Session 3592

DECONSTRUCTING ENGINEERING EDUCATION PROGRAMS (DEEP)

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The shortage of women in the engineering workforce has been a persistent problem in spite of significant efforts over decades to improve the situation. While the number of women increased as a result of the various focused efforts, the profession is no longer seeing improvements. There is even evidence that the percentage of women in engineering student bodies is backsliding rather than improving. This has led many to question what steps must now be taken to increase the number of women in engineering beyond the current level.

While the answers to the question of how to increase the number of women will undoubtedly be many and varied, reflecting the complexity of the problem, we believe that there is a simple truth that must form the framework for appropriate discussion, namely, that marginal approaches will always produce marginal gains at best. Here we define as marginal approaches which either treat symptoms rather than root causes, or which focus on actions outside of the central core defining a problem. Our analysis of the work to enhance the success of women in engineering finds much of it to be marginal on both accounts. A large fraction of the work focuses on enhancing numbers through symptomatic relief rather than making the profession more attractive. Further, there has been a strong tendency to use minor changes and additions rather than wholesale revamping to increase the participation of women. The result, we believe, is not surprising. Gains are modest at best and cannot be sustained without constant diligence.

Starting with the premise that significant improvements in the number of women in engineering will require new sorts of approaches, we have chosen to focus on the undergraduate student body in engineering schools. We propose a distinctly different approach to the problem of encouraging women – one which focuses on the curriculum. Essentially no attempts have been made to revise the engineering curriculum itself so as to increase the number of women, even though it is clear that the curriculum is central to what defines an engineering education. Instead, most gender initiatives aimed at the undergraduate engineering student population have started with a curriculum which is known to be unattractive to women, and have tried using “add-ons” or minor changes to rectify the situation. We believe that this approach fails because the curriculum is fundamentally flawed and because the rigors of the typical engineering program are not conducive to permitting “add-ons” without increasing the pressure on students.

In our work, supported by the GE Fund, we propose to reconsider the engineering curriculum from the ground up. Our goal is to produce a curriculum which retains the salient technical material, but which is more attractive to women (and probably men also). Our working hypothesis is that the undergraduate engineering curriculum will be made more attractive without compromising technically if it enhances the link between fundamentals and applications, reduces critical path lengths in the course sequence, introduces team experiences into all courses, and creates an atmosphere of inclusion rather than exclusion. The resulting curriculum will likely be revolutionary rather than a minor change from the existing standards, and will require trial, assessment, and revision before it is ready for adoption. We plan to work with a number of partnering institutions to perform the requisite tests and assessment.

While it is clear that there are two parts to making education attractive – content and pedagogy – our effort is aimed at only the content part of the equation. We do not wish to minimize the importance of pedagogical innovation in making education attractive and accessible, but we note that content has received far less scrutiny than the delivery methods, and thus we believe improvements are more critical at this juncture.

Our approach to revision of the undergraduate engineering curriculum involves six steps:
1) Determine what has been done previously that we can build upon.
2) Work with a team to examine and revise the "core curriculum" usually packed into the first two years of the engineering program.
3) Work with a team to examine and revise the material contained in courses normally taken by those in a specific engineering major.
4) Pilot new courses at a variety of locations, with careful assessment of the impact on students and revision of the courses to achieve goals more completely.
5) Pilot entire degree programs at a variety of locations.
6) Disseminate successful curricula widely.

This paper summarizes work which has been done in related areas by others, i.e., the first step of the process. We have intentionally focused on the work we find most compelling. It is not a comprehensive review article; rather, it is intended to form the basis for our discussions of how to proceed to revise curricula to make engineering more attractive to women. The last section presents conclusions we draw from the body of literature.

What may not be immediately clear in the following sections is that while some work has been done on topics important to creating an engineering curriculum that is attractive to women, there has been little effort expended in tying the pieces together. In particular, we note that there have been effectively no prior attempts to aim specifically at a new curriculum which retains the fundamental components but puts them together in a manner designed to attract a wider following. Nonetheless, work by others on pedagogical approaches and means of expanding the subject matter offered to engineering students is critically important to our work.

The Numbers

There are many reports showing that women are under-represented in engineering – both the profession and the schools leading to entry into the profession. Here we summarize just a few.

Women of all races together comprise just 9.1% of the engineering workforce. Caucasian women are 7.0%, Asian women 1.2%, black women 0.6%, Hispanic women 0.4%, and Native American women 0.03%.[1]

Men are five times more likely than women to choose engineering as their major.[2]

In 1998, of baccalaureates awarded to women, only 1.7% were in engineering.[3]

According to the National Council for Educational Statistics, the majors most attractive to undergraduates are business management and administrative services (19.3%), social sciences and history (10.6%), and education (8.9%). In contrast, baccalaureates in math and physical sciences comprise only 2.6%.

Overall 68% of students entering with a declared engineering major graduate with an engineering degree. Sophomore year is the most likely time for women to switch majors[4] and at most universities at least 15% of the students drop out of engineering by the end of their first year. The drop-out rate for women in the freshman year is 35%.

The average engineering faculty is more than 95% male.[5] Women often report feeling marginalized and facing a chilly environment.[6] Women usually cite the climate as a reason for dropping out of engineering, not insufficient academic preparation.[7]

Creating Links

The standard engineering curriculum has changed little over the years. It tends to load up on fundamentals in science and mathematics in the first two years, with engineering courses taking over for the last two years. Courses tend to be very specifically focused on a topic, with relatively little cross-linking between courses. For instance, calculus is normally taught independent of physics, the first course typically to use calculus; and physics is taught independent of statics, often the first engineering course to use physics. While there have been many studies of the relative virtues of greater integration of course material, progress in engineering curricula has been slow to materialize.

The effects of a rather rigid segmentation of topics into courses with little communication among them are the isolation of most undergraduates from the engineering faculty until their second or third year, the presentation of a picture of engineering that is divorced from application until far into the curriculum, and distributed authority for the students that makes advising and mentoring difficult. In a real sense, we expect engineering students to be so committed to the engineering endeavor from the time they set foot on a campus, that they will pursue courses which offer no insight into engineering as a profession for a minimum of a year knowing that after this “hazing”, there will be the reward of relevant classes. This sort of approach selectively disadvantages women, as they are less likely to be exposed to engineering as a profession and to be encouraged to pursue an engineering career. For most women, the structure of our curriculum is downright unattractive, uninformative, and uninviting.

Integration of Curricular Material

Bordogna, Fromm and Ernst advocate course integration, stating that 21st century leaders must make connections among seemingly disparate discoveries. Saving design projects until senior year drives students away. Technology such as computer graphic simulations allows hands-on engineering even in freshman year.[8]

At Rose-Hulman Institute of Technology, a member of the Foundation Coalition, underclassmen take comprehensive 12-credit courses integrating engineering, physics, chemistry, computer science and calculus. There is topical alignment and exams are integrated.[9]

Fromm's E4 program at Drexel integrates science, engineering and liberal studies. A team of students works with a team of faculty; all presentations, assignments and exams are coordinated by the faculty team; applications are integrated and continuous; the curriculum contains at least 10 design projects; and teams meet weekly. Courses are introduced just-in-time for a "unifying and interdisciplinary view, culture for life-long learning, societal perspective of the impact of technology, and emphasis on experimental methods."[10]

Dartmouth's Mathematics Across the Curriculum (MATC) integrated math with science, humanities, and fine arts, creating 16 new courses such as Applications of Calculus to Medicine and Biology, and Math and Renaissance Culture. The MATC project created IMPS, the Integrated Math and Physical Sciences sequence, a three-term, six-course, team-taught interdisciplinary sequence of math, physics and chemistry. IMPS consistently recruits students into the engineering track: more students finish the course intending to be engineers than enter with that goal.

Miaoulis of Tufts University instituted 56 half-credit "exploring technology" courses to introduce engineering practice in a real-world context. Some of the new real-world courses are: Behind the Scenes – components of engineering associated with film making; Children, Technology and Society – effects of toy technology; Earthquake Engineering; Gourmet Engineering – heat transfer as applied to cooking; Microbrewery Engineering; and Prototyping Home Robots. As a result, Tufts experiences an unusual net influx of women into the engineering major after freshman year. Among engineering majors, 33% are women, and the engineering faculty is 18% female, quadruple the national average.

Blewett, director of general education at University of Massachusetts, Lowell, observed that engineering majors typically take any humanities course that happens to fit their schedule. He therefore developed a more meaningful humanities curriculum for engineering students. They select any one of eight thematic clusters which afford depth, breadth, and coherence. Clusters include Technology, Society and Values; Environmental Issues and Societal Values; Diversity and Community in America; and Global Relations.[11]

Introducing Social Relevance

The need for integration is particularly acute for women, as they are seeking concrete evidence of social relevance and relevance to their gender. Here we cite a few of the studies which have been directed at women in terms of their expectations.

Women tend to choose majors that they perceive have a high level of interaction with other people and whose benefit is apparent.[12] For this reason, the Women's Experiences in College Engineering (WECE) Project recommends that every engineering course contain numerous examples of how that subject can help humanity.

In *Unlocking the Clubhouse*, Fisher and Margolis discuss their work, which led to major curriculum changes in Carnegie Mellon University's Computer Science Department. In 1995 it was only 7% female undergraduate students and 10% female faculty. The drop-out rate for women was double the rate for men. Interviews and surveys indicated that boys get into computers at an early age with tinkering and videogames, but girls are attracted to computing with a purpose. The women they interviewed wanted to use computing to study diseases, improve education, reduce traffic fatalities, and design new pacemakers: 49% of the women linked their computing interest to other arenas (compared to only 9% of the men). Building on this study, CMU introduced a series of application-focused courses into its Computer Science program. The Computer Science undergraduate student body is now 42% female.

Smith College advocates the inclusion of socially relevant design projects throughout the curriculum, and projects of social relevance are assigned even in freshman year. The course Designing the Future, for example, is a collaboration with the Institute for Women and Technology. Students develop toys with universal gender appeal, because research shows that many competitive, militaristic toys alienate girls. The Smith course includes a workshop for high schoolers called Introduce a Girl to Engineering.[13]

The NSF PROMISE project at University of Nevada, Las Vegas offers an undergraduate course designed to attract and retain women in earth science programs. Earth Systems: a Feminist Approach is team taught by a geologist and a sociologist. It seeks to situate science within its social and political context, and to strengthen women's confidence in science. They exhibit heightened participation and surveys indicate a positive impact on attitudes.[14]

Addressing Gender and Multiculturalism in the Curriculum

We must consider the role of gender and multiculturalism if we seek to encourage more women in engineering schools.

Women's Studies Programs, even if engineering does not play a role, improve the institution's climate and attract female students and faculty to all departments.

Traditional technical course materials are known for their white male bias. In 1997 Marshall and Dorward analyzed introductory physics classes and textbooks at Utah State University. They observed that the work of Inge Lehman is highlighted in the four introductory physics-astronomy textbooks, but only one mentions her name. The two astronomy books highlight Vera Rubin's work but neither mentions her by name. One physics text mentions 118 males and only 2 female physicists. No women are mentioned among the examples of ongoing work in those four texts. In a 1995 survey of 55 astronomy books, none mentioned all of the 10 most famous women astronomers.[15] This directly contrasts with recommendations of Rosser that curricular material must include contributions from women engineers acknowledged by name, and references to women must include full first names rather than initials.

Inclusion of women's contributions is only the first step. The McIntosh model of curriculum has five phases: the womanless curriculum, women as an addition, women as anomalies or victims, women as the focus, and curriculum redefined and reconstructed to include all. Many schools are still at level one according to Rosser, but a number of schools have developed courses on women in engineering.

A revised curriculum should delve into the unique experiences of women and how their gender influenced their work. In *Female Friendly Science*, Rosser gives compelling examples of unique contributions to science by women based on their experience as women, arguing that suppression of women from engineering eliminates a whole viewpoint and diminishes scientific understanding. Examples of specifically female science include Ellen Richards with sanitary engineering rooted in home economics and Jane Goodall in primatology.[16] Wulf, President of the National Academy of Engineering, also uses the need for diverse viewpoints as a justification for the need for women in engineering.

Lucena chronicled the historical arguments made for women in science and engineering.[17] The case for women in science/engineering started as a matter of social equality and fairness, then became a practical solution to the workforce shortage (the pipeline), and has shifted again, this time to respond to the challenge of global competitiveness. Our workplaces are becoming diverse, multicultural environments that demand tolerance and teamwork. Engineering now stresses multicultural awareness and communication skills.

Embry-Riddle Aeronautical University offers a degree in Science, Technology and Globalization (STG) designed to develop leaders and global citizens of the 21st century. There are eight inter-related components: general education, sciences, STG core, advanced STG, electives, foreign languages, senior thesis, and co-op. The STG core demonstrates how gender influences aviation; and how societies, economies, systems of thought, cultures, environments, and languages are being shaped by the globalization of technology and science.

To help students locate themselves in a globalizing world filled with different perspectives on engineering problem solving, Downey and Lucena developed the course Engineering Cultures, www.cyber.vt.edu/engcultures. It travels around the world and examines engineering knowledge from place to place, and from time to time.

San Jose State University's Board of General Education evaluates all new course proposals for diversity (www.aacu.org).

Streamlining the Curriculum

At most academic institutions, the course load for an engineering degree is higher than that for most other majors. While it is tempting to suggest that the rigor of the engineering curriculum is a necessity, the private colleges (with high tuition) manage to limit the requirements to that which can be accomplished in four years, while the public schools tend to be more like 4.5-year programs. Yet the engineering programs at private schools are as likely to be ABET-accredited as those at the public schools. Thus the question – how much is enough?

Complicating the issue of size of a curriculum is the self-perpetuating nature of crowded curricula. The typical engineering curriculum, replete with required classes and heavy loads, leaves little room for experimentation by students. As the profession progresses, faculty see new material that must be included, but it is rarely politically expedient to remove material from a curriculum. The net result is that crowded curricula get still more crowded as faculty seek to improve the quality of the educational offerings. Breaking this cycle is likely a key component to making the engineering degree more attractive. It will require a cultural change in which the merits of material are debated in the context of priorities, lifelong learning, and quality of experience rather than historical biases.

Kulacki and Vlachos addressed the issue of ardor in their article *Downsizing the Curriculum: a Proposed Baccalaureate Program and Contextual Base*.[18] Observing that many undergraduates require more than nine semesters to complete a curriculum designed for eight, they advocate the reduction of degree requirements to 120 credits, or a reduction from 45 to 40 courses. With a "right-sized" curriculum, engineering majors have the same degree requirements as their peers in arts and sciences.

As a specific example, in 1991 Carnegie Mellon University reduced the freshman course load from five courses per semester to four, and now requires freshmen to take two introductory electives before choosing a major. Students can start the sequence of required courses in a specific major in sophomore year fall semester and still complete their degree in four years.[19] In addition, the Electrical and Computer Engineering Department at CMU instituted its own reform. In 1991, a committee determined the absolute minimum set of technical courses required to be an engineer, reduced the required number, and freed up a year for appropriate electives.[20]

Starting Assumptions

Many undergraduate degree programs begin with few assumptions about their students. It is understood that what the student scholar needs to know, they will learn in college. In engineering and science, this is generally not the case. Rather, there is an expectation that students who enter already have a certain level of ability, with exposure to particular classes as high school students. While this assumption might seem at first blush quite reasonable, it has two problems: not all schools offer the material that we assume students will enter understanding, and by starting with this assumption we disadvantage students who do not choose the standard path to science and engineering careers at a very early age. These starting assumptions are a problem for women, because women are far less likely to see engineering and science as their future at a young age and they are less likely than their male peers to be encouraged by school counselors to consider this path. In essence, the starting assumptions for the typical engineering curriculum select for the male.

One might argue that many schools have a path to an engineering degree which allows for students who do not meet the prerequisites to take remedial courses at college and then start on the standard engineering curriculum. However, this adds to the length of time needed for obtaining the degree, posing a potential financial hurdle. It also creates a hierarchy of first-class and second-class students, which might well dissuade a newcomer.

A few academic institutions have made valiant attempts to address the problem of starting assumptions. For instance, at Carnegie Mellon University the new Computer Science curriculum provides first-year students with four different ways to enter the curriculum, depending on their level of experience. The curriculum is neither tightly scheduled nor deep in prerequisites.[21] In a conscious effort to attract more women and eliminate all artificial prerequisites, CMU eliminated prior programming experience as a prerequisite because it is not necessary for success in the major.

The University of Alabama has four tracks or points of entry depending on math preparation: pre-calculus algebra, pre-calculus trigonometry, calculus I, and calculus II+. The track system has improved retention to 70% compared to 50% for the traditional cohort. Transfer students and AP calculus students are easily accommodated. All tracks enable degree completion in four years.

At Bryn Mawr College, Abraham developed a special program to retain undergraduate women in science by designing introductory courses with a minimum of prerequisites so that young women who had not taken physics in high school could still enroll. He thus encourages women to become physicists by making it possible to have several different points of entry.[22]

Reducing Prerequisites and Shortening Critical Path Lengths

Many engineering programs have critical path lengths so long that failing a single course results in an extra semester for graduation. One of the goals of our work is to produce a more flexible curriculum, which requires reducing critical path lengths. Thus we consider studies of prerequisite reduction.

There are no fixed guidelines for use of prerequisites in a curriculum. Prerequisites might be listed because knowledge of material in the earlier course is necessary for successful completion of the later course, to control enrollment in a course, to prevent early graduation (sometimes a problem at private institutions), or to encourage a certain level of "maturity" in the student at the time a particular topic is taught. In seeking to reduce prerequisites and shorten critical path lengths, we will necessarily reject all arguments for prerequisites except the need to know the material in the earlier course to be successful in the later course.

Some studies have identified mathematics as a major source of the prerequisites in engineering courses, and seek to get around this at early levels by introducing software with pre-programmed solution approaches. The aim is not to replace the need to learn the mathematics, but to remove it as an obstacle to some early courses. For instance, Karweit at Johns Hopkins University has a virtual lab which solves a large set of equations for every new bridge design. The virtual lab can be taken without prerequisite mathematics courses and forms a key component of the freshman course pioneered by Karweit called What is Engineering.[23] At a more advanced level, Principe at the University of Florida designed a CD-ROM with interactive electronic book in order to teach adaptive systems. He replaced his 50-minute lectures with 15-minute lectures followed by student problem-solving. Adaptive systems generally are not taught to undergraduates because of the high level of math required to understand the topic; however, the electronic textbook does the number crunching.[24]

In addition to reducing prerequisites, there are a few studies which have considered reorganizing material in a course sequence in order to enhance the learning experience and reduce critical path lengths. For instance, Dally, of the University of Maryland College Park, observes that mechanics is typically fragmented into statics, mechanics of materials, dynamics, mechanics of deformable solids, dynamics of machinery, properties of materials, and a capstone design project. Many students have difficulty with the very first course and fail to retain it as they progress. Dally suggests the following sequence instead: (1) mechanics and materials: non-vector approach, with design; (2) dynamics and vibrations including vector statics, with design; (3) design and analysis of machines, with design project.[25] We note that the revised mechanics curriculum would have fewer prerequisites and thus a shorter critical path length.

The comments of Dally are precisely the sort of curriculum revision we seek to promote on a broad scale. They suggest a review of technical material in the curriculum to evaluate whether a change in the grouping and ordering might produce a better and more flexible curriculum while maintaining or enhancing the quality.

Team Experiences

To a great extent, the undergraduate academic experience is defined as competitive rather than collaborative. All too often, students see themselves in an adversarial relationship with their teachers, and in competition for good grades with their peers. Particularly in engineering, where almost all students who complete a degree are guaranteed a job, this view of the academic experience is unfortunate. It is an impediment to the well-being of women, and puts an obstacle in the path of successful team experiences. Teamwork has become an omnipresent phenomenon in US industry, and ABET requires engineering graduates to demonstrate teamwork and communication skills.

The perception of a hostile environment tends to dissuade people from entering engineering departments. For women, who already feel isolated by their under-representation, the effect of a perceived hostile environment is great. Thus, team experiences which serve to decrease isolation, make courses more collaborative and pleasant, and prepare students for their future as engineering professionals are important.

Many engineering courses have migrated to significant teaming experiences, but these tend to be focused in the latter years and in design courses. By bringing team experiences to the curriculum earlier, the cutthroat reputation of engineering might be ameliorated, and we could well find female students enjoying the academic experience much more.

Of course, the growth of team experiences in the curriculum will require training of faculty as well as students. Few engineering courses are team taught, and the academic system of rewards for faculty tends to focus more on individual accomplishments than on team progress. Thus, faculty have had little experience with teaming effectively and need assistance if they are to introduce it into more classes.

NSF's ECSEL, Foundation, and Gateway Coalitions aim at increasing the number of women graduates through team-based multidisciplinary instruction with integrated math/science/engineering/English cores and design projects from freshman year on.

Harvey Mudd College originated the Engineering Design Clinic, in which upperclassmen and graduate students form interdisciplinary teams to tackle industry-sponsored design projects. Harvey Mudd workshops teach other institutions how to use the clinic.[26]

All engineering students at Rowan University are required to take an eight-semester sequence in which multidisciplinary teams engage in semester-long design projects. Students and faculty from all four engineering departments work on lab experiments, design projects, applied research and product development.[27]

Olin College opened in 2002, funded by a grant from the Olin Corporation with the aim of "re-inventing engineering education". It embodies principles of business management, entrepreneurship, and liberal arts through hands-on learning, teams of students at all levels, and corporate partnerships. Team design projects occupy 20-60% of student time. Olin is deliberately gender-balanced, with 38 male and 37 female students.

Despite the increase of team projects, a study at University of Nebraska-Lincoln found that only half the students who worked in teams received any training. They were unclear about team purposes and characteristics of an effective team.[28] This suggests that we have an opportunity to improve the academic experience by more clearly defining the goals of teaming, and the ways of best meeting these goals.

Team assignments are not a simple statistical microcosm of a group. For example, five Hispanic women should not be assigned one each to five groups, because the isolation is harmful. Distributing a minority within a majority leads to the disappearance of the minority.[29]

Instructors at University of Wisconsin-Madison advocate all female teams, teams with female majorities, and/or rotation of duties so that an aggressive (usually male) team member does not always assume the lead role.[30]

Exclusivity versus Inclusivity

The engineering profession, not unlike law, business, and medicine, sees itself in an exclusive light. It is desirable to be an engineer, but not everyone can qualify. The air of exclusivity pervades everything associated with the profession: college admission at all levels, accreditation, licensing, and membership in a professional society, just to name a few examples.

There is, of course, a certain truth to the assumptions inherent in the exclusive attitude of the profession. Engineering isn't for everyone. It does require hard work as you learn the tools of the trade, and the rewards at the end of the road are significant by comparison to other careers. However, much like the messages of old in which new arrivals at colleges were exhorted to look at their neighbors because only one of them would graduate, the message we send by emphasizing the exclusivity of engineering as a profession is not one of encouragement, but rather one of discouragement. As discussed by Tobias, we expect the next generation to rise, as we did, like cream to the top.[31] Given the minority status of women in engineering schools, as well as the acknowledged need for confidence building in this group, it is quite likely that the message disproportionately dissuades women from considering a career in engineering.

There are many options available to us to make engineering more inclusive and more attractive for undergraduate study, including freshman courses aimed at inviting student participation in the career, a change away from gateway courses which weed out students in the degree program, and the creation of new course programs that provide flexible options to the binary choice that exists now of either majoring in engineering or not. Each of these is discussed below.

Freshman Classes

Given the high attrition from the freshman year, innovative courses for freshmen are being studied by a number of institutions. The best programs seem to greatly enhance retention and even recruitment into engineering from other majors. Two sorts of courses are options: courses for engineering majors and courses for non-majors.

Nationwide, less than one half of freshmen who start in engineering graduate in engineering, and at least one half of this attrition occurs during the freshman year.[32] The response to this reality at engineering schools has often been a fine bit of circular reasoning: we don't dedicate our precious resources at the freshman level because so many of these freshmen leave engineering, but by not providing adequate mentoring and support we create one of the prime reasons that the students choose to leave.

Indeed, Robinson and Reilly at University of Missouri-Rolla conducted a study of the educational preparation and professional success of women alumnae. Complaints about college did not center around academic preparation, but around personal and social needs not satisfied by the environment, inadequate advising and unsupportive advisors.[33]

Massachusetts Institute of Technology has held freshman advisor seminars (FAS) since 1986. Eight advisees come together with a faculty advisor and an upperclassman for an informal, weekly seminar. The FAS have become the dominant mode of freshman advising at MIT. In 1996-1997, about 90% of the freshman class enrolled in the seminars.[34]

North Carolina State University, Purdue, and The University of Texas at Austin offer or require freshman courses on the domains of engineering, careers, use of the Web, how to use email, study skills, note taking, critical thinking, school resources, time management, library orientation, student organizations, co-ops, internships, resumes, health and fitness.[35]

Watson has developed a three-credit elective at Texas A&M entitled The Role of Women in Engineering and Science. It fulfills a humanities requirement and is team taught by Watson and three other female faculty. Female engineers are invited to speak and there is a lab component. For example, a woman environmental engineer lectured about the Exxon oil spill, after which students simulated an oil spill using gravel, sand, dirt and motor oil.[36]

At The University of Oklahoma, Shirley and Carney have developed a freshman seminar course called The 21st Century Woman: Tomorrow's Woman in Science, Engineering and Technology. Topics include a historical perspective of women's contributions in engineering, what engineers do, pressures women face in engineering, networking and survival skills for women in engineering, and engineering job opportunities.

The University of Wisconsin, Madison offers an all-women's section of EPD-160, the freshman design course. There are real-life design projects, discussion of special concerns faced by women engineers, and meetings with female astronauts and women engineers in industrial careers. The women-only class forces the women to confront unfamiliar tasks. They are also more comfortable in class discussions because they do not have to compete with male classmates with more experience; they do not worry about stereotyping and are comfortable asking questions.[37]

The University of California at Davis offers a course to increase women's understanding of physical devices and tools, designed to overcome their intimidation about mechanical and electrical devices. Introduction to Physical Devices and Systems is a lower-division course for women involving hands-on cooperative learning activities and exposure to hardware. Participants dismantle bicycles and engines; solder and drill; and repair typewriters, toasters, CDs and hair dryers. The textbook used is *The Way Things Work* by David Macaulay.[38]

Conquering the Gatekeeper Courses

Many engineering schools feel a need for a mechanism that enforces a quality control or enrollment control at some point well after the college admission process. A popular mechanism for accomplishing this sort of control is the creation of gatekeeper courses which effectively "weed out" students from the program. It is difficult to think of something more discouraging than these gatekeeper courses – both for the students taking the courses, and for the faculty teaching them.

Gatekeeper courses introduce an obstacle to the academic program beyond that of the admission office. While we understand the motivations for such obstacles, particularly at the state institutions which might bar separate admission standards to the engineering school, gatekeeper courses send a message to students that being admitted to the program is not enough. Rather, students will compete with each other for some limited number of positions. This creates antagonism among peers in the program, instead of a collaborative environment. It actively discourages women, who are less likely to risk rejection than the male population.

For faculty, gatekeeper courses are also odious. Because they can be the difference between an engineering degree and failure, the motivation to cheat is high. Students who are borderline performers feel oppressed and singled out rather than encouraged and helped. Overall, it is stressful and fraught with emotional turmoil.

The problems associated with gatekeeper courses have come under some scrutiny. Overall, we believe that the solution lies in creation of alternative paths to engineering-related careers – the topic of the following section. These alternative paths should reduce enrollment pressure and permit effective channeling of students into paths for which they are best suited. However, we recognize that the elimination of gatekeeper courses may not be politically expedient for some time to come, so we review a few studies of them below. Overall, the studies we found focus on courses which serendipitously serve as winnowers, rather than courses intentionally created to "weed students out".

Traditional winnowers include calculus, differential equations, graphics, quantum mechanics, and statics.

Massachusetts Institute of Technology's Electrical Engineering and Computer Science Department addressed the under-enrollment of women and recommended "L" versions of introductory subjects. An L course is a gatekeeper course conducted at a slower pace which spills into an intersession. It can begin during intersession and continue through spring semester. The physics department conducted L courses with positive results. The same material is covered as in a normal course but it is less overwhelming (Final Report 1995, chapter 3).

Engineering graphics is a winnowing course typically required of first year students uncertain about their abilities in engineering. It requires advanced visualization skills. At Michigan Technological University, freshmen take a standardized test measuring 3-D spatial visualization ability; 50% of the women fail it. Faculty fear they are losing women who are strong in math and science but weak in 3-D visualization. Therefore, MTU developed an elective to strengthen their abilities.[39]

Creative Options for New Degree Programs

One of the striking distinctions of the engineering profession as reflected at the undergraduate level is the long-held position that there is only one right path to an engineering career and it requires an engineering or engineering technology degree. By contrast, if one considers medicine as a profession, the MD is clearly the most prestigious route, but one can also opt to become a nurse, a lab technician, a physical therapist, or even a researcher with a PhD and still be a vital part of the medical profession. Even the MD allows students to pursue various undergraduate majors rather than a specific degree program. By restricting the definition of engineering so rigidly, some would argue that we control the quality of engineering as practiced throughout the country. However, this exclusive view of engineering means we miss opportunities to broaden our appeal and our influence, and do the profession a disservice by forcing non-engineering personnel to be entirely devoid of engineering expertise. In essence, we are choosing to live with high numbers of the error which comes of losing women who might have made a contribution, in favor of very low errors of women who should not have been permitted to practice as engineers because of incompetence. Indeed, ABET supports the view of a single right path to engineering by establishing accreditation rules that recognize only two types of programs: those leading to engineering or engineering technology degrees. Licensing organizations have also promulgated this view, with some actively engaged in legislation prohibiting those without an engineering degree from referring to themselves as engineers.

We know that the concept of more options to a career path related to engineering is controversial, but we believe the time has come to seriously consider expanding the repertoire of engineering to include related jobs accessible through new and innovative degree programs, including everything from minors in engineering to programs such as technology writing. Some work in this area is well underway, and we note some of the exceptional programs here.

The BA in Engineering and Dual Degrees

When asked why they entered engineering, female survey respondents and focus group participants in the WECE Project mentioned the value of an engineering degree outside engineering, for entering business, medicine, and other fields.[40]

Some institutions, such as Harvard and Yale, already have a broader four-year AB in engineering sciences, plus a more technical five-year BS. Students can earn one degree in four years, and elect to continue for a fifth.

Since 1970 Lafayette College has offered an AB in engineering. Students take economics, government, foreign cultures, and fine arts as well as engineering. Instead of design engineering, AB recipients enter technical sales, architecture, law, or management. The curriculum is the same as for a BS in engineering for the first two years. In junior year AB students take history of technology, engineering & society, and a four-course cluster of engineering courses. Many AB engineering students major in engineering but minor in business, economics, government or law.

In four years, students at Dartmouth College earn an AB with a major in engineering sciences. This includes eight courses in their major. They can then continue, if they wish, for another year of solid engineering courses and graduate with a BE, bachelor of engineering.

In addition to its ABET-accredited engineering program, the University of Pennsylvania has a curriculum including technology as a liberal art, with an applied capstone societal project. It provides an interdisciplinary foundation with a strong technological component for students who pursue graduate work in fields other than engineering – typically medicine, business, and law.

Northwestern University offers six baccalaureates which combine engineering and another field: the Engineering Honors Programs in Education, Journalism, Law, Management, Medical Education, and Music. Female enrollment in the Engineering Honors Programs is high.

Women's colleges are over-represented in the production of science baccalaureates earned by women.[41] They provide a supportive environment, but most do not offer engineering programs. However, Texas Woman's University has a 3+2 dual degree program with Texas A&M. Students take math, liberal arts, and engineering prerequisites at TWU for three years, then engineering at TXAM for two years; they finish with a TWU math degree plus a TXAM engineering degree. Mills College has a similar 3+2 arrangement with University of Southern California. This type of articulation agreement provides women a nurturing, comfortable environment for the critical first years, when so many drop engineering; they then have a firm basis when they transfer to a coeducational school.

Lehigh University's Integrated Product Development program blends the schools of engineering, business, arts and sciences, giving students a broad range of skills that industry wants in its employees.[42]

Cogswell Polytechnical College integrates engineering with the visual and performing arts: it has a BSEE with concentration in music engineering.[43] University of Toledo Professor Bernard Bopp teaches "Music and Sound" for non-science majors. He covers wave motion, sound propagation, sound perception, physics of wind and string instruments, workings of the human voice, and sound reproduction. For the final project teams must design and build a new musical instrument (Chronicle of Higher Education, 6 September 2002).

Engineering for non-engineers: undergraduate study

The cost of providing an engineering education is high due to the need for equipment and the relatively high salaries of engineering faculty. Additionally, engineering degree programs are largely filled with courses taught within the school or college, thus producing time pressures on the engineering faculty. For these reasons, and perhaps others, there has been very little attention paid to introducing engineering to students who will not major in engineering. However, NSF suggests that engineering education should provide an opportunity for non-majors to study engineering topics and concepts. Engineering colleges must assume responsibility for promoting technological literacy throughout the university.[44] A few examples of programs are cited here.

The University of Washington's Air and Space Vehicles is a general education course designed for non-engineers. It features hands-on learning, multi-media presentations, and demonstrations. Analysis was eliminated, in order to attract a broad audience. University of Washington recognizes that the aerospace industry employs many people and only a fraction of them are engineers. Most aerospace employees do not have education backgrounds stressing math-science-technology.[45]

The University of Denver offers a series of technology electives for non-engineering students. In one course they work in interdisciplinary teams on policies concerning global warming, nuclear energy, and genetic engineering.

Princeton offers a course on the technical and non-technical aspects of space flight. From Earth to the Moon covers the history of flight. It is one of 55 freshman seminars and the first one taught by engineering faculty.[46]

University of Pennsylvania has a minor in Computer Science and Engineering for non-Computer Science students, requiring six course units including programming languages and techniques.

Some of Carnegie Mellon University's 11 engineering minors, such as Robotics and Biomedical and Health Engineering, are open to non-engineers. The requirements for the minor satisfy various categories of electives and do not increase the total number of courses required for the primary degree.

Engineering for non-engineers: master's degrees

Downey of Virginia Polytechnic Institute and Lucena from Colorado School of Mines advocate a master's degree in engineering for non-engineers. Globalization is creating unintended paths for non-engineers (such as biology majors, education majors and business majors) who become engineers after their first job in a high-tech company without going through the formal certification process of an undergraduate degree.

Carnegie Mellon's Entertainment Technology Center, for example, offers a master's program in entertainment technology, conferred jointly by the School of Computer Science and the College of Fine Arts. Technologists and fine artists work together on robot animatronics, speech recognition, streaming audio, sound synthesis, and augmented reality. Students spend 80% of their time on projects, as members of interdisciplinary teams. Electives are from the departments of robotics, ECE, ME, design, and drama.

Engineering as a Liberal Art

The traditional role of engineering education is to train engineers for the workforce. While many schools still see this as their primary niche, a growing group of schools now recognizes engineering education as a basis upon which to build in many directions – technical and non-technical. An extension of this view sees engineering as the modern liberal art – a degree which trains the mind for problem solving and to which all students should be exposed. However, the work we found on this subject suggests that we have many obstacles to overcome before engineering can assume the role of a liberal art.

The new paradigm depicts engineering education as broad and forward-looking. It offers a broad liberal education that provides diversity and breadth.[47] Yet just as engineering is not perceived as a people culture, the engineer is not perceived as a well-rounded, cultured person.[48]

Astin, professor of higher education at UCLA, conducted assessment surveys of engineering. A student answering that the purpose of college is to make him/her a more cultured person is likely to drop engineering. Engineering faculty are more likely than general faculty to say preparation for employment is the primary goal of education, and less likely to choose personal values or self-understanding. This leads to the questions - do we as faculty emphasize obtaining a job too much? Should we spend more time pointing out the ways in which engineering drives our culture?

Instructional techniques are also different. The percentage of faculty using extensive lecturing in most classes is 54% of general faculty and 78% of engineering faculty; 70% of general faculty use class discussion in most classes, but only 45% of engineering faculty do; cooperative learning is used by 24% of general and only 14% of engineering faculty.[49]

Use of Technology to Reach out to Women

When students consider a college, the first place they go to investigate it is the website. Websites can be powerful motivators; they can also discourage a prospective student. University of Notre Dame's engineering website is a motivator, with photographs of female students engaged in hands-on projects. The website reports that engineers shape the world by working in teams to serve humanity on basic and advanced levels.

The National Council for Educational Statistics reports that in AY99-00, 7.6% of undergraduates participated in distance education. They were more likely to use the Internet than live or recorded TV.

At the University of Wisconsin-Madison, engineering faculty have experimented with an online streaming video and multi-media application called eTEACH. Lectures are videotaped and viewed by students at their convenience. Then class periods become team problem-solving sessions. Student reaction is positive; however, 79% of the students involved are male. Would eTEACH work equally well with women? Foertsch says yes: eTEACH frees up class time for practical problem solving, and women prefer collaborative activities, design, real-world application, and societal relevance over abstract reasoning and competition.[50]

Participants in a faculty seminar held at the University of Illinois during AY98-99 called "Teaching at an Internet Distance: the Pedagogy of Online Teaching" made the following observations. Frequent student-faculty contact in and out of class is the most important factor in student motivation and involvement. This would certainly be true for women, who feel marginalized and isolated in the engineering disciplines. High quality online teaching is time- and labor-intensive, and not the revenue source envisioned by some administrators. Online courses are most appropriate for certification and continuing education, where interaction and campus environment are not so important. They are useful for repetitive drills and for material requiring computations or graphics. Student frustration is prevalent for two main reasons: inadequate technical support, and the lack of immediate instructor feedback. (http://www.vpaa.uillinois.edu/reports_retreats/tid_report.asp)

Conclusions and Additional Comments

The material presented above is intended to inform our subsequent discussions of potential changes in undergraduate engineering curricula. From this perspective, several conclusions can be drawn. They are discussed briefly here in the context of next steps.

First, in spite of an exhaustive search, we found no studies that consider changes to the structure and content of curricula with an aim of increasing the number of women in the undergraduate engineering student body. Although we find this conclusion startling, it suggests that such work as we propose is long overdue. To put this in a more positive light, there is a great opportunity to have an impact through a focus on curriculum change to promote gender equity.

Second, there is ample evidence that the undergraduate student population in engineering is not gender balanced, with the situation worsening in spite of ongoing attempts at improvement. As stated up front, we believe that a revolutionary change is needed – one which addresses root causes rather than easing symptoms by establishing numerical targets achieved by any means possible.

Third, there is some evidence that links early in the curriculum to specific applications help make engineering more attractive to women. There is also some evidence that integrating fundamentals and applications in courses is more attractive. In both of these cases, much more work needs to be done before conclusions can be drawn firmly. However, we are encouraged by work to date suggesting that we may be on the right track to pursue greater integration in the curriculum.

Fourth, addressing social relevance and gender throughout the curriculum is clearly of great importance in making the curriculum more attractive to women. Here the evidence seems rather solid, and points the way for a new curriculum. Overall, we tend in engineering to present fundamental concepts with little credit given to the people behind them. The data concerning the importance of social relevance to women suggest that we might consider introducing more historical and personal context into engineering courses. Even the simple act of discussing the people who first applied some fundamental concept in a particular field might have the profound effect of humanizing our courses and our profession.

Fifth, while we found a few statements about the need to reduce the number of courses required for an engineering degree, we did not find experiments with this concept which enabled us to evaluate its importance to women. However, we did find some evidence that more flexible assumptions as to the knowledge possessed by entering engineering students leads to a more attractive program for women, provided the length of the degree program is not affected. We are unable to draw any conclusions about the effect of reducing prerequisites due to the dearth of literature on this topic. Overall, this is a key area of focus for the curriculum development to come and we must address the questions of starting assumptions, prerequisites, and critical path length in creative ways.

Sixth, while we found a growing use of team experiences in engineering curricula, we found no material which evaluated the effect of this approach in making the degrees more attractive to women. This area thus requires significant additional work. We continue to hypothesize that team experiences are particularly important for women, provided that their presence is not diluted by dispersal into separate teams. It seems clear that faculty and students alike need better training on how to work in teams effectively.

Seventh, the literature supports a view that creative freshman-level classes entice women into engineering, and reinforce the correctness of that choice for entering freshmen. This approach seems to be particularly effective in recruiting women who did not originally chose engineering majors into engineering departments.

Eighth, there is ample evidence that gatekeeper courses have a strong negative impact. We believe that this issue can be addressed by a combination of flexible starting assumptions for the knowledge of entering students, and the creation of innovative engineering opportunities in addition to the standard degrees.

Ninth, there is much experimentation currently ongoing aimed at creative engineering degree programs, including minors, BA programs, dual degree programs, and even MS programs for those with no prior engineering degree. It is not yet clear whether these programs are seen as more attractive to women. Clearly, more work is needed in this area. However, we continue to believe that new degree options would serve the profession well by broadening the base of exposure and the options for using engineering skills. Fundamentally, we believe the time has come to recognize that there is more to the engineering profession than the standard engineer. Many others participate in the profession (for instance, through technical sales or science reporting) and do so largely without benefit of any educational experience in engineering.

Finally, we note that there is not yet significant data from which to determine whether technology (web-based and other distance instruction approaches) creates a situation which is significantly more attractive to women. Here again, more work is needed.

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