Improving Engineering Student Retention through Hands-On, Team Based, First-Year Design Projects

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Abstract – This longitudinal study is an investigation of the impact on student retention of a First-Year Engineering Projects (FYEP) course at a large public research university. Student retention was measured at the third, fifth and seventh semester for student takers and non-takers of a first-year, team-based design/build course. Retention data were analyzed across eight years for 5,070 students, representing 2,128 students who took the FYEP course (42%) and 2,942 students who did not take the course (58%). Significant retention gains were found for all student takers. The authors compare these results with reported retention data from other engineering institutions and discuss possible causes and ramifications of the findings.

Index terms –Design, First-Year, Hands-on, Retention

INTRODUCTION

Student retention has been an engineering education concern for many years. More than 70 years ago, the “Wickenden” Report of the Investigation of Engineering Education reported a (US) student graduation rate of only 28%. [1] In 1993, a study by Astin and Astin analyzed data from 27,065 first-year students who were enrolled at 388 four-year colleges and universities between 1985 and 1990 and found a 47% graduation rate for engineering students. [2] A review of the literature since this study found an average reported graduation rate of 56%. [3-9] The differential loss of women and under-represented minority students from engineering programs is even more troubling, with dismal 30% graduation rates reported in both populations. [10, 11]

At the University of Colorado at Boulder’s College of Engineering and Applied Science, a 53% overall graduation rate was found for undergraduate engineering students (1994-2000) — including 55% for women, 53% for Asian-American students, 53% for Caucasian students, 47% for Latino students, 44% for African-American students, and 33% for Native-American students. [12]

Early student departure from engineering programs has become a grave concern in an era of declining interest among youth in pursuing futures in engineering and technology, coupled with high global demand for qualified graduates and greater university accountability. Published data show US undergraduate engineering student enrollment in decline [12-15] while the demand for qualified engineering graduates is expected to increase. [16] Shrinking academic budgets focus more attention on retention, and cost analysis indicates that it is more expensive to recruit a new student than to retain an enrolled one. [17] Increasingly, student retention has been used as a measure of institutional effectiveness, with educational stakeholders and prospective students making university comparisons based on widely-published retention rates. [18] In an effort to address these concerns, this study targets the following research question: What impact might an integrated, team- and project-based, hands-on design course have on the retention of first-year students into their sophomore year and beyond?

THEORETICAL FRAMEWORK

The theoretical framework for this study was inspired by Tinto, a leading theorist of student attrition in higher education. He proposes that the decision to leave or stay is a result of the personal characteristics that students bring with them into higher education (e.g., skills, abilities) and the interaction of these characteristics across a range of college experiences (e.g., curriculum, faculty interactions). These experiences lead to a level of integration into the institution and shape student attitudes that ultimately impact the decision to stay or go. [19] Engineering education retention researchers have investigated a number of these factors.

Earlier retention research focused on personal student characteristics. [20] Researchers found several attributes that are predictive of students who are more likely to remain in engineering programs — including SAT scores, high school GPA, demographic variables, attitudes and personality characteristics. [21-24] These findings have been used to target at-risk students for early intervention. [25, 26] A newer body of research has investigated the impact of students’ college experiences on retention. Research in this area has been fueled by mounting evidence that only a small portion (8.5% in one study) of engineering students leave due to academic difficulty. [27, 28] This talent drain has been investigated in depth through the use of interviews, focus groups and surveys. [2, 5, 6, 29] These study results document a range of institutional variables that seem to encourage attrition, including large class sizes, inaccessible instructors, uninspiring teaching methods, inadequate student support networks and poorly integrated curricula. One study concluded, “Contrary to the common assumption that most switching is caused by personal inadequacy in the face of academic challenge, one strong finding…is the high proportion of factors cited as significant in switching decisions that arise either from structural or cultural sources within institutions…” [2] With these types of findings, engineering educators began to wonder if they had been mistakenly blaming students for deficiencies in the curriculum and pedagogy. They began to shift some of the research focus from student personal characteristics to improving curriculum and instruction.

By the early-1990s a national effort was underway to improve engineering education. Changes included the vertical and horizontal integration of curricula [30-32], the implementation of new pedagogical techniques including cooperative, active, and problem-based learning [33-35], and modifications of the larger learning environment, including the development of learning communities and the construction of state-of-the-art educational facilities to support student learning [36-39]. Most recently, the National Engineering Education Colloquies established a research agenda for engineering education [40]. Research areas from this agenda that are relevant to this study target...
engineer learning systems and the impact of these systems on engineering diversity and inclusiveness.

FIRST-YEAR CURRICULUM REFORM

The first-year engineering curriculum is one area in which significant changes have been implemented nationwide. [31, 41] Of the engineering students lost to attrition, the majority occur during the first year — with losses ranging from 50% to 84% of the total population. [9, 18] In addition to the previously mentioned criticisms of engineering curricula, traditional first-year courses have been criticized for offering little connection to engineering as a career [42] and its role in addressing society’s grand challenges — such as world hunger, poverty and environmental degradation.

A wide variety of models for first-year course reforms have been introduced, ranging from a one-credit, voluntary introduction to engineering course at the University of Florida [43] to fully integrated first-year block curricula such as Drexel’s E3 program[44], the IMPULSE program at the University of Massachusetts Dartmouth [45], and the Engage program at the University of Tennessee. [46] The case has been made that most of these programs could be labeled as integrated curricula for their integration of technical and professional skills instruction, older and younger students, and even entire courses into 12-hour blocks. [31]

Student retention has been found to consistently improve at many institutions as a result of first-year engineering curricular revision. [31, 41] Some of these retention study results are presented in Table 1 in descending order of magnitude in the “change” column, with programs at the top reporting the largest retention gains for their revised first-year curricula.

Across programs, 14 of 16 reported positive changes in retention, with an average 30% retention gain reported for experimental first-year engineering curricula. Gains were calculated with the following formula: % gain = (revised – traditional)/traditional. Only two programs (North Carolina State and the University of Wisconsin, Platteville) did not report a positive retention impact.

Few programs report data separately for women and students of color, but those that do typically report positive retention gains for students of color and even greater gains for women. The University of Florida’s first-year initiative posted a third-year retention gain of 225% for women (from 16% to 54%) and 33% for minority students (from 36% to 48%). [43] Educators at the University of Alabama reported retention gains of 44% for calculus-ready women (from 52% to 75%), but did not find gains for calculus-ready students of color. [47] Educators at Texas A&M University found that retention for women improved by 22%, moving from 72% in the traditional first-year curriculum to 88% in the revised curriculum by the third semester. Similar gains were found for African-American (from 70% to 90%) and Latino students (from 70% to 84%). [41]

In sum, student retention has been found to improve across a wide variety of reformed, integrated, first-year engineering programs. Even though these initiatives have been found to aid with the retention concerns shared by most engineering programs for more than 70 years, recent articles sound a note of concern for the future of these programs. [31] [48] These authors find that first-year curricular reforms have not been pervasive in the engineering education community, have frequently been reduced in scope from pilot efforts and have too often been initiated by individual faculty members rather than organizational commitments to reform. This has led to concerns about the sustainability of such first-year programs and wider institutionalization. The present study seeks further understanding and discussion on the important issue of retention and integrated first-year curricula through a longitudinal investigation of student retention with large experimental and control groups.

I. First-Year Engineering Projects Course

The First-Year Engineering Projects course is offered as a hands-on introduction to engineering. Initiated in 1994, the three-credit, one-semester course now serves approximately 420 or 65% of incoming students per year in sections that cap at 32 students each.

The course is required for mechanical, aerospace, civil, and environmental engineering majors, and is elective for all other engineering students. The main goal of the course is an integrative one — to make connections between the theoretical, academic aspects of engineering and the professional practice of engineering, helping budding engineers understand that engineering is a helping, people-oriented profession that underpins both our economy and our quality of life. This is accomplished through introducing students to the design/build process in a team-based setting, supported by experimental testing.
TABLE 1. SUMMARY OF RETENTION IMPACT FOLLOWING IMPLEMENTATION OF REVISED FIRST-YEAR ENGINEERING INITIATIVES AT 16 US INSTITUTIONS. RESULTS IN DESCENDING ORDER OF MAGNITUDE IN THE “CHANGE” COLUMN, WITH PROGRAMS AT THE TOP REPORTING THE LARGEST RETENTION GAINS.

<table>
<thead>
<tr>
<th>Institution</th>
<th>Retention Rates</th>
<th>Revised first-year curricula</th>
<th>Time of retention assessment</th>
<th>% Change in retention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old Dominion [49]</td>
<td>50%</td>
<td>90%</td>
<td>Year 2</td>
<td>+80%</td>
</tr>
<tr>
<td>Tennessee [46]</td>
<td>26%</td>
<td>43%</td>
<td>Year 5</td>
<td>+65%</td>
</tr>
<tr>
<td>Denver Univ. [50]</td>
<td>54%</td>
<td>83%</td>
<td>Year 2</td>
<td>+54%</td>
</tr>
<tr>
<td>Florida [43]</td>
<td>34%</td>
<td>51%</td>
<td>Year 3</td>
<td>+50%</td>
</tr>
<tr>
<td>Youngstown State [51]</td>
<td>60%</td>
<td>85%</td>
<td>Year 2</td>
<td>+42%</td>
</tr>
<tr>
<td>Mass., Dartmouth [45]</td>
<td>62%</td>
<td>83%</td>
<td>Semester 3</td>
<td>+34%</td>
</tr>
<tr>
<td>Purdue University [52]</td>
<td>63%</td>
<td>80%</td>
<td>Year 3</td>
<td>+27%</td>
</tr>
<tr>
<td>Alabama [47]</td>
<td>56%</td>
<td>71%</td>
<td>Year 7</td>
<td>+27%</td>
</tr>
<tr>
<td>Colo. School of Mines [53]</td>
<td>66%</td>
<td>84%</td>
<td>6-year grad rate</td>
<td>+27%</td>
</tr>
<tr>
<td>Drexel [41]</td>
<td>60%</td>
<td>72%</td>
<td>Term 8</td>
<td>+20%</td>
</tr>
<tr>
<td>Texas A&amp;M, Kingsville [41]</td>
<td>51%</td>
<td>61%</td>
<td>Not reported</td>
<td>+20%</td>
</tr>
<tr>
<td>Rose-Hulman [41]</td>
<td>82%</td>
<td>92%</td>
<td>Course end</td>
<td>+12%</td>
</tr>
<tr>
<td>Ohio State [54]</td>
<td>59%</td>
<td>66%</td>
<td>Year 3</td>
<td>+12%</td>
</tr>
<tr>
<td>Notre Dame [55]</td>
<td>91%</td>
<td>99%</td>
<td>Course end</td>
<td>+9%</td>
</tr>
<tr>
<td>North Carolina State [56]</td>
<td>80%</td>
<td>80%</td>
<td>Year 2</td>
<td>0%</td>
</tr>
<tr>
<td>Wisconsin, Platteville [57]</td>
<td>70%</td>
<td>65%</td>
<td>Not reported</td>
<td>-7%</td>
</tr>
</tbody>
</table>

Course components include team dynamics and communications / social styles workshops and a comprehensive design project in which students experience the complete design-build-test cycle of product prototype development. Many projects are developed for clients — introducing the ambiguity of evolving customer demands into product design specifications. The design/build cycle culminates in an end-of-semester design expo at which prototypes are showcased to the public. Past project themes include:

- Appropriate technology devices for use in developing communities;
- Assistive technology devices for people with a wide range of physical and learning disabilities (e.g., a page-turner for an adult with cerebral palsy);
- Nanotechnology interactive learning exhibits for children, aimed at teaching concepts from this emerging field;
- Rube Goldberg contraptions that perform ordinary functions in surprising ways; and
- Lego® robot competitions.

The course operates out of two dedicated 950 sq. ft. design studios — smart, IT supported classrooms that feature team tables, workbenches, computers and lockers. Each student team is issued an equipped toolbox and supported by access to a staffed manufacturing center with high quality machining, fabrication, and rapid prototyping capabilities and an electronics center with facilities to prototype, fabricate and test printed circuit boards. These facilities support product iteration and emphasize moving quickly from the theoretical to the physical world.[38, 58, 59]

II. Course Assessment

Measurements of success in first-year engineering courses have commonly focused on student reactions to the curriculum, student performance and student retention, with the most common practice being the administration of surveys to determine student satisfaction and estimates of outcomes. [43] In the Introduction to Engineering course at Tennessee Tech, a student post-project survey found that 72% rated their experience with a multidisciplinary team-based design project as positive. [42] Student performance data is also provided for some programs. For example, members of the Engage first-year program at the University of Tennessee found that Engage students outperformed students in the traditional first-year curriculum on common statics and dynamics exams and registered a higher grade in their first course after transferring into their majors. [46]

The present study is focused on student retention, which is measured differently across programs. Established programs such as Drexel’s E4 program, initiated in 1989, and Rose Hulman’s IFYCSEM program, which began in 1990, use graduation from their colleges of engineering as a measure of student retention. [41] While this type of measure is a true measure of student retention, at least 10 years’ worth of graduation data are necessary for several student cohorts to matriculate through the system. Alternatively, programs in existence for shorter periods of time use retention into specific semesters or years as indicators. For example, the University of Denver, which
began its Engineering Concepts and Composition first-year program in 2000, uses retention into the second year as an indicator. Purdue University conducted a study of its first-year engineering program and found that graduation rates and retention rates converge as the number of semesters increase, with retention into the sixth semester essentially equivalent to graduation rates. [9]

In the present investigation of CU’s First-Year Engineering Projects (FYEP) course, retention is measured into the third, fifth, and seventh semesters to investigate both the immediate impact of participating in the FYEP course and the program’s long-term effect on graduation potential. To better understand retention rates, this study makes use of a large control group of students who did not take the FYEP course. Based on previous literature findings (which initially informed the course design and continue to evolve it), our hypotheses is that students in the team-based, project-focused FYEP course would be retained at a higher rate than those who did not take the course and did not have a community-building experience that exposed them to the hands-on, creative world of engineering.

**METHOD**

Retention data were collected across eight cohorts, from students entering the college in the fall 1994 semester through the fall 2002 semester. The data set totals 5,070 engineering students, comprised of 2,128 students (42%) who took the FYEP course and 2,942 students (58%) who did not take the course. The sample includes 1,015 women and 4,055 men, with ethnicity counts of 3,992 Caucasian, 402 Asian American, 290 Latino, 80 African American, and 41 Native American students. An additional 265 students were classified as “unknown ethnicity” and thus are not included in the ethnicity analysis. The study sample includes only students who took the FYEP course while they were classified as first-year students in engineering; it does not include transfer students, students who were not engineering majors or students who took the course after their first year.

Engineering program retention was measured at the third, fifth and seventh semester for all students in the sample. Logistic regression and chi square statistical tests were used to test for differences in retention between FYEP takers and non-takers and to test for differential impacts by both gender and ethnicity. [60]

**RESULTS**

Results for the differences between takers and non-takers of the FYEP course are presented in Figures 1-3 and Table 2. Across all students (Figure 1), First-Year Engineering Projects course takers were retained at a significantly higher level into the third, fifth and seventh semesters (p < .05). This pattern holds for both men and women (Figure 2).

Through logistic regression analysis, we further explored the retention data for any differential retention impacts of the FYEP course on women. While the data clearly show women retained at a higher level into the fifth and seventh semesters, we found no statistically significant differential impacts (p < .05) at the third (p = .91), the fifth (p = .28), or the seventh semester (p = .12) that suggest that a first-year design project course experience is more beneficial for women than for men.

We further explored the retention data by student ethnicity (Figure 3), motivated to do so by a range of retention changes, from an apparent 32% retention improvement at the seventh semester for African American students to a low of 2% for Native American students. However, the regression analysis found no statistically significant (p < .05) differences in retention gains between ethnicities at the third (p = .77), the fifth (p = .74), or the seventh (p = .77) semester, suggesting the FYEP course impacts students of different ethnicities equally.

Despite current statistical results, we have reason to believe that retention patterns continue to emerge as our data set grows. Significance tests for differential impacts at the seventh semester between genders demonstrated some evidence of a differential pattern at the seventh semester (p = .12) and the analysis by ethnicity likely suffered from low samples sizes for some ethnic categories (see Table 2).

**DISCUSSION**

Across all our students, significant retention gains by takers of the first-year, project-based curriculum over their peers who took the traditional curriculum were found into the third, fifth and seventh semesters. Compared to previous research, CU’s 64% seventh semester retention rate for FYEP takers is an improvement compared to the 47% graduation rate reported by Astin [2], the more current 56% average graduation rate found in our literature review, and CU’s own (1994-2000) overall College of Engineering and Applied Sciences graduation rate published at 53%. [61]

These data add strong results to the growing body of evidence demonstrating the substantial impact of first-year project-based curricula on the retention of engineering students.

Literature-provided explanations for these retention gains are supported by our own FYEP course assessment data acquired through student focus groups conducted at semester end and pre- and post-semester surveys. In the literature, the most frequently reported conclusions identify the integrated hands-on learning of engineering skills [43, 49, 52], the development of a student learning community [47, 50], the mentoring that takes place from quality instructors [51, 53, 55], the open-ended nature of the design projects [62, 63] the effect of the curriculum on students’ attitudes [19, 64, 65] and a “volunteer effect” (discussed below). [41, 43, 56]
FIGURE 1.
The effect of the FYEP course on retention of engineering students into the third, fifth and seventh semester, regardless of gender or ethnicity.

FIGURE 2.
The effect of the FYEP course on retention of engineering students into the third, fifth and seventh semester, by gender.
The impact of an active, hands-on learning environment is supported by educators at Old Dominion who state, “It is concluded that a careful modification of the freshman curricula with emphasis on hands-on experiences increases both freshmen students’ motivation and retention levels.” [49] Similarly, FYEP focus group participants stated, “We liked the fact that it was hands-on stuff, right from the start, as opposed to listening to someone lecture us the whole class.”

Engineering educators at other universities, such as the University of Alabama’s first-year TIDE program, emphasize the development of a sense of community and a peer support network. These researchers state, “We believe the dominant effect of the TIDE program was the sense of community that developed among the students as they worked on the many team assignments.” [47] Similarly, faculty from the University of Denver state that their first-year program “creates a community (or a network of support) within the first few weeks of college whereas the typical first-year student does not gain a sense of community for months...” [50] FYEP focus group participants reported on the community aspects of the teamwork, “The class allowed us to make friendships,” and “We liked how it built teamwork among random people you really didn’t know and you learned to work with them.”

Quality instruction and mentoring by faculty is also cited as a key factor in first-year student retention literature and by our FYEP student focus groups. Educators at Youngstown State University conclude that improved retention in the Freshman Engineering Program “would not be possible without the efforts of faculty members who have the correct personality and teaching methods that work with freshmen engineering students...”[51] Similarly, our FYEP course benefits from instructors who are teaching award winners and have high faculty teaching ratings. Students commented, “He is an excellent instructor, allowing us to have the freedom we needed, but also answered questions and gave helpful advice when necessary,” and “We liked that the class was student- oriented, and the professor and TAs did not tell us what to do, but helped us towards our goal.”

Another source of data can be used to demonstrate teaching effectiveness in the FYEP course. At semester end, students participate in the university-wide Faculty Course Questionnaire (FCQ) in which they grade the course and instructor. [66] Student ratings compiled from five academic years (Table 3) yielded B+ instructor ratings across 68 sections of the course. Instructor accessibility in particular was found to be correlated with high ratings of the course.
TABLE 2.
SUMMARY OF RETENTION RESULTS FOR 5,070 FYEP COURSE TAKERS VS. NON-TAKERS — OVERALL, BY GENDER, AND BY ETHNICITY — SHOWING THE IMPACT OF THE COURSE ON ENGINEERING RETENTION INTO THE THIRD, FIFTH AND SEVENTH SEMESTER.

<table>
<thead>
<tr>
<th>Ethnicity</th>
<th>Overall (n = 5,070)</th>
<th>FYEP takers</th>
<th>FYEP non-takers</th>
<th>% Change in retention</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Third semester</td>
<td>86%</td>
<td>78%</td>
<td>10%</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td></td>
<td>Fifth semester</td>
<td>72%</td>
<td>62%</td>
<td>16%</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td></td>
<td>Seventh semester</td>
<td>64%</td>
<td>54%</td>
<td>19%</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td>Female (n = 1,015)</td>
<td>Third semester</td>
<td>86%</td>
<td>78%</td>
<td>10%</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td></td>
<td>Fifth semester</td>
<td>73%</td>
<td>61%</td>
<td>20%</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td></td>
<td>Seventh semester</td>
<td>67%</td>
<td>53%</td>
<td>26%</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td>Male (n = 4,055)</td>
<td>Third semester</td>
<td>85%</td>
<td>78%</td>
<td>9%</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td></td>
<td>Fifth semester</td>
<td>71%</td>
<td>63%</td>
<td>13%</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td></td>
<td>Seventh semester</td>
<td>63%</td>
<td>54%</td>
<td>17%</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td>Caucasian (n = 3,992)</td>
<td>Third semester</td>
<td>86%</td>
<td>78%</td>
<td>10%</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td></td>
<td>Fifth semester</td>
<td>72%</td>
<td>62%</td>
<td>16%</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td></td>
<td>Seventh semester</td>
<td>64%</td>
<td>54%</td>
<td>19%</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td>Asian American (n = 402)</td>
<td>Third semester</td>
<td>89%</td>
<td>81%</td>
<td>10%</td>
<td>0.02*</td>
</tr>
<tr>
<td></td>
<td>Fifth semester</td>
<td>77%</td>
<td>68%</td>
<td>13%</td>
<td>0.04*</td>
</tr>
<tr>
<td></td>
<td>Seventh semester</td>
<td>70%</td>
<td>57%</td>
<td>23%</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td>Latino (n = 290)</td>
<td>Third semester</td>
<td>82%</td>
<td>72%</td>
<td>14%</td>
<td>0.05*</td>
</tr>
<tr>
<td></td>
<td>Fifth semester</td>
<td>68%</td>
<td>60%</td>
<td>13%</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>Seventh semester</td>
<td>61%</td>
<td>52%</td>
<td>17%</td>
<td>0.10</td>
</tr>
<tr>
<td>African American (n = 80)</td>
<td>Third semester</td>
<td>95%</td>
<td>77%</td>
<td>23%</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>Fifth semester</td>
<td>80%</td>
<td>62%</td>
<td>29%</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>Seventh semester</td>
<td>70%</td>
<td>53%</td>
<td>32%</td>
<td>0.15</td>
</tr>
<tr>
<td>Native American (n = 41)</td>
<td>Third semester</td>
<td>77%</td>
<td>75%</td>
<td>3%</td>
<td>0.61</td>
</tr>
<tr>
<td></td>
<td>Fifth semester</td>
<td>47%</td>
<td>54%</td>
<td>-13%</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>Seventh semester</td>
<td>47%</td>
<td>46%</td>
<td>2%</td>
<td>0.59</td>
</tr>
</tbody>
</table>

Ethnicity unknown (n = 265)

*Significant p < .05

TABLE 3.
SUMMARY OF STUDENT FCQ RATINGS OF FYEP INSTRUCTORS OVER FIVE ACADEMIC YEARS.

<table>
<thead>
<tr>
<th>FCQ Category</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rating scale = 0 to 4 with 4 = A, 3 = B, etc.</td>
<td></td>
</tr>
<tr>
<td>Overall instructor</td>
<td>3.38</td>
</tr>
<tr>
<td>Treatment of student diversity</td>
<td>3.82</td>
</tr>
<tr>
<td>Fairness</td>
<td>3.42</td>
</tr>
<tr>
<td>Accessibility</td>
<td>3.22</td>
</tr>
</tbody>
</table>

Students in the FYEP focus groups often emphasize the open-ended, self-directed nature of the design projects as a real strength of the course. “To control your own project, to figure things out, open-endedness allows us to experience real engineering.” The experience of an open-ended design project has been found to benefit student intellectual development [62] and readiness for self-directed, lifelong learning. [63]

Student attitude development has been targeted as an outcome of participation in the FYEP course. Researchers at the University of Pittsburgh report, “From our study, we found that student attitudes are an effective means for...
evaluating several aspects of our freshman engineering program. Furthermore, these attitudes have proven to be especially valuable in addressing retention issues." [24] These researchers found the student attitudes that best discriminated retention results in the first-year program were confidence in engineering skills, liking engineering subjects and the major, and positive perceptions of engineering as a career.

Attitudes are also assessed in the FYEP course, where students rate their level of confidence pre- and post-semester on items related to FYEP skills objectives. [67] Figure 4 depicts the significant confidence gains across FYEP students for five academic years. On average, students posted a significant (p < .05) +19% gain in confidence from the pre-assessment score (69%) to the post-assessment (82%). The strongest confidence gains were for design skills (31%).

The volunteer effect is yet another approach to account for the improved retention effects of first-year engineering courses. This hypothesis states that students who would volunteer for a first-year course or program would, on average, be more likely to succeed in engineering due to a greater commitment to engineering or more motivation in general. [47] With this reasoning, the greater retention found in first-year programs would be the result of personal characteristics of the volunteers rather than any effect of the curriculum.

Educators at both Drexel and North Carolina State tested for the volunteer effect by assigning student volunteers to their revised first-year courses and a traditional course as a control. Results were split; Drexel found that volunteers in its E² Program were retained at a higher rate than in the control course, while NC State found no difference in retention for volunteers for either the revised or traditional curriculum. [47, 56]

The data set from the FYEP course provides another way to test for the volunteer effect. During the time span of this study, the departments of three majors — aerospace, mechanical and environmental engineering — required their students take the FYEP course while open option students and those in other majors essentially volunteered for the course. Aerospace and mechanical engineering required the course since 1997 and environmental engineering since its inception in 1999. If the volunteer effect were a significant factor in student retention, retention for FYEP takers from required majors should be lower than FYEP retention for the motivated and committed all-volunteer takers. This hypothesis was investigated on a sample of 3,625 students who took the FYEP course from 1997 when the course became required through 2002.

Figure 5 depicts the results of an analysis of 832 “required” FYEP takers and 2,793 takers from the FYEP “volunteers” sample. For each measure, chi square tests revealed no significant differences between the two student groups. These results lend support to the argument that the hands-on, project-based curriculum of first-year engineering courses positively impacts student retention, and that results are not attributable to a “volunteer effect.”

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**FIGURE 4.**

![Student Confidence Rating](image-url)
PRE/POST-SEMESTER STUDENT CONFIDENCE SELF-RATINGS ON THE FYEP COURSE SKILLS OBJECTIVES OVER FIVE YEARS. ALL RESULTS ARE STATISTICALLY SIGNIFICANT ($P < .05$).

Given the significant gains observed in retention for the FYEP and other revised first-year courses, two logical questions arise: Should a first-year course be implemented in your school, and should the course be required across all departments? The “pros” include the likelihood of improving dismal retention rates, to contribute significant added value above average retention rates (see Table 1 and 2), and students gaining experience doing real engineering early in their educational journey. The “cons” include an overcrowded curriculum (and resistance to remove legacy courses), a general reluctance to provide curricular offerings that transcend departmental boundaries, the additional resources required to offer small, community-building projects courses, and lack of resources — including money, space, and supporting technologies. [41]

Taking into account these pros and cons, our belief is that an interdisciplinary first-year projects course should be required in all engineering programs. The cost of not doing so is obviously high – to the students who are discouraged from persevering in satisfying (and lucrative) engineering fields, to the engineering profession that is denied prepared.

I. Conclusions

One remaining point is the impact of student demographics on retention in the FYEP course. Non-significant results on the differential impact of the course by gender and ethnicity were unexpected given previous findings in the literature and given different patterns in the data (e.g., +26% women vs. +17% men for retention at the seventh semester). Yet, it appears from the results that an FYEP experience is helpful for all students regardless of gender and ethnicity as students from both majority and underrepresented populations demonstrated retention gains by participating in the course. Future research is needed to fully clarify the impact of the FYEP course by demographics (see discussion below).

Taken together, this range of explanations regarding the impact of the FYEP course on student retention can be summarized under Tinto’s theoretical retention framework. [19] Specifically, students come into the first year with certain attitudinal characteristics (e.g., confidence levels) that are significantly impacted by hands-on and open-ended learning experiences, quality instruction and a close-knit, team-based community. The net result is that students feel more confident in their engineering skills and more deeply integrated into their engineering careers and therefore more likely to remain in engineering.
interested and more diverse graduates, and to the nation that needs more educated and skilled people to undertake engineering challenges in an increasingly technological society.

Clearly, losing nearly half of our talented entering students is unacceptable and should be improved by all reasonable means. Our long-term results suggest that requiring all engineering students to take a team-based, project-oriented first-year design/build course would increase the number of graduating engineers.

B. Limitations and Suggestions for Future Research

In the present study, conclusions are difficult to reach about students from underrepresented ethnic groupings due to low sample sizes. One solution would be to pool underrepresented student data across institutions to better understand retention patterns, although the risk here is that this would mask important differences between ethnicities [65].

Future research is also needed to better understand the impact of the course on women. The cooperative, success-oriented culture of the FYEP course would seem to have added impact as a diversity tool, and differential patterns in the data are compelling (Figure 2). One hypothesis is that the FYEP course serves as an isolated oasis for women, with its positive impact hampered by the surrounding culture of the college. For example, one student in Seymour and Hewitt’s qualitative investigation of student retention reported, “It’s hard, because a lot of the connotations that professors use are male. They’ll refer to us all the time as ‘You guys,’ and everything is kind of male, and I didn’t feel included.” Another woman commented, “The only other women and I in my lab were treated like we were stupid no matter what we did. If I got a wrong answer, it would be that I was stupid. If a guy got a wrong answer, it was just that he hadn’t explained it right.”[2]

Perhaps increased pervasiveness of the FYEP approach is needed throughout the college including increased faculty, staff, and student participation. A new approach that has been undertaken in the college since the onset of this data analysis is the creation of a women’s manufacturing workshop designed to increase women’s manufacturing confidence and skills — and thus increase their contribution to the technical components of their team projects. [68] Early results are very encouraging.

Additional research is also needed into the causes of the increased retention rate as a result of participating in the FYEP course. While these retention gains can be tied to conclusions reached by other researchers, including hands-on projects, the development of a learning community, incorporating a success orientation, or caring faculty, additional research is needed to tie all of these components together into a proven model that can be reliably assessed and institutionalized in engineering. Promising work in this area is ongoing through the Academic Pathways study of the Center for the Advancement of Engineering Education and the associated development of the Persistence in Engineering Survey. [29]

SUMMARY

Engineering students who take the First-Year Engineering Projects Course at the University of Colorado at Boulder are significantly more likely to be retained at the third, fifth, and seventh semesters than their peers who do not take the course. A further examination of the data supports the notion that this retention is due to impacts of the course rather than the “volunteer effect.” Likely explanations for these retention gains include the impact of active hands-on pedagogy, creation of student learning communities, an early experience of the human side of engineering, self-directed acquisition of knowledge by students, instructor mentoring, and the success orientation of the course. These results imply the need to more broadly require and implement first-year engineering curricula embodying these characteristics.

REFERENCES


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Lawrence E. Carlson is professor of mechanical engineering and founding co-director of the Integrated Teaching and Learning Program. He earned a BS from the University of Wisconsin, and MS and D.Eng. from the University of California at Berkeley, all in mechanical engineering. After three years at the University of Illinois at Chicago, he joined the University of Colorado in 1974. Dr. Carlson is passionate about hands-on learning, teaching courses that emphasize engineering design from the first-year through graduate levels. He spent a sabbatical leave at the inspirational product design firm IDEO to sharpen his design skills.


Jacquelyn F. Sullivan is founding co-director of the Integrated Teaching and Learning Program, focused on integrating hands-on learning throughout the undergraduate engineering experience. She co-led the development of a first-year engineering projects course, and co-teaches Innovation and Invention and a service-learning Engineering Outreach Corps elective. Dr. Sullivan initiated the ITL’s extensive K-12 engineering program and leads a multi-institutional NSF-supported initiative that created TeachEngineering.org, a digital library of K-12 engineering curricula. Dr. Sullivan has 14 years of industrial engineering experience and directed an interdisciplinary water resources decision support research center at CU for nine years. She received her PhD in environmental health physics and toxicology from Purdue University.