expendable systems in our bodies. Take away our hearts, and we die; our brains, ditto; our lungs, our digestive system, our excretory systems – without them we'd be dead. But we can struggle along without our testes and ovaries, without our mammary glands and pubic hair, perhaps not happy, but nonetheless alive. The things that make us different, males from females, are the least significant things about us.[29]

The only differences between men and women are cosmetic and experiential, but the bias that exists is real. If we can correct these wrongs and move beyond these issues, there is no limit to what might be possible by working together.

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Appendix A: Ball Toss Experiment[30]

Introduction

When a ball is thrown straight upward, the ball slows down until it reaches the top of its path. The ball then speeds up on its way back down. A graph of its velocity (or position, or acceleration) *vs.* time would show these changes. Is there a mathematical patter to the changes in velocity? What is the accompanying pattern to the position *vs.* time graph? What does the acceleration *vs.* time graph look like?

In this experiment, you will use a Motion Detector to collect position, velocity, and acceleration data for a ball thrown straight upward. Analysis of the graphs of this motion will answer the questions asked above. The graphs will be analyzed first in the Logger *Pro* program, and then in Microsoft Excel.

Objectives

- Collect position, velocity, and acceleration data as a ball travels straight up and down.
- Analyze the position *vs.* time, velocity *vs.* time, and acceleration *vs.* time graphs.
- Determine the best fit equations for the position *vs.* time and velocity *vs.* time graphs.
- Determine the mean acceleration from the acceleration *vs.* time graph.

Materials

- computer
- Vernier computer interface
- Logger *Pro*
- Microsoft Excel
- Vernier Motion Detector
- Volleyball or basketball
- Wire basket

Preliminary Questions

1. Think about the changes in motion a ball will undergo as it travels straight up and down. Make a sketch of your prediction for the position *vs.* time graph. Describe what this graph means.
2. Make a sketch of your prediction for the velocity *vs.* time graphs. Describe what this means.
3. Make a sketch of your prediction for the acceleration *vs.* time graph. Describe what this graph means.

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[30] Adapted from Appel, Gastineau, et al. *Physics with Computers : Physics Experiments Using Vernier Sensors*. 3rd Ed. Beaverton, OR: Vernier Software & Technology, 2003.

Procedure

1. Connect the Vernier Motion Detector to the DIG/SONIC 1 channel of the interface
2. Place the Motion Detector on the floor and protect it by placing a wire basket over it.
3. Open the file "06 Ball Toss" from the *Physics with Computers* folder.
4. In this step, you will toss the ball straight upward above the Motion Detector and let it fall back toward the Motion Detector. This step may require some practice. Hold the ball directly above and about 0.5 m from the Motion Detector. Click "Collect" to begin data collection. You will notice a clicking sound from the Motion Detector. Wait one second, then toss the ball straight upward. Be sure to move your hands out of the way after you release it. A toss of 0.5 m above the Motion Detector works well. You will get best results if you catch and hold the ball when it is about 0.5 m above the Motion Detector, although you may try and see if you can get multiple bounces if you'd like.
5. Examine the position *vs.* time graph. Repeat Step 4 if your position *vs.* time graph does not show an area of smoothly changing position. Check with the instructor or a tutor if you are not sure whether you need to repeat the data collection.

Analysis

1. Either print or sketch the three motion graphs. The graphs you have recorded are fairly complex and it is important to identify different regions of each graph. Click the Examine button, and move the mouse across any graph to answer the following questions.
   a. Identify and label the region where the ball was being tossed but still in your hands on both the velocity and acceleration *vs.* time graphs.
   b. Identify and label the region where the ball was in free fall (both upward and downward).
   c. Determine the position, velocity, and acceleration at the following specific points:
      i. On the velocity *vs.* time graph, mark the time at which the ball had its maximum velocity, and make note of the value.
      ii. On the position *vs.* time graph, mark the time at which the ball had the maximum height, and make note of the value.
      iii. What was the velocity of the ball at the top of its motion?
      iv. What was the acceleration of the ball at the top of its motion?
2. Please copy and paste your data values into Excel, and the graphing below will be in that program. In order to show the charts, graph the three sets of data as x-y scatter plots with correct labels.
3. The motion of an object in free fall is modeled by $y = y_0 + v_0 t + \frac{1}{2} g t^2$, where y is the vertical position, y_0 is the initial position, v_0 is the initial velocity, t is time, and g is the acceleration due to gravity. What is the shape of this graph? Your position *vs.* time curve should match this shape. Please add a trend line by right-clicking on the data points. When doing this, choose to have the equation

displayed and to show the R^2-value on the chart. How closely does the coefficient of the t^2 term compare to $\frac{1}{2}g$?

4. What shape is the graph of velocity *vs.* time? Please fit the correct trend line to this graph, using the same technique and labels as above. How closely does the coefficient of the t term fit compare to the accepted value of g?
5. What shape is the graph of acceleration *vs.* time? How does its average value compare to that of g? (If it's difficult to tell the average value from the graph, call a tutor to help you calculate the mean of your values.)
6. List some reasons for why the values of g from these graphs might deviate from the accepted value for g.

Extensions

1. Determine the consistency of your acceleration values and compare your measurement of g to the accepted value of g. Do this by repeating the ball toss experiment five more times. Each time, only plot the velocity *vs.* time curve in Excel, and fit a line to the data (with the equation). Average your six values to find a final value for your measurement of g. Does the variation in your six measurements explain any discrepancy between your average value and the accepted value of g?
2. What kinds of physical effects could be causing this discrepancy between the average value that you have found and the actual value? There are many different balls to choose from at the front of the room. Run the experiment again with ones of different size and different materials. How does your value for g change? Does this affect your reasoning for the discrepancy? If so, how?