GENDER DIFFERENCES IN SKILLS DEVELOPMENT IN HANDS-ON LEARNING ENVIRONMENTS

Daniel W Knight¹, Lawrence E. Carlson² and Jacquelyn F. Sullivan³

Abstract – Women’s participation in engineering education is low relative to their presence in the general and college student populations, and it is sometimes assumed that the competitive engineering culture has a detrimental effect on women’s confidence in their engineering skills. The described study investigated self-assessed confidence in five engineering skills across three K-16 curricular initiatives conducted by the Integrated Teaching and Learning Program at the University of Colorado at Boulder during a two-year period. In this investigation, attention is paid to gender differences in skills self-assessment and the reasons underlying gender disparity in engineering education. The effects of engineering and pre-engineering curricula on gender, with respect to student confidence in a number of skills necessary to succeed in engineering, are investigated. Results are discussed with respect to the structure of gender-friendly curricula and strategies for closing gender gaps. Suggestions for future research are presented.

Index Terms – Gender, Retention, Self-Confidence, Skills Assessment, Women in Engineering

INTRODUCTION

Relative to their numbers in the general and university student populations, the representation of women in undergraduate engineering education is low. Women make up 51% of the U.S. population and 55% of the undergraduate population at four-year institutions, but only 20% of first-year engineering students. [1]

Retaining women in engineering education programs is an additional challenge. On average, 70% of entering women drop out of undergraduate engineering programs, compared to a 40% overall rate for undergraduate students. [2] The origins of these female participation and retention rates in engineering education have been traced back to the middle school years. Pre-adolescent girls and boys show an equal aptitude and interest in technical coursework. But, from the teenage years onward, female enthusiasm and skills plummet. Since 1970, 13-year old boys have outperformed girls in science testing. [3] Also, 81% of middle school girls report liking math, while that number drops to 61% by high school. [4] These trends continue throughout high school; in 2002, women made up only 14% of the high school students who took AP computer science exams (down from 17% in 1999), and 30% of AP all physics exam takers. [5] With this study, we explore some of the reasons for this gender disparity in engineering education and investigate the effects of engineering and pre-engineering curricula on gender with respect to student confidence in a number of skills necessary to succeed in engineering.

Why Do Women Drop Out?

A number of reasons have been cited for the low level of retention for women in engineering education. These reasons are typically traced to a competitive, masculine, unsupportive engineering culture and its effect on eroding female confidence. [2] This culture adopts a competitive “weed out” mentality initially developed by the faculty to challenge young men. Surviving this culture with one’s own wits and little support is considered as a right of passage to an elite fraternity. This same culture is alien to the experiences of young women who have been socialized to work cooperatively for approval rather than competitively to win. When approval is not forthcoming, women mistakenly assume they must be poor performers. The cumulative effect of this culture can crush women’s’ confidence.

Researchers have identified gender gaps in confidence — situations in which women enter undergraduate engineering programs with less confidence in their engineering skills than their male counterparts. [6, 7] These researchers have also found that students with lower confidence in their skills are an increased retention risk in engineering colleges.

Gender-Friendly Curricula

Over the years, various types of curricula have been developed to help recruit and retain more women into technical fields. Five categories have been used to classify these types of interventions: 1) printed and audiovisual material, 2) short-term interventions including classes, workshops and guest speakers, 3) long-term efforts including courses and support programs, 4) experiential learning, including internships and field placements, and 5) teacher education programs. [8] The Integrated Teaching and Learning (ITL) Program at the University of Colorado at Boulder (CU) conducts curricular initiatives that fit all these categories. [9]
Although not all ITL curricula target gender explicitly, all initiatives are designed to be “gender-friendly,” and include educational objectives and components designed to appeal to a wide demographic population. For this study, five educational objectives were investigated across ITL curricula:

- **Knowledge of engineering as a career** — this includes knowledge of the type of work engineers do, the ability to distinguish engineering from other professions, and knowledge of the educational background needed to obtain an engineering degree;
- **Knowledge of engineering methodology** — this includes computer, mathematical, and basic scientific skills;
- **Design skills** — this includes knowledge of the design process, ability to work with hardware, and skill at translating and working within client requirements;
- **Communication skills** — this includes presentation, report writing and listening skills; and
- **Teamwork skills** — this includes knowledge of team dynamics, ability to fill team roles, and skill at working towards a cohesive viewpoint.

Knowledge of engineering as a career is an important introductory objective for female students who are less likely than male students to have had an exposure to the engineering profession. [10] The last two objectives, communication and teamwork skills, hold promise as retention tools for women, as cooperative, interactive environments have been found to appeal to female students. [8]

### METHODOLOGY

ITL curricula are taught in the 34,400 square foot Integrated Teaching and Learning Laboratory, an equipment-rich, hands-on learning facility. All ITL curricula have a number of educational components in common including hands-on projects, team-based cooperative learning environments, small class size, and supportive instructors who are enthusiastic about teaching. [9]

Three ITL curricular initiatives were examined for this study. Each initiative satisfied four criteria for inclusion. First, there were enough female participants to statistically analyze results. Second, data were available from more than one offering of the initiative. Third, taken together, all curricula covered a broad range of ages — from elementary-to college-age students. Finally, all curricula shared the five previously mentioned educational objectives. The three ITL initiatives chosen for this study are:

- **How Do Things Work?** (HDTW) — a weeklong, summer, pre-engineering class for upper elementary and middle school students. The goals of the course are to serve as an initial engineering outreach to kids, introducing youngsters to the basics of teamwork, graphical software, and design. Course components ensure students get their “hands dirty,” assembling and disassembling an electric motor and building a complete working circuit with given parts [11],
- **Success Institute** (SI) — a weeklong, summer resident, hands-on engineering design camp that brings 11th and 12th grade African-American and Hispanic teenagers to the CU campus. The goal of the program is to expand the pool of underrepresented students who successfully study engineering by sparking their curiosity about engineering and welcoming them to campus. Course components include exposure to minority faculty and student mentors as role models. Parents are also invited to attend during the last day of the workshop to view student presentations and learn about the necessary steps for gaining college admission for their children [12],
- **First-Year Engineering Projects** (FYEP) course — a one-semester, three-credit, introductory undergraduate engineering projects course that serves ~390 students per year. The FYEP course goals are to introduce students to the excitement of engineering as a career and the practical considerations of the design process, experimental testing and analysis, project management, oral and written communication, and working in multidisciplinary teams. Several course components are intended to accomplish these goals, including team dynamics and social-styles workshops and a comprehensive design project in which students experience the complete design-build-test cycle of product prototype development.

In a previous study, the FYEP course was investigated [13] in a manner similar to the present study, which is an extension to a larger population. The present study includes two additional semesters’ data and two additional initiatives targeting K-12 participants of much younger ages.

Table 1 provides a summary of the age and gender of the 587 study participants from the three initiatives.

<table>
<thead>
<tr>
<th>ITL Initiative</th>
<th>Average Age</th>
<th># Males</th>
<th># Females</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDTW summer kid’s class</td>
<td>11</td>
<td>41</td>
<td>30</td>
<td>71</td>
</tr>
<tr>
<td>SI summer teen camp</td>
<td>16</td>
<td>26</td>
<td>37</td>
<td>63</td>
</tr>
<tr>
<td>FYEP undergraduate course</td>
<td>18</td>
<td>37</td>
<td>82</td>
<td>453</td>
</tr>
<tr>
<td>Sub totals</td>
<td>NA</td>
<td>438</td>
<td>149</td>
<td>587</td>
</tr>
</tbody>
</table>

Participants’ confidence levels were assessed via a skills assessment inventory. This type of skills assessment has been used in the Pittsburgh Freshman Engineering Attitudes Survey, and has been found to be a valid assessment of confidence in engineering skills. [6] The process for development of this type of inventory has been described in detail elsewhere. [13] Briefly, the inventory involves the translation of the five educational objectives into written items designed to allow students to self-assess their level of
skill development. Multiple inventory items are typically used to assess each skill. Students rate their skill level using a 1-5 rating system, with a 5-rating representing the highest self-assessment of skill. For example, on the FYEP Skills Assessment Inventory, one item designed to assess design skills reads, “I can identify at least three components of the engineering design process.” Skills assessment inventories were administered before and after each ITL initiative.

RESULTS

The data were analyzed using repeated measures, multivariate analysis of variance statistical procedures. The procedures tested for differences in three categories: between the pre- and post-test (labeled “Time”), between genders (labeled “Gender”), and for gender/time interaction effects (labeled “Interaction”). The latter analyze for situations in which the slope of the pre-test/post-test line was different for each gender, as shown in Figure 1. In this example of a significant interaction effect, FYEP females started with significantly lower confidence in their knowledge of engineering as a career, but closed the gap with males during the semester.

![Figure 1](image)

**Figure 1**

**Gender Differences in Knowledge of Engineering as a Career**

Table 2 depicts the results for each of these three categories: time, gender and interaction. F-test values are listed by skill for each of the three ITL initiatives. F-test values are calculated statistics representing the magnitude of the difference between the variances of two samples. The test for significant results on the F-test was set at the p < .05 level.

Results reveal that across time, pre-test to post-test, gains were significant across all skills in all types of curricula. The strongest gains across initiatives, on average, were found for communications skills while the smallest gains were for teamwork skills.

Tests of the differences between genders revealed a different pattern. In the HDTW summer children’s class, the only significant difference between gender scores was seen in teamwork skills. Gender differences were much more prevalent in the Success Institute high school camp and FYEP course, with significant differences on four of five skills between genders in SI and significant differences between genders on all five skills in the First-Year Engineering Projects course. Across both SI and FYEP, males self-scored higher than females on knowledge of engineering as a career, knowledge of engineering methodology and design skills, while women self-scored higher than men on communication skills. On average, the largest difference between the genders was for knowledge of engineering methodology.

Tests of the interaction effects between genders and curricula only revealed significance for the FYEP course. Three of five skills indicated a significant interaction effect: knowledge of engineering as a career, knowledge of engineering methodology and design skills. On all significant interactions, female participants began with significantly lower self-ratings than their male counterparts and finished with non-significant differences between the genders (see Figure 1). In communication and teamwork skills, both men and women increased these skills at approximately the same rate.

DISCUSSION

Differences Across Time

The strongest findings were pre-test/post-test differences, with significant gains measured on all skills across all curricula, ranging from elementary through first-year college.

<table>
<thead>
<tr>
<th>Skill</th>
<th>HDTW Summer Class</th>
<th>Success Institute Summer Camp</th>
<th>FYEP University Course</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grades 5-7</td>
<td>Grades 11-12</td>
<td>First-year college (and higher)</td>
</tr>
<tr>
<td>Engineering as a Career</td>
<td>Time 4.99*</td>
<td>Gender♂ 1.76</td>
<td>Gender♀ 3.54*</td>
</tr>
<tr>
<td>Engineering Methodology</td>
<td>11.05*</td>
<td>1.80</td>
<td>9.33*</td>
</tr>
<tr>
<td>Design</td>
<td>25.00*</td>
<td>1.88</td>
<td>19.58*</td>
</tr>
<tr>
<td>Communication</td>
<td>8.63*</td>
<td>2.02</td>
<td>19.39*</td>
</tr>
<tr>
<td>Teamwork</td>
<td>4.58*</td>
<td>13.75*</td>
<td>3.08*</td>
</tr>
</tbody>
</table>

*Significant p<.05
†Symbols indicate which gender scored significantly higher
‡Significance indicates different slopes, with females closing gender gaps
students. These results represent a larger sample size (two academic years) and broader view (three types and age groups of hands-on engineering curricula) than previous assessments of ITL initiatives, and can be viewed as a strong indicator that students are gaining confidence in the skills necessary to be successful at engineering. This has not always been the case, particularly with females. Other studies have found that women’s confidence in their engineering skills often deteriorates as they move through the curriculum. [14] Increased confidence in skills has also been associated with retention and may help to explain why the FYEP course has been found to dramatically increase retention in CU’s College of Engineering and Applied Science, especially for women and students of color. [15]

On average, communications skills increased the most across all three types of curricula. This is a positive finding, as communication skills are highly valued by women. A study of 1,723 women found that females place a higher value than men on communication skills and more frequently use interpersonal skills to gather information. [16] The smallest gains were found on teamwork skills, largely due to high confidence in these skills coming into the class, camp or course. Additional data collected from the FYEP course indicates that students may overestimate their teamwork skills entering the curriculum. At the end of the FYEP course, students have been asked to rate their pre-course skills. Results of this retrospective analysis reveal significantly lower self-estimates of pre-course teamwork skills than students’ original ratings.

Gender Gaps
Differences between genders in students’ self-ratings of their own skills were largely not present in the children’s HDTW class, appeared more frequently in the high school SI camp, and were universal in the college-level FYEP course. This finding is in line with other studies that have identified gender differences in enrollment in technical subjects and science/math achievement scores beginning at adolescence, with boys showing greater aptitude and enthusiasm in these areas. [3, 4] These differences are not found in pre-adolescent populations, such as the students enrolled in the HDTW class. The one difference by gender in the HDTW is of note; males scored significantly higher than females on their confidence in their teamwork skills. An item analysis conducted to better explain this surprising finding found that the majority of difference between genders on this skill could be attributed to one skills inventory item, “comfort working with boys.” Females rated this item much lower than males, with no gain from pre- to post-test. This finding demonstrates an early discomfort among girls working with the opposite gender, at a time when other differences between the genders have not yet emerged.

Turning to gender differences across SI and FYEP, males rated themselves higher than females on the technical skills: knowledge of engineering methodology and design skills, as well as knowledge of engineering as a career. The greater confidence of males in the area of knowledge of engineering methodology was the largest gender gap in the study. A skills inventory item analysis revealed that this was mainly due to males’ greater confidence in their ability to apply math and mathematical software to solve engineering problems. It is interesting that this gender gap is still quite strong, even though in recent years greater numbers of girls have enrolled in high school math classes such as algebra I, algebra II, trigonometry and calculus. [17] In 2002, 46% of all high school AP calculus test takers were girls, although girls still under performed boys on the test. [5]

Women tend to report greater confidence than men on communication skills. These types of skill differences have been found in other studies of engineering students. For example, an investigation across 17 institutions with 6,180 participants found that men rated themselves higher on technical skills such as basic engineering knowledge and engineering abilities while women rated themselves higher on “softer” skills. [18] These gender gaps in skills have been attributed to different socialization practices in which young boys are taught to play with tools and machines while young women are taught to be nurturing and socially supportive. [2]

Closing Gender Gaps
While both short- and long-term educational curricula examined in this study appear to be effective for increasing confidence in engineering skills, only in the semester-long FYEP course were gender gaps in confidence closed. The results suggest that more long-term intensive courses are necessary to narrow the distance between the genders. This is consistent with other studies that have found that long-range interventions are more effective than other types of curricula for changing student attitudes. [8]

In each of three FYEP skills where a gender gap was closed—knowledge of engineering as a career, knowledge of engineering methodology and design skills — women rated themselves significantly lower than men on the pre-test and closed the gap by the end of the curriculum. One reason for the reduction in gender differences could be the structure of the First-Year Engineering Projects course, which is designed as an alternative to the typical introductory engineering “weed out” courses, which are competitive, large and impersonal, and follow the traditional socialization practices of Caucasian men. Women have been found to view this type of traditional introductory engineering course as attacking and unsupportive. [2]

In contrast, the FYEP course is populated by instructors who are committed to a personal, nurturing pedagogy, and emphasize and cultivate success. Instructors are consistently praised for this approach in end-of-semester student interviews. Students have commented, “(Instructor) was always coming around and asking how it was coming and making suggestions,” and “He is an excellent instructor, allowing us to have the freedom we needed, but also answered questions and gave helpful advice when
necessary.” [15] In addition, the emphasis on hands-on learning, and real-world clients and projects likely helps reduce deficits in these skills areas caused by differences in women’s early socialization experiences. In summary, this team-based, project-oriented approach is more likely to build, rather than crush, the confidence of female students, and likely propel them toward graduation rather than toward non-engineering majors.

First-year engineering students failed to close gender gaps in communication and teamwork skills; males both started lower and failed to close the distance between their female counterparts. Despite the culture of cooperation built into the course structure, these findings could indicate that norms that are part of the larger engineering culture are operating within the teams to marginalize interpersonal skills in favor of technical skills, resulting in male students not working to develop these skills. [19] This is problematic given the established necessity of these skills for success in the engineering profession, and the existing negative interpersonal stereotype for engineers working in industrial settings.

**Implications**

Our study findings have implications for future gender-based interventions in engineering education. One conclusion is that closing gender gaps in confidence is difficult at the college level, necessitating longer-term approaches. These findings imply the need to place a heavy focus on intervention in the pre-adolescent years, before biased attitudes have become ingrained in students. Efforts to increase awareness of potential gender-based issues with parents of young children, elementary school teacher workshops, and short-term classes for kids might inhibit the development of gender gaps. In the absence of these early interventions, more effective long-term, college-level strategies must be found.

Researchers have called for better integration of long-term intervention initiatives at the undergraduate level where mentoring systems, pre-college orientation programs, gender-friendly introductory courses, female-only curricula, and professional women’s societies work together in the recruitment and retention of women. [2] One example of an integrated effort at CU is a Women’s Manufacturing Workshop, which is an optional, not-for-credit workshop series exclusively for women in the FYEP course. This joint offering by the ITL and the College’s Women in Engineering Program is intended to close gender gaps for women in manufacturing skills and confidence. [20]

These findings also imply the need to emphasize teamwork and communications skills as universal objectives in engineering initiatives. Communication skills in particular are an area that women value and report confidence in, and the presence of this objective is likely to increase their retention. A consistent emphasis on teamwork and communication skills throughout the engineering culture may also induce males to place more focus and effort in building confidence and closing gender gaps in these skill areas.

It is not enough to simply insert teamwork and oral presentations into the curriculum. Teamwork, in particular, requires continuous nurturing, especially given that students may tend to initially over-rate their teamwork skills. Overconfidence can lead team members to avoid seeking assistance with teamwork problems, allowing disturbances to build up until significant damage to team relationships has taken place. Skills inventory item analysis reveals that males appear to particularly need guidance in learning when to ask for help. This deficit has, on more than one occasion, led to a situation in a team in which one male team member dominates, not allowing other team members to help with the project, only to discover at the end that the project was too big for one person. As mentioned, young girls appear to need help learning to feel comfortable working with young boys, implying the need for pre-engineering class instructors to observe closely and intervene when necessary. Early team-building activities, social styles workshops, and weekly team meetings are extremely helpful tools for building effective teams for engineering students of all ages. [21]

**Future Research**

As the ITL continues evaluating its programs, future research will focus on improving the measurement tools, generalizing the findings to other populations and curricula, and better understanding the gender experience in engineering curricula. One strategy for increasing the utility of the skills assessment inventories used in this study would be to develop a common pool of items used across different types of curricula. For example, all three inventories used for this study have an item referring to knowledge of the design abilities to close gender gaps in confidence.

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CONCLUSION

Data taken across two years and three types of ITL curricular initiatives indicate students are gaining confidence in the skills necessary to succeed in engineering. This appeared especially so for women in the First-Year Engineering Projects course who began lower than their male counterparts on confidence in technical skills, but gained at a faster rate and finished the course at a similar level of confidence. These data imply the need for a greater focus on long-term integrated curricula for the purpose of closing gender gaps and a corresponding focus at the pre-adolescent stage to prevent gender gaps from developing.

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REFERENCES


