AC 2008-1061: GENERAL TRENDS IN ENGINEERING EDUCATION SUPPORT THE PARTICIPATION OF WOMEN

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General Trends in Engineering Education
Support the Participation of Women

Abstract

This paper summarizes major trends identified in engineering education based upon an analysis of several influential reports published within the past 15 years as well as a synthesis of articles published within the past 5 years. Because of technological advances as well as the globalization of businesses, economies and cultures in the twenty-first century, the importance of engineering disciplines and education has reached a critical state and prompted several examinations within the past few years. Although numerous studies and research on changing or restructuring engineering education have been conducted over the last century, many findings have remained the same over time, such as (a) what to include in the curricula, (b) how long engineering education should be, (c) what level of specialization, (d) how to prepare students, and (e) how to meet the needs of society. The trends in engineering education that we found to be most prevalent in reviewed reports and articles are increased attention to (1) curricular flexibility, (2) continuous learning by students, and (3) diversity in engineering education. Additionally, key themes identified in our review of the literature on women in engineering focused on (1) historical male-domination of the Science, Technology, Engineering, and Mathematics (STEM) fields, (2) the need for intervention programs for women and minorities to keep their interest in STEM fields and (3) the need for educational system changes to include both curriculum and faculty role-models and influence. In this paper we show how it appears that the trends in engineering education are in line with and supportive of the themes underlying the types of changes needed to draw more women into engineering.

Background and Methods

This paper is the product of one of two required Individualized Learning Area projects that are part of the Antioch University Ph.D. program in Leadership and Change. The goals, strategies and activities used were as follows:

a) Perform background reading on major trends in engineering education by reviewing documents available from the National Academy of Engineering, the American Society for Engineering Education, and the National Science Foundation.

b) Review articles published since January 2003 in the *Journal of Women and Minorities in Science and Engineering (JWMSE)* and the *Journal of Engineering Education (JEE)* in order to identify broad what works to enhance the education of women in engineering.

c) From the readings performed, relate the identified trends in engineering education to those strategies and methodologies found to be effective in the education of women in engineering.

Introduction

Studies have shown that women and minority students still do not achieve degrees in STEM at the same rate as their white male counterparts.[1,3,4,6,8,13,16,21,25,29,30,32,40,41,42,43,51,52] There is a need

for more diversity within STEM fields, especially in engineering, which is the least successful of all STEM fields in recruiting and retaining women and minorities.[3,4,8,11,28,42,48,49] Natural and biological sciences have a higher percentage of women faculty, graduate students, and undergraduate students than do math, computer science or engineering. [1,16,30,32,47,52] Because of global competitiveness, social needs and the workforce shortage, a diversified STEM workforce is needed in the United States.[8,13,35,44,50] As Busch-Vishniac and Jarosz stated, "diversity is now seen as a business necessity driven by two primary factors: First, the globalization of business and the need to have an employee base that is both comfortable and accepted in a wide variety of cultures; and second, the desire to have a broad range of perspectives and experiences to enhance the function of engineering design so critical to product development".[8, p. 255]

There have been numerous studies and research during the last century about changing or restructuring engineering education. Many topics have remained the same over time, such as (a) what to include in the curricula, (b) how long engineering education should be, (c) what level of specialization, (d) how to prepare students, and (e) how to meet the needs of society.[41]

Although study topics have remained relatively constant, there have been increases in the speed of technological advances and the level of globalization. Engineering educators will need to adapt to these changes by taking three actions: (1) broadening their curricula to encompass cross-disciplinary education; (2) blending theory and practice in the classroom as well as collaborating with industry, communities, and society in general; and (3) attracting students from all walks of life.

The trends most prevalent in the engineering education literature reviewed were increased attention to (1) curricular flexibility, (2) continuous learning by students, and (3) diversity in engineering education. Increased curricular flexibility is sought so that students are able to take classes that integrate engineering with the social sciences, arts and humanities so students are better prepared to contribute as professionals in the working world. Continuous learning is being promoted so students become life-long learners able to keep up with the rapid changes and needs of the world. Increased attention to diversity has multiple dimensions: diversifying the faculty; bringing more women and minorities into the engineering field; providing instruction in a multiple ways; and diversity in experience.[39]

The general trend of developments in engineering education are in line with many themes and focus areas identified as ways to enhance the attraction and education of women in engineering. The themes are (1) historical male-domination of the STEM fields, (2) the need for intervention programs for women and minorities to keep their interest in STEM fields and (3) the need for educational system changes to include both curriculum and faculty role-models and influence.

The following sections show how the trends in engineering education are consistent with and supportive of the types of changes needed to draw more women into engineering.

Curricular Flexibility

The basic foundation to achieving flexibility in engineering curricula is ensuring cross-disciplinary learning. The cross-disciplinary learning has to be mutual. Engineering

departments and their faculty need to reach out to non-engineering departments and their faculty in order to share engineering knowledge as well as to be receptive to how to broaden engineering students' education to include aspects of social sciences, arts and humanities. "Engineering colleges must be more effective and visible partners within the broader university community. … Engineering deans should actively encourage their faculty members to participate in research, educational and leadership activities beyond the engineering college".[2, p. 7] The theme of changing the education system by encouraging cross-department integration of course material was suggested in the education literature as a way of retaining women and minorities in STEM programs. Because of the complexities of world issues, globalization and meeting society needs, students need to understand and make connections among disparate areas (e.g., environments, issues, topics). Cross-department integration affords the opportunity to prepare students for future careers by linking technical classes with course work in business management, liberal arts, entrepreneurship and systems thinking.[9]

The education literature emphasizes that faculty are rewarded for individualized work. If the classroom environment is to move from being hostile and competitive to being collaborative, faculty will need to be trained on teaming and collaboration so that they can model and promote these behaviors.[24,28,32,45,46] To ensure buy-in and support from faculty, they need to be rewarded more for teaming, collaboration, and working across departments and with industry than they are for individual accomplishments. Research trends suggests that enabling faculty to fully participate in the restructuring of engineering education and putting reward systems in place that encourage cross-disciplinary teaming and diverse ways of teaching would encourage faculty to adopt change.[7] This is strong evidence that faculty need to change the curriculum and how they teach and that they have to be partners in making the changes. Trends evident in studies have also suggested that partnering with industry, communities and government for exchange sessions and workshops would keep faculty current with the latest needs and issues. Curriculum enhancements should include faculty working with outside experts to ensure currency and breadth of information needed for industry work are covered. This also supports the theme of changing the education system and the need for faculty influence and acting as role-models to students.

Continuous Learning
One of the trends indentified in the literature was that continuous learning by students is critical because of the proliferation of engineering and technological knowledge. There is too much to learn in a traditional program. In order to get students ready for the working world, they must learn not only the basics of engineering but also how to be problem solvers, effective communicators, and team members. By working collaboratively with industry, local and global communities, and government, universities will better prepare students for work and will provide a foundation for continuous learning opportunities once students graduate. In the future, adequate preparation for an engineering career will require many more topics than can be covered in a traditional baccalaureate degree program. Continuous learning would ensure engineers maintain their currency and gain greater breadth as well as depth in relevant fields.

The point is made above that a rapidly changing knowledge base has made it difficult to put more and more knowledge into the curriculum. The literature on gender equity argues that engineering and other STEM fields already have too much in the curriculum.[8,43] Furthermore,

even though there has been a lot of research on what to keep, what to put off for later (continuing education), and what to get rid of, not much progress has been made in changing the curriculum.[8,30] Because of the relatively slow pace of change in the undergraduate curriculum, many of the desired changes in curricular content will have to be deferred to workplace-based continuous learning regimes. Themes reviewed in the literature on women in engineering suggest that curricular changes made to invigorate the engineering curriculum can also support increased participation by women. Therefore, the curricular changes originally targeted to the undergraduate curriculum that may instead appear within the context of continuous learning, can be seen as further supporting the retention of post-graduate women in engineering.

Diversity

Diversity is the most critical of all the trends. Without diversity in faculty, students, and programs, engineering education will not keep up with the needs of the world.

Diversity in Faculty

Faculty members who are members of underrepresented populations provide women and minority students with positive role models and mentors. More fundamentally, it provides the variety of viewpoints necessary for novel approaches to engineering challenges. As former president of the National Academy of Engineering, William. A. Wulf has noted in a different context, "As a consequence of a lack of diversity [in engineering] we pay an opportunity cost, a cost in designs not thought of, in solutions not produced".[55] Wulf also notes that engineering is a creative profession that thrives with diversity. "[The] creativity of individual engineers is dependent on their life experiences, and if everyone on a team has similar life experiences, you won't get much diversity of ideas. A diverse engineering team equates to more creativity and a better product".[38] Having cross-disciplinary faculty teams will enable students to gain a systemic view of the complexity of issues facing engineers. According to a National Academy of Engineering report, "Indisputably, engineers of today and tomorrow must conceive and direct projects of enormous complexity that require a new, highly integrative view of engineering systems".[41, p. 165]

Diversity in faculty is a trend that is recognized as instrumental in increasing diversity in the student body and is backed by the themes in the literature. Themes reviewed in the educational literature show that there is a lack of female faculty in STEM departments.[6,13] It has been shown that the presence of female faculty members in STEM fields is strongly correlated with the number of female students who become scientists/engineers.[16,30,43,51] Female faculty are more likely to experiment with innovative teaching methods and interactive classes which has been proven to appeal to many women and minorities.[18,24,51] Based on the trends and themes, it is critical for the success of STEM fields to ensure women and minorities are recruited and retained at all levels of academia and industry.

Faculty and student interaction is critical, especially for women because many women value personal interactions. Also, students need affirmation from faculty for confidence building. Many women and minorities tend to drop out of school and/or change out of STEM majors because of lack of or loss of confidence. Some won't even consider entering into a STEM major because of the lack of confidence and the feeling that they are not prepared nor have enough

experience.[16,22,32,34,57] It is important that women and minorities be able to see themselves as scientists and engineers. "An explicit goal of instruction should be to support students in developing identities that have an interest in, see value in, and have confidence in engaging in mathematics and scientific inquiry".[27, p. 246] Trends and themes support the fact that faculty need to be engaged with students to ensure persistence of students, especially women and minorities in STEM fields. "Prior studies identify classroom practices that promote collaboration and knowledge sharing as supporting the recruitment and retention of women in technical disciplines".[30, p. 276]

Diversity – Bringing More Women and Minorities into the Engineering Field

Diversity of students is critical because we need to tap into the talents of all people to meet the demands of engineering now and in the future. "[B]y 2050, almost half of the U.S. population will be non-white (U.S. Census Bureau, 2002)… the engineering profession will need to develop solutions that are acceptable to an increasingly diverse population".[40, p. 28] One way of ensuring a more diverse student population is continuing support for the trend of universities working with K-12 schools to bring awareness of engineering as a career field, awareness of the benefits and rewards of pursuing an engineering degree, and awareness of the proper preparation required to successfully enter (and successfully complete) an engineering degree program. Themes identified in the literature support this trend. The main theme throughout most of literature reviewed was the value of intervention at each academic level in preparing women and minorities for the next level: elementary school to middle school, middle school to high school, high school to undergraduate studies and on into graduate, doctorial and post-doctorial studies and finally into academia (faculty) and industry.[5,6,13,15,29,31,42,44,47,50,52,54] "Particular attention must be paid to transition points along that continuum…because women and minorities leave the engineering path at each of these transitions in greater proportions than non-minorities and men".[13, p. 79] Interventions can be applied in many ways to include networking, mentoring, hands-on experience, collaborative/team work, relating STEM to real-life, and promoting the social relevance of STEM fields.[4,24,29,51,52] Women and minorities usually do not possess the same types of experiences that white males do entering into college because of lack of resources in their schools, lack of interest in STEM fields (possibly because the social relevance is not clear), or lack of awareness of STEM fields.[3,12,21,30,35,47] Partnering of middle or high school faculty with university faculty to explore strategies for integrating science and engineering into the classrooms is a critical component of intervention.[10,17] Also, the partnering of academic and work-based intervention programs can show young women and minorities future career opportunities while also providing role models.[53]

Diversity – Multiple Ways of Providing the Education

Diversity in engineering programs, both in what degrees are available and how education is provided, is essential to the success of engineering education. "The overall goal of engineering curricula should be to develop engineering graduates who are professional contributors and lifelong learners capable of succeeding in the current and future global, multi-disciplinary markets".[39] A clear trend in the literature is to show that making engineering studies more attractive to women and minorities requires moving beyond the traditional classroom lecture. Students need to be aware of the ramifications and practicality of engineering in solving broad

global and national societal concerns as well as issues in their local communities. Getting first year students involved in research and practical learning seems to help in retaining students. Another way of retaining students is having different methods of teaching to take into account the different learning styles of students. For example, including classroom lectures, team projects, interactive-technology driven assignments, lab/research activities, and other activities into the curriculum all contribute to higher levels of retention. Universities need to take this into account as they reform their curricula.

Themes in the literature on women in engineering support the trends of providing education in diverse ways. Computer designs, websites and other digital resources frequently do not reflect the design and content preferences of female students and thus fail to elicit their interest in STEM.[1] Changes to curriculum and tools used need to take this into consideration. Many resources are available to help faculty change the curriculum, classroom environment, or teaching methods to recruit and retain women and minorities.[7,9,17,28]

The literature notes that engineering majors have limited flexibility in their paths to degree attainment. This causes lack of interest among many who might otherwise enter engineering fields, because other fields have multiple options for degrees.[8,35] Many researchers believe that gatekeeper courses can cause undo pressures, foster too much competition among students, and are not conducive to teamwork among students.[8,11,32,42,43] "Many academically capable students that left the STEM track appeared to have become disenchanted by teaching methods that focused on 'weeding-out' less-determined students".[42] To help retain first year college students, the faculty and schools need to incorporate research and hands-on exercises up-front in the curriculum, instead of just lectures and theories.[8,43,51] Additionally, the curriculum and faculty should reference diverse populations in the examples used; women and minorities should be incorporated into references, lectures, readings, and other course work.[8]

Diversity in Experience

Finally, enhanced global awareness and experience are critical if the U.S. is to maintain an equal footing with the rest of the world in engineering. Many countries are working on ensuring quality engineering education and diversification. Global awareness would ensure an appreciation of different cultures and business practices. To guarantee that the U.S. remains competitive, STEM fields have to be seen as advantageous careers. Current stereotypes of those with an interest in STEM – as geeks, nerds, or generally anti-social individuals – turn off many women and minorities. In fact, some white males are also turned-off by the stereotypes. It is important to make STEM professions more attractive.[8,14,34-36,56]

Engineering is seen as an elite field that is dominated by white males.[4,20,26,33,49] Science as traditionally practiced is based on male cultural norms. With STEM fields based on male cultural norms, the appeal to women and minorities is likely to be less pronounced. Many women and minorities feel marginalized and face chilly environments.[3,8,21,22,35,37,43,49,50] The literature shows that women are leaving STEM fields not because of insufficient academic preparation or performance, but because of these feelings of isolation.[5,8,43,57] The environment for studying STEM fields, especially engineering, needs to change from exclusion to inclusion, from competition to collaboration, and from narrow specialization to appreciation for diverse

ideas.[8,18,34] Emphasizing interaction with other people and the prosocial aspects of STEM work make more apparent are ways to appeal to more women. Stressing social relevance and the value to subcultures are ways to appeal to more minorities. [22,43] Recruitment and retention efforts need to emphasize an inclusive atmosphere in order to make attract more women to undergraduate study in STEM fields.

Other Areas of Focus

Other areas covered in the literature included the role of alumni and how they can be mentors and role models to encourage women and minorities to pursue STEM careers.[51] Family support plays a key role in the level of interest shown by women and minorities in STEM fields.[15,27,47] "[P]arents and teachers…play a strong role in the development of students' self-concept, perceptions, expectancies, and values".[21] Recruiting and out-reach programs can help in making STEM careers more attractive to women and minorities by addressing work/life balance.[13,14,43,51] Direct student support is also important. Financial-aid as well as investments in student lounges, tutorial services, lab assistants, seminars, clubs, etc… foster teaming, collaboration, inclusion, and help build confidence and support environments that are conducive to women and minorities persisting in their field of studies.[13,21,35,51]

Conclusion

The major trends in engineering education drawn from the literature are the need for greater attention to (1) curricular flexibility, (2) continuous learning by student, and (3) diversity in engineering education. In reviewing the education literature, these trends are supported. Themes identified in the literature on women in engineering included (1) the value of intervention to attract and retain women, (2) the importance of curriculum changes which highlight faculty as role models and (3) the negative impact of the current male-dominance of STEM fields. The literature on these themes all have examples and actions to support the trends for the future of engineering education specifically and STEM fields in general.

Review of the literature did not reveal any silver bullets to ensure that more women enter and stay in engineering specifically or other STEM fields. Many small things add up to make a supportive, female-friendly environment that is successful in recruiting and retaining women in STEM.[21,43,50,51] Also, looking at gender alone to understand why there is a lack of participation of women in STEM fields isn't the answer.[21,23,25,48] Each STEM field is unique in its educational frameworks, pedagogical conditions and economic opportunities.[34,43] Further studies and research are needed to look at individual majors as well as women within minority groups.

It is critical to understand that in order to be successful in enhancing diversity, there is a need for change, cooperation and collaboration among universities, communities, industry, and government. Without full faculty and student participation, change will not be successful. Faculty have to be willing to step out of the norm/traditional educational approach to meet the demands now and in the future and to engage students so the students want to stay in engineering. As NAE president, and former MIT president, Charles Vest has observed, "In the long run, making universities and engineering schools exciting, creative, adventurous, rigorous,

demanding, and empowering milieus is more important than specifying curricular details".[41, p. 162]

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