AC 2012-5260: LEADERSHIP AND SERVICE LEARNING IMPROVES CONFIDENCE OF ENGINEERING SKILLS IN WOMEN

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Leadership and Service Learning
Improves Confidence of Engineering Skills in Women

Abstract

As part of an undergraduate first-year engineering course, a five-week module on leadership was offered in addition to two other modules focused on more traditional engineering topics, bioengineering and mechanical engineering. Students were able to choose two out of the three modules as part of their requirement for the course. The leadership module presented mechanisms for developing professional skills and also provided hands-on application of these skills through K-12 service learning at a local science museum. Because women tend to be drawn to engineering sectors that give back to society, we hypothesized that the confidence levels of women would reflect the benefit of the leadership module.

To assess the impact of the module, we developed a survey based on the eleven ABET criteria and the National Academy of Engineering's (NAE) ten criteria. We also asked open-ended questions for student feedback on the course. The survey was administered to all students at the beginning (pre-course) and end (post-course) of the semester. Results from our pre- and post-course surveys reveal that women in our leadership module increased their confidence in all of the amalgamated NAE-ABET engineering skills while women who did not participate in our module showed no significant increased confidence in these skills. Furthermore, we found women's confidence in the leadership module to have improved considerably compared to men in all modules. Finally, qualitative responses from women indicate overwhelming appreciation for the experience and skills gained from the leadership module, as well as an increase in confidence for women as engineers.

Introduction

Professional skills are often underemphasized in engineering programs. These "soft" skills – proficiencies such as leadership, teamwork, and communication – are important attributes of a successful engineer. Traditional engineering curricula and lecture formats need to be revised to enhance these professional skills, as "the quality of future engineers depends very much on the quality of engineering education"[1]. Service learning and design projects are new pedagogical methods found to be effective in nurturing these skills[2,3]. Moreover, service learning has the potential to attract and retain women in engineering[4]. This paper explores the development of professional and leadership skills in the context of a service learning project and its impact on first-year women enrolled in engineering.

Professional Skills

A survey of professionals, academics, and students found that engineering education failed to develop the skills and attributes of engineers desired by industry[1]. Many engineering programs offer a strong emphasis on technical competence but poor training in non-technical attributes. Thus, engineering students often graduate weak in essential skills such as communication, management, leadership, decision-making, and teamwork[1,5]. Instead, these professional and leadership skills are usually learned the hard way – through experience in the workplace as a professional engineer[3]. The importance of these attributes is also underlined by its close alignment with the skills delineated by ABET[28]. The skills outlined by ABET are (a) an ability to apply knowledge of mathematics, science, and engineering; (b) an ability to design and conduct experiments, as well as to analyze and interpret data; (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability; (d) an ability to function on multidisciplinary teams; (e) an ability to identify, formulate, and solve engineering problems; (f) an understanding of professional and ethical responsibility; (g) an ability to communicate effectively; (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context; (i) a recognition of the need for, and an ability to engage in life-long learning; (j) a knowledge of contemporary issues; and (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Previous studies have shown that professional skills can be taught, and they greatly enhance the experience of students[2,5]. Traditional lecture formats can be ineffective, and innovative techniques such as active and cooperative learning, service learning, and real world experiences can help nurture and grow these skills[2,3]. Through such approaches, students are more engaged and show greater interest[6,7].

Women in Engineering

Highlighting engineering as contributing to society through service learning is more appealing to women[4,8]. Furthermore, Fouad and Singh[9] recommend promoting the human-value of engineering and supporting women's self-efficacy not only in technical skills, but career management and workplace skills and behaviors to recruit and retain women in engineering.

Self-efficacy and confidence are important factors for recruiting and retaining women, as most women who drop out of engineering report lower confidence in engineering skills even though their competence is comparable with the men and women who stay enrolled in this major[9-11]. Moreover, women generally tend to rate themselves lower than men do in terms of self-efficacy and confidence in engineering[6,12]. In a survey of female engineering alumni, Robinson and Reilly[8] found that women rated self-confidence and communication as the most important elements for professional success and advancement and wanted "the technically oriented college environment" improved to promote these attributes. Innovative approaches such as real world engineering projects can increase women's confidence[12]. As such, we hypothesize that a service learning engineering course with an emphasis on professional skills will better recruit and retain women by increasing their confidence in engineering skills. Zhang and RiCharde[13] found that self-efficacy, closely related to self-confidence, is a positive predictor of first-year student retention. Thus, implementing such a course in the first year could help retain women earlier in the pipeline.

Service Learning and First-Year Design Courses

As mentioned previously, service learning has been found to be effective not only for fostering professional skills, but also recruiting and retaining women[2,4]. Service learning is the implementation of classroom learning with service in the community[14]. Service learning complements engineering because students can work on projects that are beneficial to the community and to local organizations. Not only are students helping the community, they gain real world experience in design and engineering[15]. Service learning also aligns well with much of the ABET criteria[16,17]. Service learning in the context of outreach teaching has been shown to improve women's confidence and retention[38]. It has also been shown that students engaged in such experiential learning opportunities have better retention of technical knowledge and are better able to apply what they have learned in college courses to real life situations after graduation[18-22].

The National Science Board[23] noted that students "develop little identity as engineers in their first two years of college because they take math and science courses and have little exposure to the engineering practice." However, through design projects such as service learning projects, students are exposed to engineering early on, as recommended by the National Research Council[24]. First-year design courses, or cornerstone courses, are beginning to appear in engineering curricula[25], and have been found to have positive impacts on students[25-27]. First-year design courses enhance student interest in engineering, motivate learning in upper division technical courses, and improve retention rates, especially among women and minorities[25].

Course Format

Engineering Design and Analysis is a freshman level course that offers an introduction to the profession of engineering through a variety of modular projects and laboratories. The primary learning objectives of the course are based on criteria for graduating competent engineers as recommended by the National Academy of Engineering (NAE)[39] and ABET[28]. Four weeks of the semester comprise general lectures that provide an overview of the engineering profession and include the topics of failure analysis, design methodology and human-centered design, societal context of engineering, as well as leadership and ethical considerations in engineering as a discipline. Following the general lectures are two sets of five-week modules.

For the semester in which this study took place, a five-week module on leadership was offered in addition to two other modules focused on more traditional engineering topics, bioengineering and mechanical engineering. Each module was taught by a different instructor. Students chose two out of the three modules to enroll in. The leadership module presented mechanisms for developing professional skills and also provided hands-on application of these skills through K-12 service learning at a local science museum. Students in the leadership module engaged in outreach teaching and, for the final project, developed a framework for the engineering design process at an exhibit activity for visitors to the museum. In essence, students worked with the science museum as a client and engaged with other stakeholders, the visitors, to develop their final designs in which they implemented the engineering design process in actual interactive exhibits.

The lecture sections of the leadership module provided the framework for development of the core competencies[28]. A central focus of the leadership module was the three "C"s of leadership: *competence*, *compassion*, and *chronos* (time management). The module offered methods for developing personal and team leadership styles; addressed differences in learning and personality styles; presented pathways for implementing mission statements and plans of action; offered opportunities for strategic thinking, problem solving and brainstorming; utilized teamwork in diverse settings; and implemented K-12 service learning through outreach teaching activities. Table 1 provides a summary of the lecture topics provided within the leadership framework.

Table 1. Lecture topics in the leadership module

Development of Self: Development of 3Cs of leadership: *competence*, *compassion*, and *chronos* (time management). Assessment of personal strengths and weaknesses. Building congruency, trust and ethical standards (development of a personal mission statement). Life balance and time management as a practice. Awareness of body language and voice. Strategic thinking and problem solving. Creativity, brainstorming and innovation. Review of primal leadership styles (visionary, coaching, affiliative, democratic, pacesetting, and commanding)[29]. Assessment of personal leadership styles.
Diversity and Teamwork: Assessment of personality styles (Introverted vs. Extraverted; Intuitive vs. Sensing; Thinking vs. Feeling; Judging vs. Perceiving)[30]. Assessment of learning preferences (Global vs. Sequential; Intuitive vs. Sensing, Active vs. Reflective; Verbal vs. Visual)[31]. Decision trees and methods for mentoring. Group communication and conflict management tools[32]. Development of a plan of action (formulation, negotiation, fulfillment, and review). Project lifecycles and rhythm of action for teamwork.
K-12 outreach: Levels of learning based on the revised Bloom's taxonomy (remembering, understanding, applying, analyzing, evaluating, and creating)[33]. Teaching methodologies in the K-12 domain and the public sector. Assessment tools.

In the first week of the module, the students were assembled into teams of three to six based on learning styles[31], the premise being that diverse groups can enhance outcomes and provide a more well-rounded educational exhibit[34,35]. Undergraduate teams met in a lab for three hours each week and also independently conducted user needs research through exhibit facilitation for two hours per week. The hands-on aspect of the leadership module (three hours per week) is based on the "Engineering is Elementary" design process loop developed by the Museum of Science, Boston[36]. The service learning project required the students to interact directly with K-12 learners and apply a facilitation strategy for making the engineering design process explicit to museum visitors, thus providing the museum with an implementable design. In the final week, students wrote a technical report and gave oral presentations on their research and exhibit design to museum employees. The professional reports developed by the freshmen outlined their engineering design process and how they implemented their project in a way that a layperson could understand the "thought process of an engineer." The oral presentation served as their professional "marketing" pitch to the client (the museum). Student grades were based on the quality of their implemented project as well as on the technical quality of their written report and oral presentation (communication skills).

Research Question

We sought to assess the impact of an engineering course with an emphasis on "soft" skills on women. In particular, our research question is: What is the impact of an engineering leadership module, focusing on professional skills and service learning, on the confidence of women in engineering skills?

Because women tend to be drawn to engineering sectors that give back to society, we hypothesized that the confidence levels of women would reflect the benefit of the outreach teaching and service learning aspect of the leadership module.

Methods

Participants

The students in this study were comprised of all the students in the Spring 2011 *Engineering Design and Analysis* first-year course. The course surveys were given at the beginning and the end of the course and we have a total response rate of 113 out of 125 students (90%) that returned both surveys. Of those students that took the leadership module, 62 out of 67 (93%) returned both surveys. Of those students that did not take the leadership module, 51 out of the 58 (88%) returned both surveys. The gender breakdown of the students within the leadership module that returned both surveys was 19 women and 43 men. The gender breakdown of the students not in the leadership module that returned both surveys was 15 women and 36 men.

Surveys

We distributed pre- and post-surveys to all students in the course. The survey asked students to "perform an honest self-assessment of the extent to which" they possess the engineering traits as described by the NAE-ABET criteria in Table 2. The students performed the self-assessment of the NAE-ABET engineering traits using a 1-5 Likert scale where 1 is Low, 2 is Medium-Low, 3 is Neutral, 4 is Medium-High, and 5 is High. In order to test for statistical significance, a two-tailed Student's t-test with equal variance was utilized with a confidence level of both 95% and 90%. Both surveys were given at the beginning and end of the course. The NAE-ABET survey also asked qualitative questions at the end of the course.

Table 2. Necessary skills for competent graduating engineers as defined by NAE and ABET; engineering traits designated "professional" traits (soft skills) are highlighted.

	Engineering Traits
a.	Possess strong analytical skills
b.	Exhibit creativity and practical ingenuity
c.	Ability to develop designs that meet needs, constraints and objectives
d.	Ability to identify, formulate, and solve engineering problems
e.	Good communication skills with multiple stakeholders
f.	Good team skills with people from diverse backgrounds and disciplines
g.	Leadership and management skills
h.	High ethical standards and a strong sense of professionalism
i.	Dynamic/agile/resilient/flexible
j.	Ability to learn and use the techniques and tools used in engineering practice
k.	Ability to recognize the global, economic, environmental, and societal impact of engineering design and analysis

It should be noted that the survey utilized by the authors in this paper is based on an amalgamation of the National Academy of Engineering Criteria for the Engineer of 2020[39] and ABET accreditation criteria[28] as both organizations are considered to be highly authoritative on the skills and traits that competent engineers within the United States should possess. Tables 3 and 4 show the original NAE and ABET criteria.

Table 3. NAE Criteria for Engineers[39]

	National Academy of Engineering Criteria for The Engineer of 2020
1	Possess strong analytical skills
2	Exhibit practical ingenuity
3	Exhibit creativity
4	Good communication skills with multiple stakeholders
5	Possess business and management skills
6	Possess leadership skills
7	High ethical standards
8	Strong sense of professionalism
9	Possess dynamism, agility, resilience, and flexibility in an uncertain and changing world
10	Be lifelong learners

Table 4. ABET Student Outcomes Criteria[28]

	ABET Engineering Criteria
a.	An ability to apply knowledge of mathematics, science, and engineering
b.	An ability to design and conduct experiments, as well as to analyze and interpret data
c.	An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
d.	An ability to function on multidisciplinary teams
e.	An ability to identify, formulate, and solve engineering problems
f.	An understanding of professional and ethical responsibility
g.	An ability to communicate effectively
h.	The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
i.	A recognition of the need for, and an ability to engage in life-long learning
j.	A knowledge of contemporary issues
k.	An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Results

Within the leadership module, we found that students' confidence in engineering and leadership skills were higher at the end of the course than at the beginning. In particular, the confidence for women that partook in the leadership module improved much more than that for women that did not take the leadership module. We found that this focus on leadership skills also yielded increased confidences in technical skills instead of a decrease.

Leadership module improved confidence in engineering and leadership skills for women

All students in the course were given a pre- and post-survey, where students assessed their own confidence in engineering skills, as delineated by NAE-ABET. These skills are listed in Figure 1 (and in Table 2) along with the average change in confidence for students in the leadership module and students not in the leadership module. As seen in Figure 1, the only significant improvements were for students in the leadership module. Female students in the leadership module increased their confidence in all but one of the eleven NAE-ABET skills of Table 2, with statistical significance in the following five skills: recognize global impact*, develop design**, engineering problems**, use techniques/tools**, strong analytical skills* (*$p < 0.10$, **$p < 0.05$). The only skill in which these women's confidence did not increase was the ability to be dynamic, agile, resilient, and flexible. In stark contrast, women that did not take the leadership module experienced decreases in their confidence in many of the skills: recognize global impact, use techniques/tools, ethics, engineering problem solving, develop designs, creativity and ingenuity, and analytics skills, although the only statistically significant decrease at $p < 0.10$ was for recognizing global impact. In fact, women in the leadership module increased their confidence in four of the skills by almost a full point (25% of the Likert range) more than the

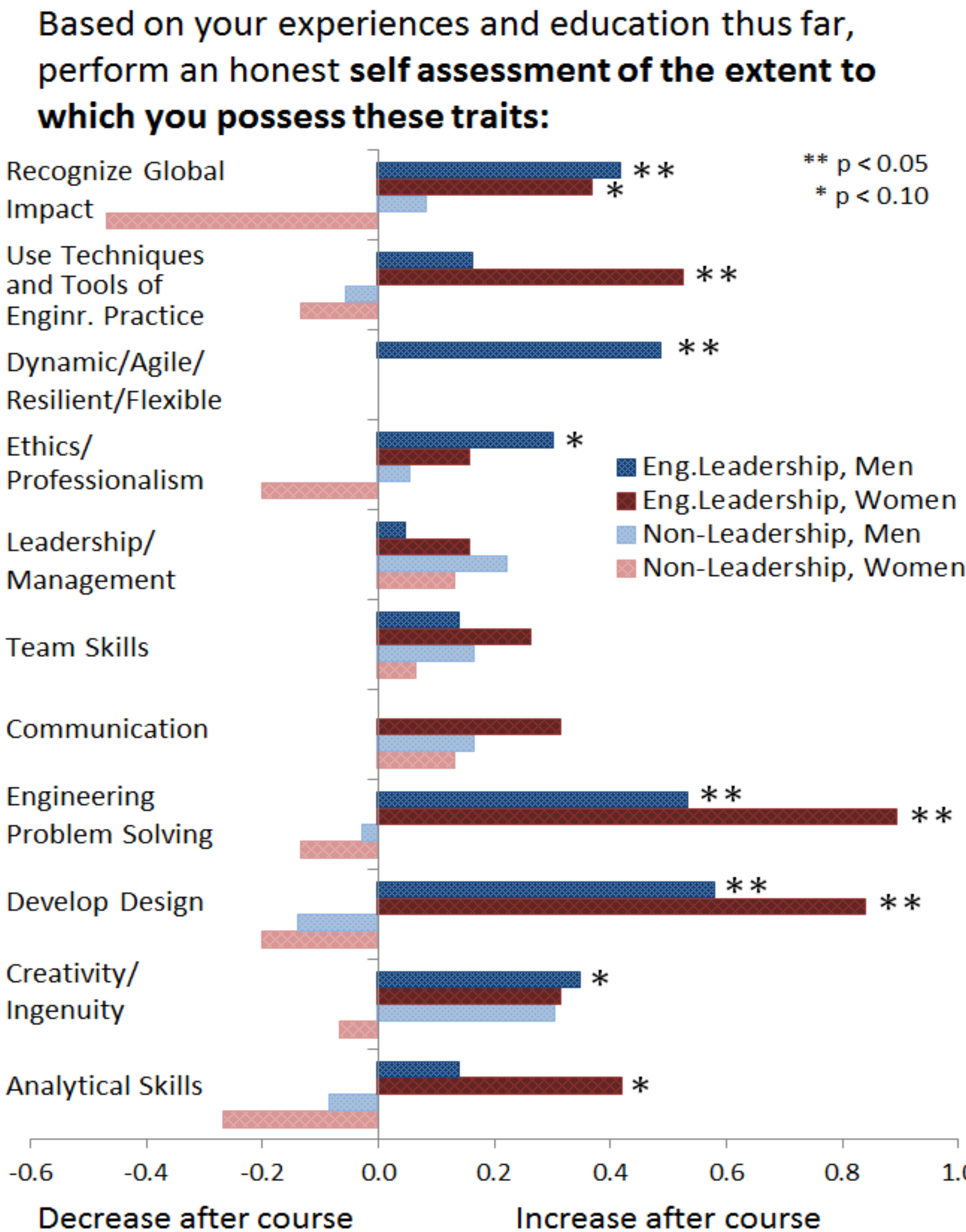

Figure 1: Average change in men and women's self-assessment of ABET skills for students that took the engineering leadership module and students that did not take the leadership module. N = 51 students not in the leadership module (88% response rate); N = 62 students in the leadership modules (93% response rate). Data points without a bar signify no change after the course.

women not in the leadership module (see Figure 1). For almost all skills, women in the leadership module also reported greater increases in confidence than men that did not take the leadership module (see Figure 1).

These improvements were not due to differences in confidence at the beginning of the course between those who did and did not take the leadership module; at the end of the course, all students in the leadership module, especially women, reported overall higher levels of confidences than students that did not take the leadership module (Figure 2). Specifically, students in the leadership module reported higher confidence for developing design, engineering problem solving, using techniques/tools, and recognizing global impact. Students not in the leadership module were only more confident than the students that took the leadership module in creativity. Also notable is that at the beginning of the course, women in general tended to report lower levels of confidence than men for technical skills such as engineering problem solving, developing designs, and analytical skills. By the end of the course, though, women reported higher confidence than men in several of the professional skills, such as communication, team skills, leadership, and ethics. In the leadership module, women also reported higher confidence than men in using the techniques and tools of engineering and in recognizing global impact.

The improvements in confidence for women in the leadership course did not come at the expense of men. Men in the leadership module showed a significant increase in confidence in even more skills than women had (Figure 1). Additionally, for most of the skills, men in the leadership module reported greater increases in confidence than men who did not take the leadership module.

Focus on professional skills in leadership module does not compromise confidence in technical skills

These results also show that students in the leadership module still reported increases in confidence of their technical skills, such as using techniques and tools of engineering practice, engineering problem solving, developing designs, and analytical skills (see Figure 1). In fact, these were some of the skills with the largest amounts of improvement. These improvements are especially notable compared to students that took the technically-focused engineering modules instead of the leadership module.

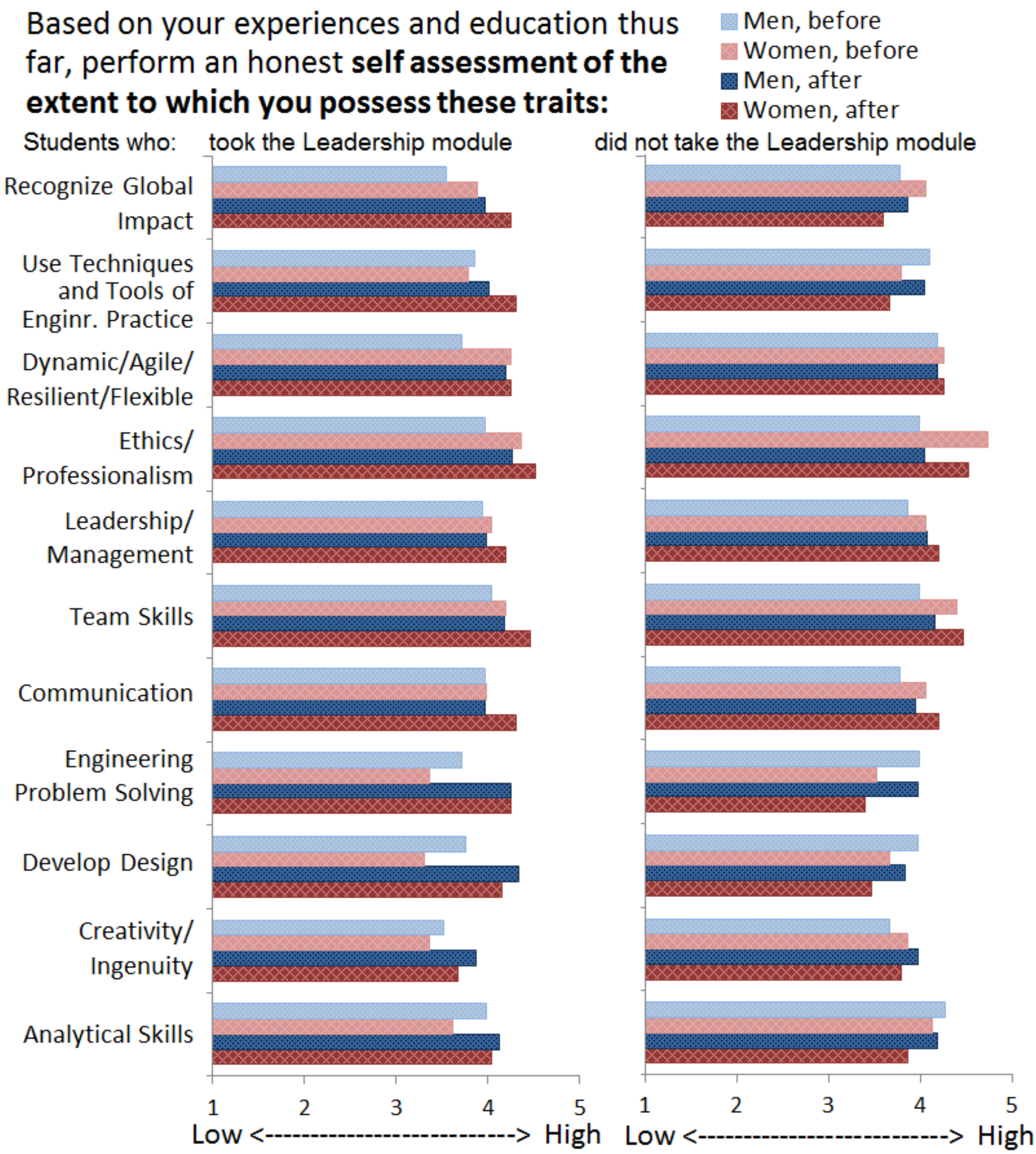

Figure 2: Average responses for self-assessment of ABET skills at the beginning and end of the course for men and women who did and did not take the leadership module. N = 51 students not in the leadership module (88% response rate); N = 62 students in the leadership modules (93% response rate).

Qualitative feedback from women

A majority of the post-module survey comments from female students in the leadership module expressed overwhelming appreciation for the class, as they felt they had learned practical engineering and broader skills, they enjoyed working on such a unique and socially-relevant project, and they felt that the module was worthwhile and enjoyable.

Many of the comments from women indicated the usefulness of the skills and lessons taught in the module. Several women spoke of the skills' utility not only in school, but also in a career as a professional engineer and in their own personal lives. Only one noted that the module was not relevant to engineering. Women's comments on the usefulness and applicability of the professional and leadership skills include:

"Lessons taught were very useful and applicable."

"I felt that this class taught me the fundamentals of being an engineer and how to be a leader."

"Engineering Leadership was a very informative and useful course. The material presented during lectures was applicable and useful in our real and current lives. Lessons on things like time management, organization, and leadership were interesting and it was helpful that we were receiving this information from professors and [teaching assistants] as opposed to our parents, whom we usually tone out because it comes across as annoying nagging."

"I learned a lot of potentially important skills [for] not only my professional career but also [for] school."

"The leadership module is very beneficial for those who will work in teams in the future. The module is very effective at advising how to manage and maintain a productive team. It gives a prototype on how effective teamwork can produce a competitive design."

"Although [the leadership module] was only [a] five-week class, I started to see the field of engineering from a different view. This module taught me that engineers are the future leaders. In addition, it encouraged me to improve my leadership skills. It gave me an insight about which skills leaders have and how I can improve these leadership skills."

Moreover, women commented positively on the context of the module at the science museum, the Lawrence Hall of Science (LHS), and the socially-relevant and authentic project:

"Working with LHS was fun."

"Compared to other modules, [the leadership module] seemed to push us a lot more. But it was actually a good thing since we [were] able to engineer something to profit the community."

"… the project that we did in this module as a group was the best part of [the leadership module]. It helped me to see the practical aspects of everything that we covered in the lectures such as time management or conflict resolution."

"I also really liked how we could implement what we learned in projects and user needs research hours at LHS. Many classes at Berkeley do not offer experiences like this module offered where we got to interact in an enjoyable way with children in an outside setting."

Finally, women also provided very positive feedback on the module itself:

"I felt like it was the best module offered."

"I really enjoyed the lectures and the breaking down of the different qualities in good leaders."

"I enjoyed engineering leadership a great deal. It was very well run and organized. The lecture topics were very engaging and helpful. "

To end with, we provide one last quote from a female student who was afraid of her inability to perform and the impact the module had on her:

"At the beginning, I [was] scared ... and I even wanted to switch it to another module because of my limited speaking and leadership abilities. However, now I know that this class taught me a lot and opened the way to improve myself ... I want to further improve my leadership skills and it was this module that showed me the necessity of it. Thank you for enlightening and supporting us!!"

Discussion

In this study of a first-year, introduction-to-engineering course, we found that women seemed to especially benefit from an engineering leadership module that focused on professional skills, outreach teaching, and service learning. This benefit did not come at the expense of either the improvement in confidence for men or improvement in confidence in technical engineering skills. These results are similar to results from previous research on the impact of service learning and professional skill development on women engineers[4,37,38].

There are several reasons that might explain why the leadership module helped increase the confidence of women. One factor that could have contributed to this increase in confidence is the disproportionately high representation of women in the teaching staff of the leadership module, including the female professor and museum clients. Additionally, women generally rate their self-confidence lower than men in technical engineering skills[6,12]. Thus, their greater increase in confidence may have resulted from a lower initial rating. Furthermore, women who might have especially been able to benefit from this type of course may also have self-selected into the module. However, we know of at least one female student that selected the leadership module despite fear she would perform poorly.

Finally, what we believe to be the main reason for the increase in confidence is that through its focus on leadership and service learning, our module may have been more authentic, useful, and personally-relevant to women compared to other engineering courses. The module emphasized a hands-on experience, working with a real client and real end-users to solve a socially oriented problem. Teamwork was necessary as students had to work together in a quick five-week module to both collect data while working at the exhibit and develop a final project to be presented to the client. Women are drawn toward careers that are viewed as contributing to society[4], so this focus on a non-technical, real-world project might have piqued their interest and been more accessible for their first-year level abilities. This may explain their increase in confidence after participating in the leadership module and implies greater potential for staying in engineering instead of switching majors after the few plug-and-chug courses during the first two years of an engineering program. Even though it was still early in their academic program, women in the module indicated their appreciation and enjoyment of the course in comments left on the surveys.

Further limitations

We also note a limitation of our study that could contribute to the increase in confidence of all students, both men and women, in the leadership module: each module had a different instructional team. The effectiveness of an instructional team certainly plays an important role in student learning and could account for some of the differences seen among the modules. Unfortunately, controlling for this variable by breaking the class into more sections and having the instructors cover multiple modules teaching redundant material was not practical for this study.

Furthermore, one limitation of a survey-based study is an inflated average increase in confidence, since those students that did not turn in both surveys were probably those not as engaged in the course; however, completion rates of the NAE-ABET survey were similar for both leadership and non-leadership modules and should not affect the final trends. Another limitation is that the surveys themselves were students' self-assessments of their skills and we did not correlate confidence with module grades or other external assessments of skills. A review of recent studies assessing professional skills published by Schuman et al.[2] demonstrates that significant challenges exist in effectively evaluating these skills; those that exist often address skills individually and have little assurance of transferability to real world situations. This distinction between confidence and skill is important, though confidence often correlates with achievement[11]. Thus, we believe our findings of increased confidence imply related increases in skill. Future studies may further explore the relationship between students' confidence and their actual skill set improvement to investigate more effective methods of assessment. Actual retention rates and continued survey-based assessment, as they become available, will provide a better long-term understanding of our impact on students, especially women.

Finally, with more emphasis on professional and non-technical skills, there is often a concern that technical skills will be compromised. Though our study did not directly assess technical skills and abilities, we believe that our finding of an increase in confidence in technical ability is an important indicator of improved technical performance, as the related concept of self-efficacy is found to be a reliable predictor of performance as well as persistence[11]. Additionally, in teaching professional skills, there is no need to neglect the technical skills so important to engineering. Instead, teaching professional and leadership abilities may complement and reinforce technical skills.

Conclusion

In our implementation of a leadership module, we found that a first-year course with emphasis on professional and leadership skills through service learning may improve the recruitment and retention of women in engineering. Results from our pre- and post-surveys show that women in our leadership module had a greater increase in confidence in NAE-ABET engineering skills compared to women not in the leadership module. Their confidence also increased more than the men's confidence for men in the leadership module and men not in the module. Thus, with an increase in confidence, these women are more likely to persist in engineering[9-12]. Long-term follow-up on these students will determine the actual retention.

For now, this study suggests that professional skills can and should be taught. Engineers in industry emphasize the need for professional skills and point out this weakness in engineering education. These skills supplement and reinforce the many technical and theoretical courses already a part of the engineering curricula. We found no loss in confidence in technical expertise or learning in our young engineers. With the realization and implementation of programs emphasizing the professional skill set, we can foster and sustain a broader and more diverse set of engineers that are well-equipped for the real world.

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