The Impact of a Discipline-Based Introduction to Engineering Course on Improving Retention

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Abstract

An Introduction to Engineering course at the University of Florida was converted from a lecture-based offering to a laboratory format in a project sponsored by the Southeastern University and College Coalition for Engineering Education (SUCCEED) (NSF Cooperative Agreement No. EID-9109853). The revised course rotates student groups through laboratories in each of the undergraduate engineering disciplines. Majors and non-majors receive a grade for this one credit course which meets three hours per week. The laboratories employ active learning and a smaller class size to achieve two objectives: 1) to better inform students about the nature of engineering and its specific disciplines and 2) to improve the retention of these students in engineering. The achievement of the first objective has been shown in our earlier work. This paper focuses on the achievement of the latter objective, which is shown by a longitudinal study to be dramatically improved. The magnitude (a 17% improvement in retention for the general population and greater for women and minorities) is surprising for a single course, but reasons are suggested which might explain such a large effect.

I. Introduction

In 1990, the ASEE Engineering Deans Council Pipeline Implementation Committee identified specific tasks and objectives for engineering education. Among the four tasks that the Committee considered particularly important was a charge to “develop or expand...first-year entry programs [that] should introduce students...to the spectrum of opportunities in engineering and provide them with engineering experiences.” One of the responses to this charge has been the widespread introduction and revision of “Introduction to Engineering” courses and those of similar names and purposes.

A wide range of objectives, credit hours, and approaches characterize these introductory courses. One approach focuses on developing the success skills of students with the objective of improving retention in engineering programs. Success skills programs introduce students to various resources, habits, and equipment that will improve their chances of succeeding in an engineering program. Many success-based introduction to engineering courses are based on the Landis model; they have been implemented with a summer residential component, as one- or two-credit courses, and as a three-credit, two-course sequence.

Ilan et al. describe how limiting the focus of an introductory course to a subset of engineering disciplines (usually mechanical, electrical, and either manufacturing or industrial) enabled the instructors to devote more time to each design effort. Dini et al., McDonough and Hardin; and Rizkalla et al. used a similar approach, but also included some aspects of the success-based courses described earlier. In-depth interdisciplinary projects have also been used to give greater insight to the design process.

Still other implementations of an introductory engineering course use an approach which is designed to foster creative thinking in the manner of Lumsdaine and Lumsdaine. MCDough and Hardin used methods in preparation completing an interdisciplinary design project. A very intensive introductory experience is described by Orris—a two-semester course of three credits per semester at the University of Virginia covers creativity and other conceptual topics, skill-based components, case studies, and multiple design projects.

II. Method of Course Implementation

The Introduction to Engineering course at the University of Florida prior to 1993 was a lecture-based pass/fail class of the type which has been characterized as “Sleep 101” by Ercolano, poking fun at the large numbers of students who sleep during such classes. The revitalization of this course was funded by the NSF-sponsored SUCCEED Engineering Education Coalition. The revised course is open to majors and non-majors, but the course is not counted as part of the engineering curriculum.

One of the specific goals of the SUCCEED coalition has been to increase enrollment and retention especially among minorities and women. In order to achieve these goals, it was proposed to infuse design into the early years of engineering education, expand undergraduate laboratory experiences, and promote engineering in the public school system. The laboratories designed for the revised Introduction to Engineering course, described below, employ all these tactics—the public school system applicability is achieved by keeping the laboratories simple and inexpensive.

The resulting laboratory-based course provides a hands-on experience of the engineering function, introduces students to teamwork in engineering and allows an early opportunity to develop communication skills. This format is intended to tap the benefit of “experiential learning” as described by Kolb which is widely recognized in engineering education.

The traditional University of Florida lecture course format has
been a one credit, one hour, pass/no pass format. About 180 students met weekly to hear a representative from each engineering discipline lecture about the representative’s field of engineering. The pass/no-past grading is based on attendance only. Large numbers of students sleep, talk, or read the paper and receive no benefit from the lecture class. We felt that retaining the departmental structure of the course was important. Even though engineering is becoming increasingly interdisciplinary, the academic structure is still organized into departments, each with its own character. Developing a relationship with a department in the freshman year is considered to hold promise for contributing to the retention of students.

The majority of the freshman introductory experiences discussed earlier are assigned three credits. At the University of Florida, there is pressure from the state legislature to reduce the number of credit hours required for graduation. This places the constraint that students for greater effort with no additional credit is a precarious position for a course, so letter grades were added to the laboratory version of the course to provide an added incentive. The assignment of a letter grade is justified because of the improved level of contact.

The laboratory class was offered to students in lieu of the lecture course. The format of the laboratory course follows. Students meet weekly for a three-hour block (three times the duration of the lecture section) and are given a letter grade. The departments are not required to use the full three-hour block, but must make full use of the allotted time. The grade for this one-credit course is based on both attendance and participation, but students are allowed to miss two classes without affecting their grade. Each absence after the second decreases the student’s grade by one half letter grade. The 14 groups of students meet once at the beginning of the semester to receive instructions for the remainder of the semester. Students remain in the same groups through the remainder of the semester as they are rotated through 14 meetings: 11 engineering departments that have undergraduate programs, 2 computer skills sessions, and 1 week off (which can be used to make up missed classes).

The first year of this two-year project was used to establish a foundation for the program. In fall 1992, individual experiments were developed and evaluation criteria were established. In spring 1993, the laboratory was introduced in an experimental phase to a small number of students. Summer 1993 was used to update the experimental handouts, and share the preliminary results with SUCCEED member schools. In fall 1993, the capacity of the laboratory section of the class was expanded to accommodate approximately the same numbers of students as the lecture section.

The spring 1993 cohort in the laboratory section was selected as follows: enrollment was first solicited through honors advising, which yielded approximately 15 students. This was done to minimize the potential damage of the educational experiment. This was not a large enough enrollment, so additional students were recruited by H oil, who made an appeal to students already registered for the lecture section. This appeal was made at the lecture section’s first meeting. Subsequent cohorts were self-selected, i.e., students were informed of both sections during the college’s orientation and could choose either the lecture or the laboratory section. The implications of this selection process for the interpretation of our results is discussed in the Results and Discussion section.

Enrollment figures for the lecture and laboratory during the evaluation period are shown in Table 1. These three cohorts have been studied longitudinally.

Class sizes have grown since the institutionalization of the revised course and can now accommodate 14 groups of 20 students each. In order to have a high level of interaction with the professors and the other students, and in order to be able to manage the same level of student activity, an upper limit of 20 students per group has been set. To serve as many students as possible, the course is offered during the fall, spring, and the second summer terms, achieving an annual capacity of 840 students.

III. Laboratory Content

Each department with an undergraduate engineering program has designed activities representative of its discipline to engage the students during their visit. Each department designed its own laboratory, but the designers were asked to design their laboratories within a framework of three goals: to demonstrate the diversity of engineering, to give students a simplified and exciting view of what the engineering process includes, and to teach basic skills and concepts. The different departments weigh these goals differently. As a result, in addition to achieving these goals, students also learn about the character of individual departments.

Below is a brief description of each department’s activity. These activities are readily and regularly modified, however. The actual content of each semester is at the discretion of the individual departments. Many of the departments have extensive handouts for the students describing in greater detail the specific activities of the day and the department and its degree programs in general. These handouts help eliminate lecture time during the class period.

A. Aerospace Engineering, Mechanics, and Engineering Science

Student teams build a composite plate using hydraulic cement, cotton balls, string, and other materials. The plate is intended to protect an egg from damage when a steel ball is dropped on the plate with the egg underneath. The drop height is increased until failure.

B. Agricultural Engineering

Students conduct one of three activities:

- comparing a corn kernel's calculated terminal velocity to the true terminal velocity measured in an aerodynamic wind tunnel;
- a sheet to illustrate the effects of various factors on the true terminal velocity of a steel ball dropped on the plate with the egg underneath.

<table>
<thead>
<tr>
<th></th>
<th>Lecture</th>
<th>Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring 1993:</td>
<td>128</td>
<td>35</td>
</tr>
<tr>
<td>Fall 1993:</td>
<td>125</td>
<td>108</td>
</tr>
<tr>
<td>Spring 1994:</td>
<td>68</td>
<td>55</td>
</tr>
</tbody>
</table>

Table 1. Enrollment in lecture and laboratory sections.
Students tour the University of Florida (UF) cogeneration plant, which is a teaching facility. They then hear about the department and discuss their expectations of engineering and college. This laboratory focuses particularly on success skills and student discussion.

K. Nuclear Engineering

Students tour the department's facilities, ending in the reactor facility where sub-groups conduct hot channel factor measurements, a trace element analysis using neutron activation analysis, and half-life measurements.

The computer skills sessions were originally an introduction to word processing and spreadsheet use, but it was quickly discovered that the vast majority of students already possessed these skills. In the current sessions, students search for a variety of information on the World Wide Web and use MathCAD™ to study a variety of problems and perform what-if analyses.

IV. An Example of the Design of an Activity (Civil Engineering)

As an example of how the former lecture-dominated model was updated to the more active laboratory version, the modifications to the civil engineering component will be discussed. As a faculty member and graduate student in the Civil Engineering Department, Hoit designed the original civil engineering activity for the survey course described in this article and Hoit and Ohland collaborated in the improvement of the activity. All other activities were designed by the faculty within their respective disciplines.

The new laboratory has much greater student interaction than the lecture version and, consequently, more opportunity for feedback. As a result, the laboratory activity has experienced some modification since its inception. This does not violate this study, since the feedback loop that improves the laboratory version of the course is part of its advantage over the lecture version.

The design of the civil engineering laboratory activity assumed little preparation, since high school experiences may vary. Since each group of students will only be in a particular activity for three hours with no follow-up, the activity is designed to be short and self-contained. In order to foster a team effort in producing a group product,26 a short design project was included. Although we chose to feature the design, construction, and testing of a 2-D truss, it was not consistent with the objectives of this course to conduct an extensive project (such as those by others27,37) that requires a greater time for problem definition and demands significant prerequisite knowledge.

The handouts for the Truss Bridge Laboratory can be viewed on the World Wide Web.36 We consciously decided to minimize lecture time and maximize the time used for activities or demonstrations. Some parts of the older format (graduation requirements, salary expectations, etc.) were included in a laboratory handout rather than discussed. Our experience has been that students with a prior interest in civil engineering or those who are particularly excited by the laboratory keep the handouts to read this information at a later time.

The new format, taught by either or both of us throughout the experimental period, follows: first, the various disciplines of civil engineering are described in a brief account (5-10 minutes in total) which includes examples of the work done by each; concrete and steel specimens are then tested to failure (15 minutes); a lecture (~15 minutes) follows to introduce students to the concepts of moment, moment of inertia, neutral axis, failure modes, and truss design.36 Instructor-assigned student teams of 3-4 individuals then design and construct 2-D trusses out of popsicle sticks with bolted connections (45 minutes). The trusses are then tested to failure in a...
special load frame. The testing process is accompanied by commentary from the instructor. The benefit of using instructor-assigned teams is somewhat thwarted since we do not have the opportunity to employ a sophisticated assignment technique. Two objectives have been met through the instructor-assignment process, however. Students who are clearly good friends (and might therefore dominate the group) can be separated, and women and minority students can be grouped so they are not outnumbered in their teams, improving their experience.28

A score for each truss is computed on a strength-to-cost basis (~10 minutes) (cost being a function of the amount of material used). A hurricane testing apparatus (which is essentially a pneumatic cannon that launches a piece of lumber) is then demonstrated. The laboratory ends with the instructor encouraging students to seek student membership in technical societies (a society representative is sometimes present) and to take advantage of various services offered by the UF College of Engineering (including advising).

V. Assessment Methodology

The assessment methods used to evaluate freshman introductory experiences vary greatly. While many indicate that among their objectives is the improvement of retention, it is a common practice to assume that the assessment of the professor or the positive attitude of the students as measured through a questionnaire is sufficient to conclude that such an improvement will occur. A number of studies, at the time of publication, mention either no assessment or assessment only by the course professor.5,6,13,16,20 Aiso common is the evaluation of student interests, attitudes, and knowledge through the use of a survey/questionnaire instrument.7,11,14,15,16 Two studies were found that used written student evaluations and interviews to assess student opinions in more depth.10,13 Retention studies have been used in a minority of cases, either alone or in combination with a questionnaire.6,12 The absence of a control group is pervasive, especially in studies that use a questionnaire.

As Sanders and Burton29 suggest, both questionnaire and retention data used together complement each other. Questionnaire data by themselves may suffer from the uninformed opinion of students, who might recognize a course’s value only after entering the work force. Retention data in isolation provide no formative evaluation, require longitudinal study to accurately collect, and can fall short of demonstrating a causal relationship between a program and an observed improvement in retention. We used both a questionnaire and longitudinal retention data in order to demonstrate, as convincingly as possible, both an effect and a causal relationship.

We administered a pre- and post-questionnaire to both the lecture and laboratory cohorts.1 The results of this questionnaire were useful for evaluating our first objective of teaching about the nature of engineering and were especially useful for the purpose of formative evaluation.

Some researchers have developed models or predictors of attrition.29-32 One might presume to use these conversely to identify early estimates of retention, but these theories are as yet inadequate predictors to give validity to such an approach. Retention can only be measured accurately through a longitudinal study. The most accurate measure of retention requires waiting until the students in each cohort would be expected to graduate and comparing the graduation rate of the experimental group with that of the control group. We decided to define retention as remaining in an engineering program into the third year of study. Since attrition is much more prevalent in the first two years of engineering education, this measure should be an excellent estimator of the true retention rate. In very specific terms, students are defined as “retained” if their status as indicated by their university of Florida transcript records indicated they were still within the engineering college at the time the data were reported. We obtained our data set from student transcripts in the summer of 1996.

VI. Results and Discussion

Tables 2 and 3 show the number of students enrolled, the number retained, and the retention percentage for all students, women students, and minority students of the laboratory and lecture courses respectively. Entries in the “semester” column indicate the semester in which the students took the course. The overall percentages are the most significant because they describe the behavior over all three cohorts. This is especially important in the case of women and minority statistics, for which the number enrolled in a particular semester is generally small, and the sample population of all three cohorts is needed to achieve an adequate sample size.

Please note that the “women” and “minorities” categories overlap, in that some of the minorities are women and are thus counted in the fifth column. While numbers were too small to permit separate analyses, the number of women included in the minority group has been added in parentheses for reference.

Figure 1 shows graphically the large gains in retention of those students who took the laboratory course.

Since the data set used for this analysis was obtained in the summer of 1996, the fall 1994 cohort and more recent cohorts are not included in this study, as the students of later cohorts would not yet have been expected to have reached the upper division in significant numbers.

The expected and observed retention frequencies were compared using a 2x2 Chi-Square test, to which Yates’ correction was applied.30 The test showed that the retention of the general population and that of women was significantly greater (α = .05) for students taking the laboratory course (in fact, p<.001 in both cases). In the case of minority retention, however, the observed trend lacked statistical significance due to the smaller sample size.

These substantial improvements seem too great to be effected by a single course, which suggests searching for other factors that would cause the measured difference. Selection was investigated as a possible contributor—that the laboratory enrollment was filled with students with a greater commitment to engineering at the outset. This is discounted based on the results of the survey discussed in greater detail in our earlier work.12 If the lecture and laboratory cohorts had a different level of commitment to engineering, then there should be a measurable difference in their response to key survey questions. This was not the case as shown in Table 4.

One of the responses in Table 4 has practical significance, so statistical significance need not be checked. If students in the laboratory section had a higher confidence level, question 1 should reveal that distinction, which is not the case. Similar conclusions can be drawn about the attitudes of the two groups toward engineering and their prior understanding of the profession, based on the other questions.
Students were also questioned as to the factors motivating them to choose engineering as a major. The responses for the lecture and laboratory students are shown in Table 5.

We first note from Table 5 that the rank ordering of the student preferences is identical for the students in the lecture section and those in the laboratory section. Since we do not know that these two populations are different at entry into the different courses, the expected frequency of responses must be assumed to be the average of all responses. This means that neither group differs by more than five percentage points from the expected frequency.

Two observations from Table 5 are critical. First, parental influence, which is recognized as a strong factor in student persistence, appears to be equal in the two groups (#4). Second, the percentage of students who had no plan on majoring in engineering but took the class anyway was the same in both groups. Therefore, these biases are removed from consideration.

We next investigated the possibility that other programs had caused the difference between the groups. No programs could be identified which would have preferentially influenced the laboratory group. A variety of educational reforms have taken place in the University of Florida College of Engineering in recent years. Among these have been advising within the college for freshmen and sophomores and a transition program for minority students. Neither of these programs, however, were initiated early enough to have an impact on the results presented here. The advising of lower division students was officially initiated just this year, and the Successful Transition through Enhancing Preparation for Undergraduate Programs (STEPUP) program was initiated in the summer of 1995.

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**Table 2. Laboratory retention percentages**

<table>
<thead>
<tr>
<th>Semester</th>
<th>total registered</th>
<th>total retained</th>
<th>overall retention</th>
<th>women enrolled</th>
<th>women retention</th>
<th>minorities enrolled (note)</th>
<th>minority retention</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/93</td>
<td>35</td>
<td>19</td>
<td>54%</td>
<td>11</td>
<td>45%</td>
<td>10 (5)</td>
<td>30%</td>
</tr>
<tr>
<td>8/93</td>
<td>108</td>
<td>54</td>
<td>50%</td>
<td>20</td>
<td>50%</td>
<td>16 (3)</td>
<td>63%</td>
</tr>
<tr>
<td>1/94</td>
<td>55</td>
<td>27</td>
<td>49%</td>
<td>11</td>
<td>64%</td>
<td>7 (0)</td>
<td>43%</td>
</tr>
<tr>
<td>Overall</td>
<td>198</td>
<td>100</td>
<td>51%</td>
<td>42</td>
<td>52%</td>
<td>33 (8)</td>
<td>48%</td>
</tr>
</tbody>
</table>

Note: for the minorities enrolled column, the number of women in the sample is in parentheses.

**Table 3. Lecture retention percentages**

<table>
<thead>
<tr>
<th>Semester</th>
<th>total registered</th>
<th>total retained</th>
<th>overall retention</th>
<th>women enrolled</th>
<th>women retention</th>
<th>minorities enrolled (note)</th>
<th>minority retention</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/93</td>
<td>128</td>
<td>36</td>
<td>28%</td>
<td>41</td>
<td>10%</td>
<td>22 (7)</td>
<td>27%</td>
</tr>
<tr>
<td>8/93</td>
<td>125</td>
<td>45</td>
<td>36%</td>
<td>36</td>
<td>25%</td>
<td>22 (4)</td>
<td>36%</td>
</tr>
<tr>
<td>1/94</td>
<td>68</td>
<td>30</td>
<td>44%</td>
<td>15</td>
<td>13%</td>
<td>11 (3)</td>
<td>55%</td>
</tr>
<tr>
<td>Overall</td>
<td>321</td>
<td>111</td>
<td>34%</td>
<td>92</td>
<td>16%</td>
<td>55 (14)</td>
<td>36%</td>
</tr>
</tbody>
</table>

Note: for the minorities enrolled column, the number of women in the sample is in parentheses.

**Table 4. Typical pre-test responses for lecture and laboratory sections**

<table>
<thead>
<tr>
<th>Survey statement</th>
<th>Lecture Students</th>
<th>Laboratory Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I am sure I want to be an engineer.</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>2. I like the subjects of math and science the most.</td>
<td>4.0</td>
<td>3.9</td>
</tr>
<tr>
<td>3. I know a lot about what engineers do.</td>
<td>2.8</td>
<td>2.8</td>
</tr>
<tr>
<td>4. Engineering is a respected profession.</td>
<td>4.5</td>
<td>4.6</td>
</tr>
<tr>
<td>5. All engineers sit behind a desk all day working with numbers.</td>
<td>1.8</td>
<td>1.8</td>
</tr>
</tbody>
</table>

* all scores are average Likert scale responses, where 1=Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly Agree.

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VII. CONCLUSIONS

The conversion of the University of Florida’s Introduction to Engineering course to one with laboratory activities in place of lectures has been accompanied by significant improvements in retention. Although the magnitude of the change apparently caused by a single course engenders skepticism, we have been unable to identify any other causes which account for the observed improvements.

We suggest that the primary advantages of the course as designed are the use of active learning and the early association of students with the engineering departments. The latter of these will help students to receive discipline-specific advising, join professional society student chapters, and meet at least one department faculty member in a small-group environment.

Retention of women and minorities was raised to the level of the general population, a level much higher than that observed among those students attending the lecture version. It is unfortunate that low numbers of minorities prevented conclusions with statistical significance, but the observed trend seems likely to be borne out in years to come.

The results of this study therefore suggest that a course which surveys all the engineering disciplines through the use of active laboratories has significant potential for improving student retention. While we do not wish to suggest that a course such as ours should supersede other proven methods of increasing student persistence, we believe that it adds to the arsenal of such approaches.

Table 5. Sources of motivation for lecture and laboratory students.

<table>
<thead>
<tr>
<th>Motivation</th>
<th>Lecture Students *</th>
<th>Laboratory Students *</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. General interest in math / sciences</td>
<td>65 %</td>
<td>73 %</td>
</tr>
<tr>
<td>2. Desire to help humanity.</td>
<td>54 %</td>
<td>64 %</td>
</tr>
<tr>
<td>3. Financial security.</td>
<td>53 %</td>
<td>62 %</td>
</tr>
<tr>
<td>4. Family tradition.</td>
<td>20 %</td>
<td>25 %</td>
</tr>
<tr>
<td>5. Not majoring in engineering.</td>
<td>20 %</td>
<td>20 %</td>
</tr>
<tr>
<td>6. Previous work experience.</td>
<td>17 %</td>
<td>15 %</td>
</tr>
<tr>
<td>7. Nothing else interesting.</td>
<td>8 %</td>
<td>13 %</td>
</tr>
</tbody>
</table>

* multiple responses were allowed in this section of the questionnaire.
ACKNOWLEDGMENTS

Funding for this work was provided by the NSF to SUCCEED (Cooperative Agreement No. 9109853) and by matching contributions provided by the University of Florida. The University of Florida is acknowledged for its institutionalization of the survey course described in this article.

REFERENCES


