Skills Assessment in Hands-On Learning and Implications for Gender Differences in Engineering Education

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Abstract

A comprehensive course evaluation plan is a helpful tool for the development and revision of new curricula. One component of an evaluation plan is the assessment of student skill development. This paper describes one type of skills assessment — student self-estimates of skill — in a first-year engineering projects course. The Skills Assessment Inventory for this course was developed by translating the course objectives into six measurement scales. One hundred sixty-two, first-year students completed the Skills Assessment Inventory at the beginning and end of the semester. This paper provides discussion of the significant differences between the pre-test and post-test scores as well as significant differences between genders on the Skills Assessment Inventory scales.

Introduction

Hands-on curricula have been found to be an effective method for teaching engineering concepts.[1] In the Integrated Teaching and Learning Laboratory (ITLL) and Program at the University of Colorado at Boulder, hands-on curricula are an integral part of lower division engineering projects courses and K-12 engineering outreach programs.[2 3] An extensive evaluation plan has been developed to investigate the efficacy of these curricula. One component of this evaluation plan is the assessment of student skill development. This type of assessment is accomplished by several methods, including instructor assessment, peer assessment, and self-assessment. The present study focused on student self-assessment of skills in the ITLL *First-Year Engineering Projects* course.

Student skill self-assessment is a useful component of the projects course evaluation plan. Instructors from a wide range of engineering disciplines offer at least 12 sections of the course annually. Additionally, the nature of the design/build projects and grading methods both vary with the instructor and course section. Given these variables, student self-assessments on a standardized inventory offer a method for making comparisons across sections on achievement of course goals. Student self-assessments provide an alternate perspective to instructor assessment and give students the opportunity to provide feedback on their own development. Student self-assessments also provide an opportunity to assess demographic differences. For this study, skills assessment differences between genders were investigated. Gender differences in skills have been reported in other investigations of engineering students[4]

Methodology

Skills assessment inventory development is a rigorous process that begins with the development of a program evaluation matrix.[5] Table 1 presents an example of a portion of the evaluation matrix for the *First-Year Engineering Projects* course, depicting one of the six overall course goals. To develop the evaluation matrix, the first two steps are to specify goals and learning objectives for the course. Next, performance criteria are developed to determine success in meeting the learning objectives. In step four, assessment methods are developed to measure the performance criteria. Finally, steps one through four are related to corresponding ABET criteria.

Skills assessment inventories are structured around multiple assessment scales with each scale corresponding to a specific course goal. For example, the matrix in Table 1 depicts one overall course goal: “Introduction to Engineering Methodology.” The Skills Assessment Inventory administered to students in the course includes a corresponding assessment scale entitled “Knowledge of Engineering Methodology.” Thus, the items that comprise the skills inventory scales correspond to the performance criteria for each course goal. For example, Table 1 lists “Can write a simple, clear hypothesis” as one performance criterion of the course goal, “Introduction to Engineering Methodology.” The corresponding skills assessment item is, “I know how to state a scientific hypothesis.”

For the present study, skills self-assessments were administered to students in the *First-Year Engineering Projects* course, which is a hands-on, team-based, semester-long introduction to the engineering design process. The overall course goals are to introduce students to engineering as a career and to basic engineering methodology through experiencing, first hand, the fundamentals of the design process. Additional goals are to develop communications skills, productive work practices, and teamwork skills. First-year students work in teams to construct design/build projects during a 12- to 13-week period. Throughout the semester, papers and oral presentation assignments serve to cultivate and reinforce students’ communication skills, culminating in an end-of-semester public Design Expo, at which projects are judged and showcased to the public.

Approximately 350 students per year complete the Skills Assessment Inventory administered at the beginning of the semester and following the end-of-semester Design Expo. The skills inventory is composed of 60 items organized into six scales that measure the six overall course goals. The six inventory scales are:

- Knowledge of Engineering as a Career
- Knowledge of Engineering Methodology
- Design Skills
- Productive Work Practices
- Communication Skills
- Teamwork Skills

Data for this study were collected during one semester from 162 first-year students, with 137 men and 25 women responding. Students rated themselves on each of the 60 items using a five-point Likert-type scale with choices that range from “strongly agree” to “strongly disagree.”

Table 1. ***First-Year Engineering Projects*** **course program evaluation matrix, depicting one of the six overall course goals.**

Goals	Learning Objectives	Performance Criteria	Assessment Methods	ABET Criteria
Overall program goal	What the student should be able to do and know	The level of performance required to meet the objective	Tools for assessing each criterion	ABET 2000 criteria
Introduction to engineering methodology	1) Formulates hypotheses.	1) Can write a simple, clear hypothesis.	1) Skills Inventory and Project Reports	1) B and E
	2) Quantitatively tests hypotheses.	2a) Can define a null hypothesis. 2b) Collects and records data. 2c) Designs multiple tests of hypotheses. 2d) Analyzes data and draws reasonable conclusions.	2) Skills Inventory, Project Design Reports and Project Presentations	2) B
	3) Analyzes product designs.	3) Uses appropriate engineering analysis to model behavior of design components.	3) Skills Inventory, Design Project Reports and Project Presentations	3) A
	4) Uses IT tools and engineering software applications to perform engineering analysis.	4a) Navigates the Internet to find information. 4b) Develops spreadsheets to evaluate data. 4c) Uses CAD/CAM software in the design/build process. 4d) Uses software tutorials to learn new applications.	4) Skills Inventory, Design Project Reports and Instructor Observation	4) K

For the data analysis process, student scores on each item were combined to produce a mean score for each of the six scales. Paired samples, t-test, statistical procedures were used to test for differences between the means. The data were also analyzed with respect to gender. Repeated measures analysis of variance procedures were used to test for gender differences. Significance was tested at the $p < .05$ level.

Results

Figure 1 shows a graph of the pre- and post-test mean scores for each of the six Skills Assessment Inventory scales. On this graph, solid bars indicate significant changes between the pre- and post-test and striped bars indicate non-significant changes. Scores are presented as percentages on the graphs to allow for standardized comparisons between scales with different numbers of items. Thus, on the post-test, students rated themselves at the 86^{th} percentile for the Teamwork Skills scale and at the 81^{st} percentile for the Productive Work Practices scale. All mean scale scores increased significantly between the pre- and post-test with the exception of the Productive Work Practices scale.

Gender analyses indicated significant differences between women and men on all six of the scales. Men scored themselves significantly higher than women on the Knowledge of Engineering Methodology and Design Skills scales. Women scored themselves significantly higher than men on the Productive Work Practices and Teamwork Skills scales. Significant interactions were found in the analysis of the remaining two scales with women and men reporting significantly different patterns of development on the Knowledge of Engineering as a Career scale and the Communication Skills scale. On the Knowledge of Engineering as a Career scale, women reported a significantly greater increase than men across the semester. On the Communication Skills scale, both men and women began with the same scores. However, women rated themselves on the post-test with significantly higher Communications Skills scale scores than men. The graph in Figure 2 shows the Communications Skills scale scores for men and women.

Due to a small sample size for female participants, statistical tests were conducted to investigate any irregularities in sample variance. Lavene's test for equality of variance was conducted to look for differences in the variance between the male and female samples across each of the six Skills Assessment Inventory scales. Mauchly's test of sphericity was conducted to look for irregularities in the variance on the pre-test and the post-test. Across all six scales, results were not significant for either Lavene's or Mauchly's test, indicating that the small number of females in the sample did not lead to a biased estimate of the sample mean.

Discussion

Students in the *First-Year Engineering Projects* course reported significant gains on five of six Skills Assessment Inventory scales, indicating gains in their perceptions of their Knowledge of Engineering as a Career, Knowledge of Engineering Methodology, Design Skills, Communication Skills and Team Skills. The largest increase was in the area of Design Skills,

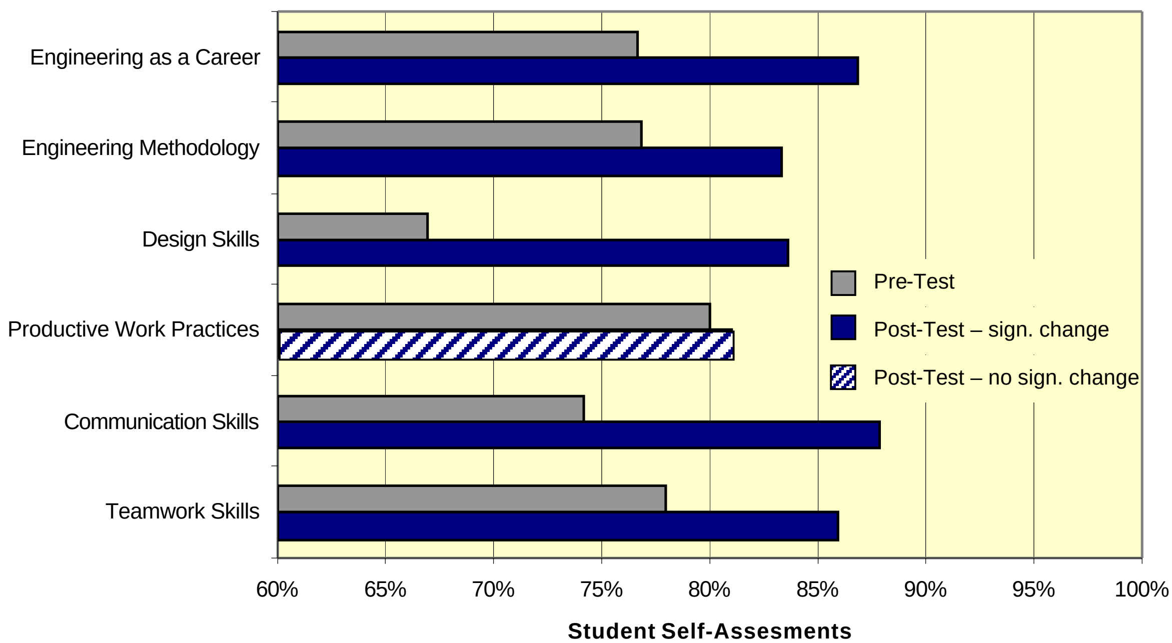

Figure 1. Statistically significant changes in student self-assessments of skills, from beginning-of-semester (Pre-Test) to end-of-semester (Post-Test).

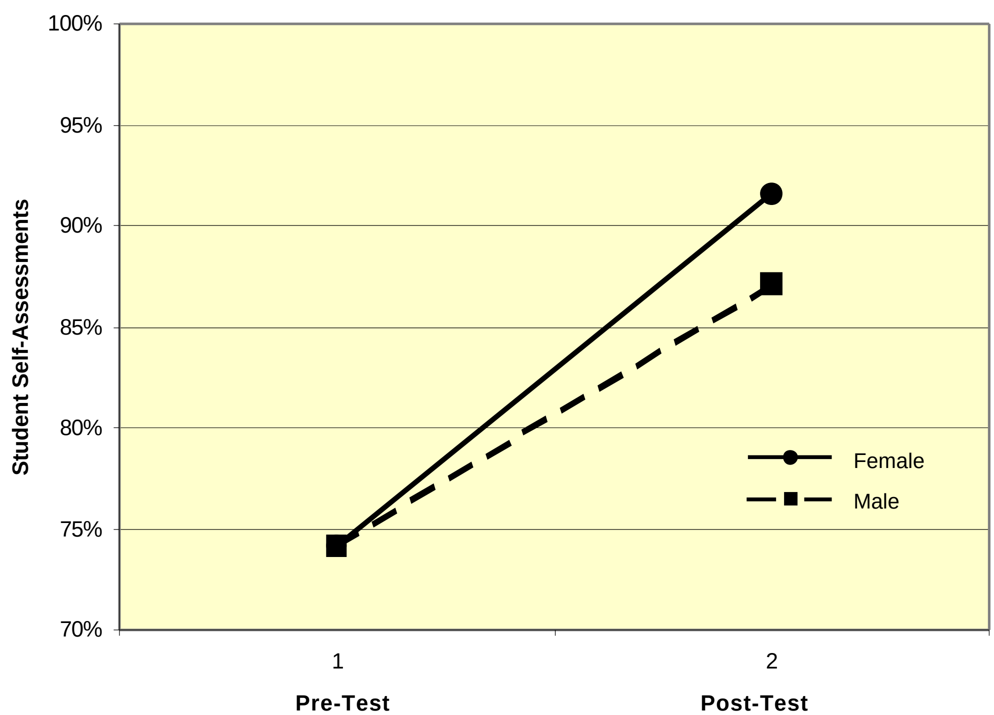

Figure 2. Comparison of beginning-of-semester (Pre-Test) to end-of-semester (Post-Test) communication skills scores by gender.

with students reporting a gain of 17 percentage points. This scale is intended to measure skill with machining, as well as use of CAD software and hand tools. The Design Skills scale also evaluates students' understanding of the components of the design process and their ability to create an engineered product to meet client specifications. The development of design skills in first-year students is an important course goal and is in line with the movement in engineering education to vertically integrate design curricula from senior capstone courses down through first-year courses.[6] In addition, evidence of design skills corresponds with ABET accreditation guidelines Outcomes Criterion C, "…an ability to design a system, component, or process to meet client needs."[7]

Students did not report a significant increase in their productive work practices. This scale primarily measures their ability to work individually, meet goals, and manage their time. These results were surprising, as this first-year course is less structured than other freshman classes and offers ample opportunity for students to develop independence and goal orientation. Productive Work Practices scale ratings were both the highest scores at the pre-test and the lowest scores at the post-test. Perhaps these students, who were generally high achievers in high school, were over-confident about their work practices skills entering the class, and subsequently provided a more accurate rating of their performance at the course conclusion.

Analysis of all six Skills Assessment Inventory scales indicated significant differences between genders. Men scored themselves significantly higher on the pre- and post-tests in the technical skill areas, including Design Skills and Knowledge of Engineering Methodology, while women scored themselves higher on the pre- and post-tests on the performance skills, including Productive Work Practices and Teamwork Skills. These types of skill differences between women and men have been documented across a number of educational settings and as early as middle school. At age 13, a gender gap begins to appear in science proficiency scores, with boys outperforming girls. This gap continues in high school, with boys scoring higher than girls on the SAT Mathematics and Science Achievement Tests, as well as on the mathematics and science Advanced Placement Examinations.[8] These differences have been found to persist in other first-year college samples. One study of 17 institutions and 6,180 students found gender differences in student ratings on the Pittsburgh Freshman Engineering Attitude Survey. Men rated themselves higher on technical skills, including a Confidence in Basic Engineering Knowledge and Skills scale and an Engineering Abilities scale while women rated themselves higher on an Adequate Study Habits scale.[9] These findings set off a debate about the origins of gender differences in ability, with some researchers suggesting innate differences in math and science skills while others attributed these differences to gender biased testing.[10-12] More recent reviews of the literature attribute these gender differences to social factors including attitudes and prejudices acquired before college, the development of different priorities on the relationship between coursework and personal relationships, and instructional methods and attitudes employed by instructors, advisors, and classmates that favor the learning style most often preferred by males.[13] For example, one possible social factor is the common early socialization experience in which boys are taught to play with tools and machinery, while girls are taught to be more socially supportive.[14]

In this study, women and men exhibited different developmental patterns on two scales—Knowledge of Engineering as a Career and Communication Skills—with women reporting greater gains than men in these two areas. Greater gains in Knowledge of Engineering as a Career could again be attributed to earlier socialization experiences that isolate women such that they are less exposed to engineering role models and less encouraged to think of themselves as potential engineers.[15] Exposed to a curriculum that validates their interest in engineering, women could have quickly closed this gender gap. Gains in the Communications Skills scale were also of note, with men and women initially rating their skills the same, but women ending up with scores significantly higher than men. This could be attributed to the value that women place on communication skills. A survey of 1,723 engineering students found that female engineering students place a higher value than males on oral communication skills and that female engineering students more often rely on interpersonal sources for information gathering.[16] These gains in communications skills estimates could also be attributed to the course structure. The *First-Year Engineering Projects* course emphasizes teacher/student and student/student interactions through the use of cooperative learning groups and small (maximum of 30) class size. Smaller, more interactive courses support the learning style of many women who more frequently report a preference for cooperation over competition and a dislike of impersonal classroom dynamics.[17]

Implications

These study results can be taken as one indicator of success with five of six of the course objectives. From their perspective, students reported significant skill development as a result of participating in the *First-Year Engineering Projects* course. This is important, as it has been found that engineering students' who have high confidence in their engineering skills consider a wider range of engineering occupations, achieve higher grades, and persist longer in an engineering major.[18]

Although there were differences in skill estimates found between males and females in this study, both genders reported significant gains across five of the six skills sets. A finding such as this has not always been the case in course evaluations. An investigation of five, sequenced chemical engineering courses found that men and women began the sequence with similar levels of confidence in their skills. Then, women, but not men, experienced an erosion of confidence as they progressed through the curriculum. Significant gains for both genders across skill assessments in our *First-Year Engineering Projects* course imply a positive evaluation of the course structure, suggesting an attention to diversity. An increased awareness of this diversity is in line with a current movement in engineering education to incorporate student individual differences into curricula design.[19]

Implementing an understanding of gender-based differences in skill self-estimates within a team-based, hands-on projects course can be challenging. Instructors must integrate their knowledge of skill differences with a wide variety of other information such as social styles and peer evaluation data. Instructors must use this information to make a number of decisions about their teams—selecting members, resolving conflict, and supporting the structure of the project, all in a manner that ensures an equal opportunity for everyone to improve their skills. The process of ensuring equity is complicated by inconsistencies in cultural norms.[20] While industry surveys and ABET accreditation procedures place great emphasis on the non-technical skills in which women rate themselves higher, researchers continue to report that cultural norms in engineering courses marginalize non-technical skills while inhibiting female students' abilities to acquire the more technical skills.[21] The authors have also directly observed this phenomena in their upper level invention and innovation project-based course.

Future Research

While findings from the Skills Assessment Inventory provide useful information for course evaluation, multiple assessment methods are necessary to fully investigate the outcomes of the *First-Year Engineering Projects* course.[22] Other forms of student self-assessment, as well as peer and faculty assessment, are incorporated into the overall evaluation plan. For example, students participate in a qualitative student group interview conducted by a third party, in which they delineate what they find to be strengths of the course and also provide suggestions for course improvement. This information is integrated with student skills self-assessment results to produce a comprehensive assessment report as feedback to course instructors, administrators and teaching assistants at an end-of-semester course evaluation and debriefing session.

Additional research will focus on further validating the Skills Assessment Inventory. The results will be compared to other methods of assessment to better determine the meaning of the ratings. Students' desires and ability to accurately self-assess in an evaluative context have been questioned by some researchers.[23] In the study, efforts were made to simplify the inventory items so that introductory students would easily understand the concepts, and assure the students' that inventory ratings would not affect their grades. In the future, end-of-semester assessments will also ask students to estimate their level of skill at the beginning of the semester. These retrospective estimates will be compared with pre-test scores to better determine the accuracy of self-estimates of skills. In addition, comparisons with peer and faculty assessments, as well as other measures similar to the skills scales, will further validate the results learned from the use of student self-assessment tools.

Additional research is underway to investigate skill development in other ITL hands-on learning initiatives, most notably an extensive engineering outreach program designed to build skills, knowledge and interest in engineering within the K-12 population. A Skills Assessment Inventory is also being refined for an undergraduate invention and innovation design/build course for transfer and non-traditional students, and for the investigation of hands-on experimental modules that teach engineering students about the applications of a wide range of engineering concepts.

Future research should be focused on a more in-depth understanding of the effect of gender differences in skill development within a first-year projects course. Post-course qualitative interviews with male and female members of mixed gender design teams would be one method of deepening the understanding of gender relations within engineering teams. Also, more female assessments on the Skills Assessment Inventory would provide additional statistical power to better determine the degree of differences between men and women.

Summary

Student self-assessment of skills is one method of outcomes assessment in hands-on projects courses. In the Integrated Teaching and Learning Program at the University of Colorado at Boulder, first-year engineering students rated their development on six skills sets associated with overall course goals using a Skills Assessment Inventory. Students reported significant gains on five of the six scales (Engineering as a Career, Engineering Methodology, Design Skills, Communication Skills and Teamwork Skills), with only one scale (Productive Work Practices) demonstrating a non-significant increase. Significant differences were found between the genders on all six scales of the Inventory, with men rating themselves higher on the more technical skills and women rating themselves higher on performance skills. In addition, women reported significantly higher *gains* than men across the semester on Knowledge of Engineering as a Career and Communication Skills.

These results are one indicator of the achievement of course goals. Future research will focus on expanding skills assessment use in other ITL courses and programs, and integrating the results of a variety of measures to provide a more complete picture of student learning and course outcomes. The data imply the need for increased awareness of gender differences in skills development in first-year projects courses. Future research will focus on gaining a more in-depth understanding of the work-related interactions between women and men in engineering design teams.

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