Staying in Engineering: Impact of a Hands-On, Team-Based, First-Year Projects Course on Student Retention

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Abstract

This study evaluates the impact on student retention of the First-Year Engineering Projects (FYEP) course at the University of Colorado at Boulder. Student retention was measured at the third, fifth and seventh semester for student takers and non-takers of the FYEP design/build course. Data were analyzed for 2,581 students over five years, representing 1,035 students who took the FYEP course (40%) and 1,546 students who did not take the course (60%). Significant gains in retention were found for student takers, and even higher retention rates were observed for students typically underrepresented in engineering — women and students of color. This paper compares these results with reported retention data from other institutions and discusses possible causes and ramifications of the findings.

Introduction

Student retention has been a concern in engineering education since enrollments began to decline nationally in the mid-1980s. Termed "leakage" from the engineering "pipeline," an average of 40% of students nationally leave engineering before graduation, with some schools reporting losses up to 70%. Leakage for women and underrepresented ethnic minority students is more troubling, with 70% of women, 70% of Latino students, and 50% of African-American and Native-American students dropping out of engineering before graduation.[1] At the University of Colorado at Boulder (CU), a similar pattern is found. Across a 10-year span from 1986-96, dropout rates were 50% overall, 48% for women, 59% for Latino and African-American students, and 70% for Native-American students.[2]

Causes of the high leakage rate have been debated by a series of commissions, task forces, conferences and research studies. One of the more comprehensive initiatives to investigate student attrition was conducted by Elaine Seymour and Nancy Hewitt.[3] These researchers used qualitative interviewing methods to investigate retention issues for 335 science, mathematics and engineering students at seven, four-year institutions. Students identified a number of factors that contributed to switching majors including poor teaching, lack of peer group support, lost confidence, the competitive culture, problems related to class size, and an overall feeling of having lost interest or having been "turned off" on the subject matter. These results led the

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authors to conclude, "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 which arise either from structural or cultural sources within institutions..."[3]

By the mid-1990s a national effort had been initiated to improve engineering curricula and increase participation in the engineering pipeline from the kindergarten through graduate school level. Changes included tailoring the curricula to attract a more diverse group of students, integrating the curricula to present a unified rather than compartmentalized view of engineering science and practice, and broadening the curricula to include an emphasis on the additional professional skills needed to practice engineering.[4-5] One area in which these changes have been implemented is in the introduction of entry-level engineering courses. A wide variety of models exist, ranging from a one-credit, voluntary introduction to engineering course at the University of Florida[6] to fully integrated first-year curricula such as the 12-credit IFYCSEM program at the Rose-Hulman Institute of Technology.[6]

First-Year Engineering Projects Course

CU's College of Engineering and Applied Science offers the First-Year Engineering Projects Design-Build Course (FYEP). Initiated in 1994, this course is a three-credit, one-semester course that now serves approximately 350 students per year. The course is required by the mechanical, aerospace, and environmental engineering majors and is an elective for the rest of the college's departments. In contrast to large, impersonal math and science courses, each FYEP section is limited to 30 students. Instruction and enrollment are interdisciplinary; sections are staffed with instructors from a variety of engineering departments. The goals of the course 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. The course also serves to cement the concepts students concurrently learn in core physics, chemistry and mathematics courses.

Several course components are used to accomplish this goal, 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. Many projects are client-based, developed for real customers. The projects include design reviews, team-based oral presentations, written communications, cost considerations, and culminate in an end-of-semester design expo at which prototypes are showcased to the public. Past project themes include:

- Rube Goldberg contraptions to perform ordinary functions in surprising ways;
- "Green" designs to make it easier for the campus recycling center to collect materials;
- Sensors that accurately measure a physical quantity, such as the amount of fuel remaining in a vehicle's tank, regardless of its orientation;
- Appropriate technology devices for use in developing countries;
- Assistive technology devices, e.g., a page-turner for an adult with cerebral palsy; and
- Interactive learning exhibits aimed at teaching an engineering or scientific concept to children, either in a middle school class, or in a youth museum exhibit.

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The course operates out of two design studios in the Integrated Teaching and Learning Laboratory (ITLL), a well-equipped 34,400 sq. ft. hands-on learning facility. The design studios are smart classrooms that feature tables instead of desks (to facilitate teamwork), workbenches, computers and high-resolution video projection. Each student team is loaned use of a toolbox and supported by the ITLL Manufacturing Center with state-of-the art machining and fabrication capabilities and the ITLL Electronics Center with facilities to prototype, fabricate and test printed circuit boards.[7-8]

Assessment of First-Year Engineering Courses

Measurements of success in first-year engineering courses have commonly focused on student grade point average (GPA), student self-evaluation and student retention.[6] For example, the Ohio State University found that participants in their first-year engineering program had an overall higher GPA by their junior year than students who did not participate in the program.[6] Student self-evaluations have been used as one measure of success in the FYEP course at CU. Using pre- and post-semester surveys, students self-reported gains in their design skills, teamwork skills and communication skills, as well as increased knowledge of engineering methodology and engineering as a career.[9]

The present study is focused on student retention, which has been found to consistently improve at many institutions as a result of first-year engineering curricular changes. On average, retention rates of students who take first-year engineering courses has been found to increase 16%.[10] These rates have been found to be similar across a number of different types of programs including: Rose-Hulman, Purdue, Ohio State, University of Alabama, University of Florida and Texas A&M.[10] Some first-year programs have reported even higher retention rates for women and students of color. Texas A&M found that retention in their integrated first-year program was higher than the traditional program by 22% for women, 29% for African-American students and 20% higher for Hispanic students.[11] The University of Florida found that retention of women and ethnic minority students who took their first-year program substantially increased by 225% and 33% respectively.[12] Likewise, the University of Alabama reported a 44% increase in retention of women engineering students over the traditional first-year program.[10]

Retention rates have been measured differently across programs. Established programs such as Drexel's E^4 program, which began in 1989, and Rose Hulman's IFYCSEM program, which began in 1990, use graduation from the college of engineering as a measure of retention.[6] While this type of measure is the most accurate, at least 10 years worth of data are necessary to allow enough time for several student cohorts to matriculate through the system. Programs that have been in existence for a shorter period of time use retention into a specific semester as an indicator. For example, the University of Florida, which began its program in 1993, has used retention into the third year while the University of Massachusetts at Dartmouth (which began its program in 1998) has used retention into the third semester as an indicator.[13] 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.[14]

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In the present investigation of CU's FYEP course, retention is measured into the third, fifth and seventh semesters to investigate both the immediate effects of participating in the FYEP course and the program's long-term effect on graduation potential.

Methodology

Retention data were collected across five years from the spring semester 1994 through the fall semester 1998. The data total 2,581 students with 1,035 students who took the FYEP course and 1,546 students who did not take the course. The sample includes 2,057 men and 524 women with 2,063 Caucasian students (80%), 190 Asian students (7.4%), 160 Latino students (6.2%), and 35 African-American students (1.4%). One hundred thirty-three students were listed as ethnicity, "unknown" or were from an ethnic group with too few students to analyze (e.g., American Indian). This sample only includes students who entered the College of Engineering and Applied Science classified as first-year students and does not include transfer students. Retention in the college was measured at the third, fifth and seventh semester for all students in the sample, both by gender and by ethnicity. Chi square statistical tests were used to test differences between FYEP takers and non-takers on the retention measures.

Results and Discussion

Figures 1, 2 and 3 depict the results in graphical format. Across all students, FYEP takers were retained at a significantly higher level than non-takers on all three measures: third, fifth and seventh semester retention ($p < .001$). This same pattern holds up for men and women as well as the Caucasian and Latino ethnicities ($p < .05$). Neither Asian nor African-American student retention rates were significantly different for FYEP takers and non-takers, although the pattern was similar to the previous results. Table 1 depicts the seventh semester retention numbers for all samples. It can be seen that the largest significant gains are for the Latino and women students, respectively, while the smallest gains are for the Asian students.

The 19% seventh semester retention gain among all students who took the FYEP course over non-takers is similar to the 16% retention gain reported, on average, in similar courses at other institutions. As these gains have been found across programs, there has been some debate in the literature about how to account for these effects. One suggestion is that through these types of programs students develop a peer support network. Members of the University of Alabama's TIDE first-year program 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."[10]

Other universities tout the effects of first-year engineering courses on building the skills necessary to succeed as an engineering student. Members of Purdue's Department of Freshman Engineering state, "There is a relationship between ultimately graduating in engineering and first obtaining a thorough understanding of basic mathematics and science principals… At Purdue University, we believe that the (first-year) courses in calculus, chemistry and physics supply the collegian with these necessary skills."[14] Skill development has also been investigated in CU's FYEP course in which students have reported increased skills across several dimensions

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important for success in engineering including design skills, teamwork skills and communication skills.[9]

Still other universities, such as the University of Florida, cite the influence of the active, hands-on learning environment of their first-year laboratory course for significant improvements in retention.[12] This influence is also supported by data from CU's FYEP course. At the end of each semester, FYEP students participate in a qualitative assessment procedure in which they work in teams to arrive at a consensus about the strengths of the course. Across teams and semesters, one of the most consistently mentioned strengths is the hands-on experience provided by the course.

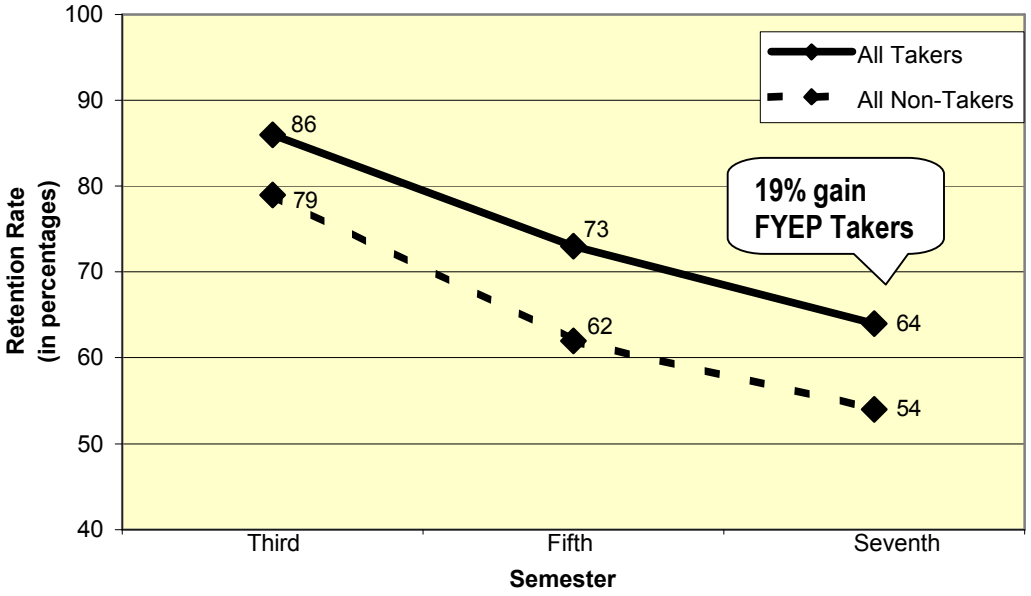

Figure 1: Effect of the First-Year Engineering Projects course on retention: All Students.

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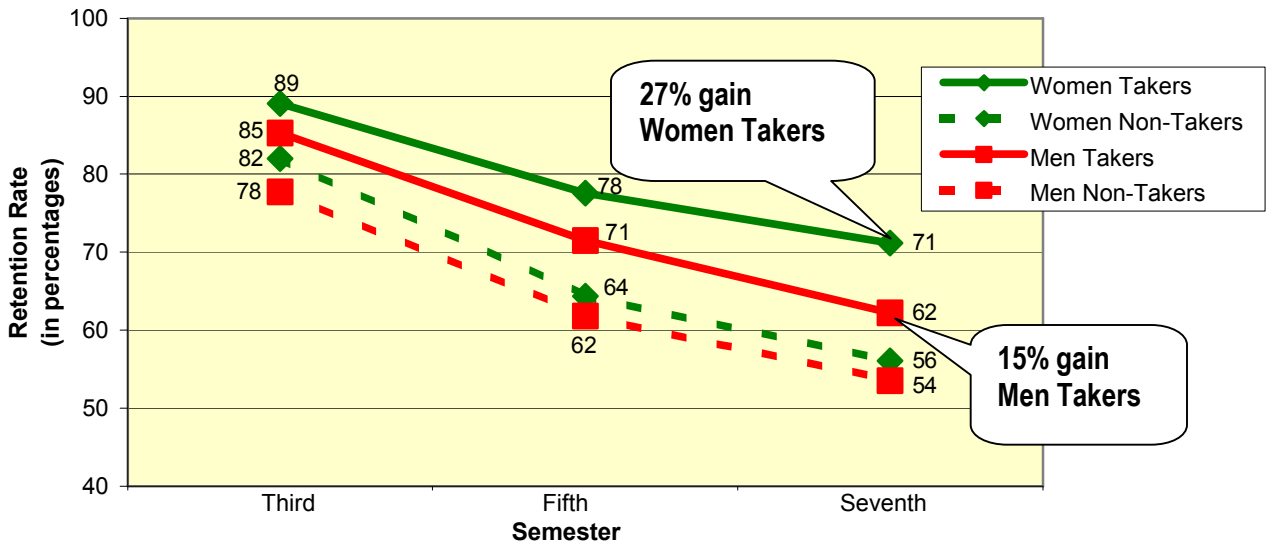

Figure 2: Effect of the First-Year Engineering Projects course on retention: By Gender.

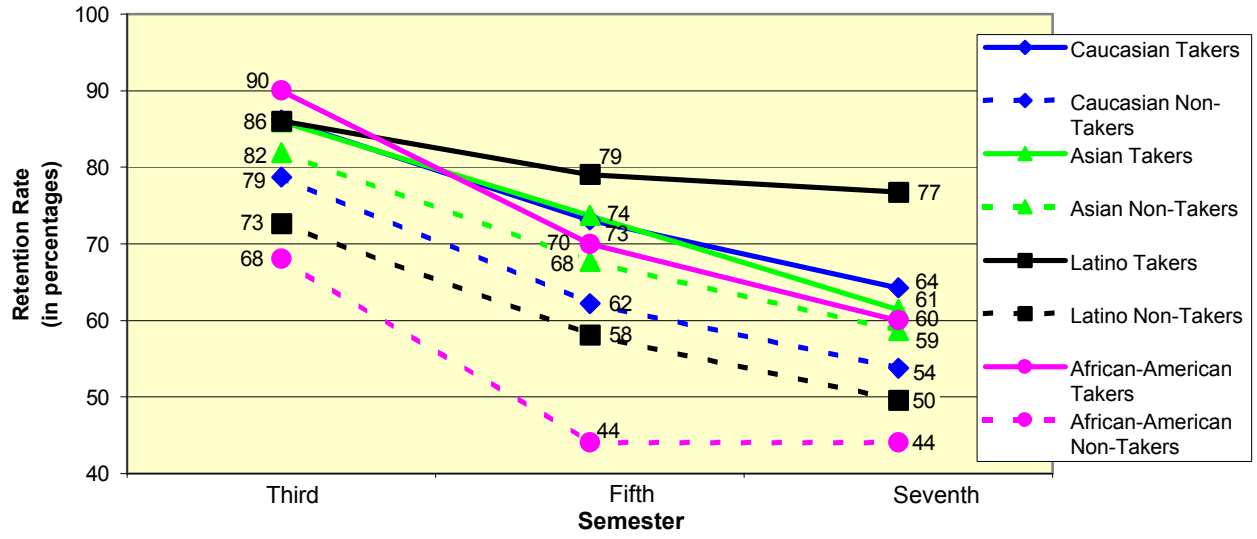

Figure 3: Effect of First-Year Engineering Projects course on retention: By Ethnicity.

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Table 1: Seventh semester retention gains for all students.

Sample	Takers Retention	Non-Takers Retention	Retention Gain	Chi-Square Value
All Students	64%	54%	+19%	24.88*
Women	71%	56%	+27%	11.98*
Men	62%	54%	+15%	15.22*
Caucasian	64%	54%	+19%	22.78*
Asian	61%	59%	+3%	.12
Latino	77%	50%	+54%	9.47†
African-American	60%	44%	+36%	.73
			*p < .001	†p < .01

The "volunteer effect" is yet another way of accounting for the 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.[10] Thus, the greater retention found in these programs would be the result of inherent attributes of the volunteers rather than any effect of the curriculum. Several universities have tested for the volunteer effect. Both Drexel and North Carolina State University controlled for the volunteer effect by assigning student volunteers to their experimental first-year courses and a comparison course as a control. Results were split, as Drexel found that volunteers in its E^4 program were retained at a higher rate than in the control program while North Carolina State found no difference in retention for volunteers in both programs.[10] The University of Florida tested for the volunteer effect in a different way, surveying students before the semester on their level of commitment to engineering in both the experimental, voluntary laboratory course and the standard lecture course that served as a control. No difference in reported level of commitment was found between the experimental and control students, leading to the conclusion that the volunteers had no greater commitment to engineering going into the experimental course than did their peers in the control group.[12]

The data set for the present CU study provides another way of testing for the volunteer effect. Three majors — aerospace, mechanical and environmental engineering — require the FYEP course. If the volunteer effect were an important factor in student retention, a significant decline in retention improvements would be expected in the required classes as (theoretically) less motivated students became mixed with the volunteers. Only one major, aerospace engineering, provides enough data to analyze the volunteer effect. Since the fall semester, 1997, the Aerospace Engineering Sciences Department (ASEN) at CU has required its first-year students take the FYEP course. Before that, ASEN students who took the course were "volunteers." Figure 4 depicts the results of an analysis of 94 takers in the volunteer sample and 127 takers in the required 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 curriculum of first-year engineering courses positively affects student retention independent of any "volunteer effect."

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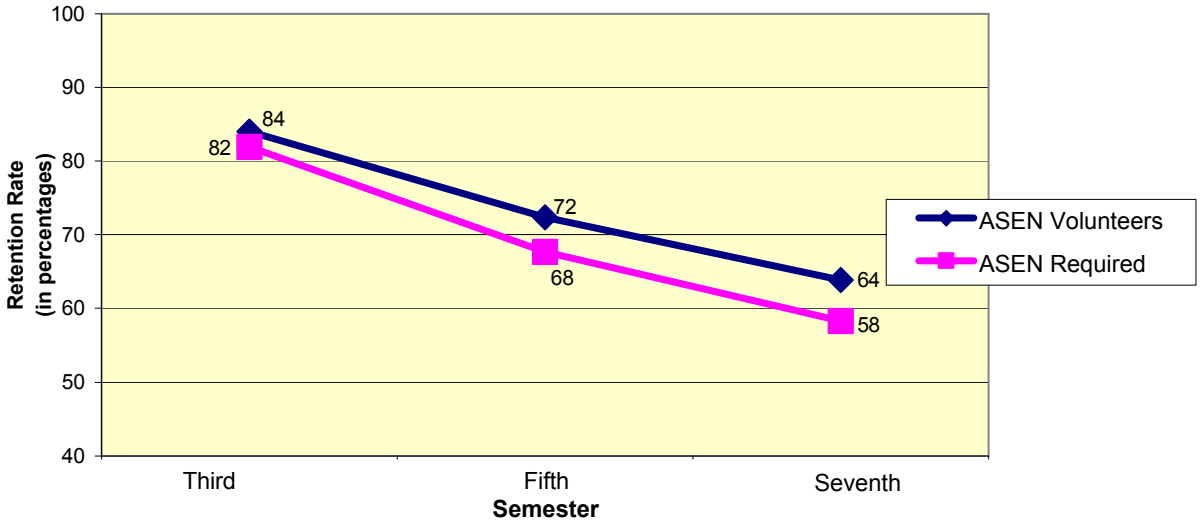

Figure 4: Testing the volunteer effect on student retention in the First-Year Engineering Projects course.

Gender and Ethnicity

Substantially higher retention gains were found for women and Latino students who took the FYEP course. The same pattern was present for African-American students, with non-significant results most likely due to a low sample size (n = 35). Greater retention rates for women and ethnic minority students have been reported in other studies as well.

One reason for increased retention for women and Latino students as a result of the CU FYEP course is that this course is oriented toward success in a cooperative setting. First-year students traditionally encounter a series of "weed out" courses, frequently in large, impersonal settings. These courses are built around an educational culture that is designed to be challenging and competitive, generally supporting the socialization and preferred learning style of Caucasian men. Women and ethnic minority students are more likely to see this culture as attacking or unsupportive. In their qualitative investigation of retention behavior in the sciences, mathematics and engineering, Seymour and Hewitt heard these types of comments in their interviews.[3] One woman reported, "Male professors are — I don't know what the right word is — rude? You know, attacking and aggressive." Similarly, an African-American student reported, "I learned that the instructors here are very indifferent to the needs of students, especially minority students." To make matters worse, women and ethnic minority students were found to be more likely to internalize negative feedback. One women reported, "Most girls take it to heart, and guys are like, 'Oh, yeah! I don't need to listen to you.' Girls say, 'Maybe they're right.' They are more apt to make something into a criticism. A guy would just blow it off. I'm not good at blowing things off. I take it personally. I'm hurt."

In contrast to the dynamics of the weed-out culture, CU's FYEP course emphasizes a supportive pedagogy and student success. Instructors consistently receive praise 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,

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allowing us to have the freedom we needed, but also answered questions and gave helpful advice when necessary."

While students in the FYEP course consistently rate it as having a (too) heavy workload, students are typically rewarded rather than failed for their hard work, with a 'B' as the average grade earned in the course. These factors likely combine to build, rather than crush, the confidence of all students, including women and ethnic minority students, and likely propel them toward graduation rather than toward non-engineering majors.

Implications

Given the significant gains observed in retention, a logical question arises: Why don't all CU engineering majors require the FYEP course? One obvious answer is cost. Providing hands-on, project-oriented design courses to all 650+ first-year students is expensive. The CU model is resource intensive, with an instructor and two undergraduate TAs for each section of 30, in addition to peripheral support in the form of CAD/CAM tutoring and mentoring, as well as highly skilled manufacturing and electronics experts. In addition, space is an issue. The need for design studios for team-based learning and additional student project storage results in significant space requirements. Finally, the fact that departments tend to function autonomously creates an environment in which the acceptance of mandatory college-wide curriculum initiatives is not welcomed.

In spite of these challenges, the college leadership is evaluating implementing the First-Year Engineering Projects course college-wide. 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 and interested graduates, and to the nation that needs more educated and skilled people to undertake technical challenges in an increasingly technological society.

Like many engineering colleges, we invest resources in programs specifically targeted at improving the diversity of our student body. Given the significantly improved retention of those students who take the FYEP course who are underrepresented in engineering — women and students of color — it would seem inexcusable not to provide a learning experience that promotes their retention in engineering.

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

Summary

Engineering students who take the First-Year Engineering Projects course at the University of Colorado at Boulder are 19% more likely to be retained into their senior year in engineering than students who do not take the course. This effect is even greater for women (27%), Latino students (54%), and African-American students (36%). These retention outcomes are attributed

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to impacts of the course rather than characteristics of the students who choose to take the class. Positive course benefits include an increased sense of community, development of the skills and confidence necessary to succeed in engineering, hands-on design experience, and a supportive culture that emphasizes success and teamwork.

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