Enthusiasm, Intrigue and Retention: Alliance for a New Millennium in Freshman Engineering Education

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Abstract

Eleven years ago, the Department of Civil and Environmental Engineering at The Citadel established an Introduction to Civil and Environmental Engineering course. Over the years, the course has been gradually modified, both in content and teaching techniques to promote not only the preparation of young engineering students, but to motivate them to continue their pursuit of a degree in engineering. This paper summarizes the findings of a growing body of literature and lessons learned through teaching an introduction to engineering course for the past eleven years. In addition, the paper discusses further course refinements planned by a departmental committee responsible for assessing the course.

Introduction

“Look carefully at the student on your left. Now, look at the student to your right. I ask you to look carefully at these students because by next year, one of them will not be here. And when you graduate, the other will no longer be your classmate.” Words such as these could well have been used several decades ago as part of an initial meeting with freshman engineering students to stimulate them to persevere. If the same words were used today, however, they could easily be taken to mean that the engineering program plans to weed out many of the would-be engineers. In striking contrast, most engineering schools are currently striving to improve retention, particularly at the freshman level. John White, former dean of engineering at Georgia Tech appropriately expressed the spirit of engineering education today when he said, “Instead of thinking in terms of weeding out engineering students, we should be thinking in terms of cultivating engineering students.” Cultivating freshman engineering students - including helping them to develop study skills for academic success in a demanding curriculum, teaching them the fundamental knowledge they need to progress to the next level of courses, and generating enough enthusiasm about engineering that they will want to continue in engineering - is one of the significant challenges that engineering educators will face in coming years.

According to the Engineering Workforce Commission, the number of freshman engineering students declined 26 percent between 1982 and 1994. While this trend began to level off in 1995, a comparison of freshman and sophomore enrollments in 1994 and 1995 shows that the enrollment had dropped 20% between the freshman and sophomore years. Such decreases - or even larger ones - are frequently mentioned at engineering education conferences. In recent years, engineering educators, motivated by high attrition rates, have been working diligently to change the basic nature of historical engineering orientation classes. Although a variety of introduction to engineering courses have been reported over the years, a typical offering in the past might have featured presentations by a series of departmental chairpersons, highlighting the opportunities of their particular department in a factual presentation. To emphasize the absence of motivation for young freshmen in such a course, Vincent Ercolano in 1982 dubbed such

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courses “Sleep 101.” With these things in mind, many programs have begun to redesign the freshman curriculum, including introduction to engineering courses, in light of “what works” for today’s engineering students.

The Department of Civil and Environmental Engineering at The Citadel initiated an “Introduction to Civil and Environmental Engineering” course over a decade ago. Based on contributions from a number of departmental faculty, the course was intended to be motivational while at the same time providing foundations for future years and giving students a “feel” for being a Civil Engineer. Unfortunately, high attrition rates have persisted, with attrition between the freshman and sophomore years significantly higher than the national figures noted above. Over the last two years, the departmental Freshman Committee has been examining the freshman year experience, including the introduction to civil and environmental engineering course. The purpose of this paper is to highlight course changes that are in progress in light of an assessment of course content.

**Background**

According to a survey conducted by Landis\(^2\), approximately two-thirds of engineering programs had an “introduction to engineering” course in 1992. The survey also demonstrated the widespread interest in creating a better product, with 89 percent of the respondents expressing a desire to enhance their courses. Since that time, a number of innovations for improving the freshman year experience have been initiated. Among other things, these innovations help motivate freshman students, help them to develop critical success skills, and/or strengthen the curriculum to promote a better understanding of engineering and other subjects. A representative number of projects are highlighted in this section.

Noting the low transfer rates of students from community colleges to full undergraduate engineering programs and the low retention of minority students, Raymond Landis of California State University proposed teaching skills that promote success in engineering programs\(^4\). Following a workshop conducted by Landis and funded by the National Science Foundation, faculty from 13 universities cooperated in drafting guidelines for introduction to engineering courses\(^2\). Five subjects were identified for inclusion in introductory courses: academic success skills, personal development, community building, and orientation to the engineering college and university. Other schools have since incorporated at least some of these in their introductory courses.

Developing strong success skills early in a student’s academic career is essential. A study by Budny, *et al.*\(^5\) at Purdue University indicated a positive relationship between retention and first semester grade point average. As a result, the authors emphasized the critical role of the advisor during the initial semester. In addition, they discussed the success of a Counselor-Tutorial (CT) program at Purdue University in helping high-risk students. The key to retention of high-risk students appeared to be providing the support for these students to complete first-year courses in mathematics, chemistry, and physics. Another concept for helping struggling first-year students is called Supplemental Instruction (SI), which was actually developed in 1973 by Deanna Martin of the University of Missouri-Kansas City\(^6\). With an interest in improving the retention rate, the Core Engineering Department at Rensselaer Polytechnic Institute combined efforts with the school’s Advising and Learning Center to offer voluntarily attended SI review sessions in Introduction to Engineering Analysis\(^7\). Those who participated in the review sessions (composed primarily of high-risk students) made higher grades than the non-SI students and were less likely to make a D or F. Multimedia and information technology also offer the opportunity to directly help students outside the traditional classroom. One example reported features a WWW-based asynchronous learning environment in which students can receive immediate feedback after doing homework in the environment\(^8\). Additional help is available from teaching assistants through the use of a Java-based interactive whiteboard.

At MIT, many freshman needs are met through Freshman Advisor Seminars\(^9\). Not only do these seminars cover a wide range of topics designed to intrigue freshmen, but they also create a situation that
significantly increases valuable contact time between freshman and advisors. Improving student-faculty contact was a motivational factor in the 1993 decision to create a number of small classes as alternatives to the large freshman orientation class at Purdue University\textsuperscript{2}. The degree of satisfaction with Purdue was higher among those that attended the experimental classes. Phillip Wankat of Purdue (and co-author of a leading textbook on teaching engineering) proclaimed, “Contact - not content - is the critical element\textsuperscript{10}.”

Much of the innovative work that has been accomplished with the freshman experience over the last few years has been to enhance the motivational aspects of introduction to engineering or similar courses. Active learning exercises, hands-on laboratory projects, or first-year design experiences have been incorporated into first-year courses to increase retention, improve problem-solving skills, and/or provide students with an initial design experience which may be built upon in later years. For example, a Fundamentals of Mechanical Engineering course at Carnegie Mellon University\textsuperscript{11} incorporates classroom demonstrations between lectures, weekly hands-on mini-projects for individuals, and group projects. The group projects involve designing a steam-powered electric generator and a steam-powered car. A competition is eventually held for the most efficient car. Another example involved the modification of an existing introduction to engineering course at Indiana University-Purdue University - Indianapolis to a new course using the principle of attached learning\textsuperscript{12}. In the existing course, “Little emphasis was placed on factors that affect retention, such as building peer networks, developing collaborative learning skills, and motivating students to pursue excellence by making the course exciting and by making learning relevant\textsuperscript{12}.” Attached learning ties course material to a hands-on design project. Assessment data from the initial experimental offering of the course showed clear gains in terms of student satisfaction when compared to data from the previous course. Other examples of meaningful experiences with hands-on projects and/or freshman design experiences reported in recent years include a University of Wisconsin-Madison introduction to engineering course that featured the design and construction of a handicap access for buildings at a historic site\textsuperscript{13}, a new North Carolina State Product and Process Engineering Laboratory for freshmen in which students explore six engineering products through the eyes of users, assemblers, and engineering analysts\textsuperscript{14}, a hands-on freshman elective laboratory course at Rensselaer Polytechnic Institute\textsuperscript{15}, a first-year design project involving the re-design of a paper clip described by Henry Petroski of Duke University\textsuperscript{16}, the design and siting of a municipal wastewater facility in a Chemical and Civil Engineering module at the New Jersey Institute of Technology\textsuperscript{17}, a Rodent Control Project in a West Virginia University freshman design course\textsuperscript{18}, and reverse engineering on an electric toothbrush at Rowan University\textsuperscript{19}. Many of these projects involved the use of teams.

Finally, it should be noted that some universities are involved in curriculum reform in which a number of subjects are integrated as opposed to keeping the subjects completely isolated. A Foundation Coalition project at Texas A&M University integrates chemistry, English, engineering, mathematics, and physics\textsuperscript{20}. Commitments from faculty members involved in the project include weekly faculty team meetings, teacher training in teamwork and teaching in an active-learning environment, decreased lecture time used in classes, and increased use of technology in classes. Early results are that retention has been higher for coalition students than traditional students and that performance of coalition students on standardized tests has exceeded that of traditional students. Work on integration of freshman course work has also been accomplished at Arizona State University\textsuperscript{21}, the University of Alabama\textsuperscript{22}, and other universities in recent years.

**Evolution of an Introduction to Civil and Environmental Engineering Course**

Prior to 1988 the Department of Civil and Environmental Engineering at The Citadel offered two freshman engineering drawing courses. The second semester engineering drawing course essentially served as the freshman orientation course. In addition to course material in Descriptive Geometry, there were seven mini-projects highlighting applications in different areas of civil engineering and four seminars conducted by members of the civil engineering faculty.
In 1988, a new introduction to civil engineering course was established to replace the second engineering drawing course. Classes were conducted in a laboratory setting, with two-hour class meetings held twice a week. The course was initially called Engineering Design and Analysis, but eventually was renamed to Introduction to Civil and Environmental Engineering. Initial course topics included an introduction to engineering, engineering fields, areas of civil engineering, the design process, professionalism and ethics, fundamentals of problem solving, and a number of civil engineering mini-projects. As soon as a new microcomputer laboratory had been completed, instruction on operating systems and spreadsheets was incorporated into the course.

Among the reasons for establishing the new course were to motivate students and improve retention. It was felt that the civil engineering mini-projects could help to achieve this if projects were created that would give first-year students a “feel” for performing engineering work. With this in mind, civil engineering faculty members were asked to help develop projects from their fields that would be suitable for freshman students. An important goal was to structure projects to teach fundamental design knowledge which could be built upon throughout a student’s academic career. An excellent tool for developing design content and formulating problems is the classic work by Bloom. A model for adapting Bloom's taxonomy to teaching design in the freshman year and throughout a four-year curriculum has been published elsewhere.

**Course Modifications**

In the early years of the course, a number of adjustments were made to improve upon student motivation. Traditional “lecture time” was decreased and where possible, subject material was presented in short segments. For example, topics such as introduction to engineering, areas of civil engineering, etc. were presented at the beginning of the class period in 15 to 20 minute segments. Following the introductory segment, a completely different topic was begun, such as one of the civil engineering projects. Lecture material on ethics was replaced by a “role-play” and case study discussion. Teamwork was incorporated into an open-ended office layout mini-project. A film (“To Engineer is Human,” a BBC Production based on the book of the same title by Henry Petroski, distributed in the U.S. by Films Incorporated) was introduced to help illustrate how engineers learn through design failures. Hence, to promote enthusiasm and enhance learning, the course was organized to minimize long periods of lecturing, to maximize student-teacher interaction, and to use a variety of teaching techniques such as team problem-solving, discussion, video tapes, interactive computer demonstrations, and role play.

As faculty gained experience with the course, it was realized that visual, hands-on projects seemed to be more effective for student learning and much more motivational for the students. As a result, changes were made in certain projects to enhance the visual and hands-on aspects. For example, one segment of the course introduces students to how contours and plan and profile drawings are used in civil engineering. During the first few offerings of the course, much of this material was introduced to the students in traditional fashion, with explanations from the teacher complemented by drawings on the blackboard. To create a more visual presentation, physical scale models were constructed from foam insulation boards. One of the models represented a piece of property on which a subdivision called “Horseshoe Acres” was to be constructed. Sets of plan and profile drawings of the proposed development were provided to the students. The model could be separated into two pieces along the proposed road to reveal a sewer to be constructed beneath the ground surface. The model was valuable in teaching students how to read contours, interpret the drawings, and other concepts. A second model of another property was designed to allow students working in teams to determine elevations on the model in a manner that is conceptually consistent with surveying techniques. In a course evaluation, over 90 percent of the students gave the highest possible rating to the contribution of the models in learning course concepts.

Another teaching technique that generated enthusiasm among students was to plan activities in the civil engineering laboratories. For example, during some years a class was scheduled in the materials testing laboratory.
laboratory, where students took stress-strain data of a metal specimen in tension. In other years, students attended a fluid mechanics laboratory demonstration before exploring the basics of graphing and curve fitting using flow data for a triangular weir.

**Course Assessment**

The Citadel is a unique educational environment, with separate day and evening student bodies. Day classes are for undergraduate cadets attending the Military College of South Carolina. In the evening, programs available for local residents include undergraduate classes in engineering or business and graduate programs in other curricula. Most of the civil engineering students attending in the evening enter the program in their junior year after having completed a two-year program at another institution. Therefore, these students do not impact retention considerations associated with freshmen students. Because there is a cap on the number of students who can participate in the day (cadet) program, the pool of potential civil engineering students is limited. Retention, then, is key to a healthy civil engineering program.

The number of freshmen entering the civil engineering program at The Citadel over the last few years has at best been reasonably constant. Attempting to derive meaningful attrition data based on the first semester freshman year is difficult because of the relatively large number of cadets who change majors during the first few weeks of school. Over the last five years attrition rates in civil engineering program at The Citadel have ranged from 25 to 31 percent, with an average of almost 30 percent. Due to limitations in tracking data, these numbers only reflect the drop in students between the beginning of the second semester freshman year to the beginning of the sophomore year. Nevertheless, it is clear that the attrition rates given above would be even greater if the rates could be appropriately benchmarked to the first semester of the freshman year.

With these things in mind, a departmental committee was formed to study what could be done to improve the freshman experience. The committee has been looking at a wide spectrum of things in addition to the introduction to civil and environmental engineering course. These include creating a mentor system with upper class students, including freshmen on the recently formed student advisory committee, establishing a freshman advisory committee, enhancing freshman advising, incorporating freshmen field trips, modifying the freshman curriculum, and creating assessment tools (such as an exit interview form for those students changing majors).

A major part of the committee’s work, however, has been on evaluating and modifying the introduction to civil and environmental engineering course. Through roundtable type discussions with students and independent discussions among faculty members who have taught the course, several things became evident: (a) in general, students showed a high degree of satisfaction for the course, (b) students often identify the visual/hands-on/active-learning portions of the course as being what they enjoyed most about the course, and (c) some of the mini-projects that do not include hands-on elements often received little comment or even negative comments.

An example of a mini-project that has not been received well by students is the “truss optimization problem.” For this problem, students are presented with a sketch of a simple wooden truss. Although minimal background is needed to work the problem, a few concepts related to design of trusses is explained (for example, a class demonstration is used to explain buckling). The problem is ultimately placed on spreadsheet and a graph is generated to identify the optimum design. The problem was designed with the intention that students would learn some fundamental knowledge about design such as an introductory knowledge of force, stress, and buckling. Furthermore, students learned how geometric constraints impact economy and how to optimize a design through computer iteration. Although students may have intuitively learned these things, when they were asked, “What did you learn from this project?” they usually responded with comments about working with spreadsheets. This indicated that the student focus was
almost entirely on the spreadsheet commands needed to conduct the calculations, with most grasping little understanding of the optimization concept. The truss problem was often referred to as “tedious” and never as “fun” or “intriguing.”

An example of a mini-project that has been very well received is the “office layout project.” Working in teams, students develop a conceptual engineering office layout for a single-story 75-ft by 75-ft building. The open-ended exercise is competitive since a winning team is eventually identified. The competitive nature of the exercise is not only enjoyable for most of the students, but it has also often stimulated students to be creative and do quality work. Over the years, the problem has been refined in an attempt to make it an even more positive experience for students. In one class during Spring 1999, the project featured self-assessment of the team’s performance, in-class presentations and peer evaluation, and debriefing and discussion at the close of the project. The project was deemed highly successful by both students and faculty. It should also be mentioned that although a winner is identified in the competition, an effort is made to recognize the contributions made by all teams.

Because of its success in promoting student enthusiasm, the committee has decided to use the “office layout project” as a model for several additional mini-projects in Spring 2000. One of these new mini-projects (“Concrete Strength Test) is described in Table 1. The proposed changes in the mini-projects are shown in Table 2. While all of the new mini-projects are presented as competitive team exercises in Table 2, some projects will be conducted as team experiments during Spring 2000 to prevent “overkill” on the competition theme. In the new exercises, all or some of the following components will be used to help promote student enthusiasm:

- Work conducted in teams of 3 - 4 students
- In-class review and discussion of specific project evaluation criteria
- Team preparation of multi-faceted submittals that may include reports, design documentation, presentations and exhibits
- Peer evaluation of the team’s performance by team members
- In-class team presentations and peer evaluation of team submittals
- Announcement of competition results, recognition of winners and ranking of team performance
- Debriefing and discussion of competition results

Concluding Comments

A growing number of engineering educators, including the authors of this paper, believe that the traditional freshman engineering orientation class marked by lecture-style presentations of departmental representatives can be greatly enhanced by a number of active-learning and success-oriented teaching techniques. Eleven years of development on an introduction to civil and environmental engineering course have demonstrated the motivational potential of visual/hands-on/laboratory-style activities in such a course. A committee studying the freshman experience believes that enthusiasm for learning engineering is crucial for a freshman to persevere through four years of an engineering program. Further, the committee believes that the freshman year is the key to retention and ultimate graduation. To generate more energetic learning opportunities for students, some mini-projects that have been used for a number of years in the course are being replaced by competitive team exercises based on the long-standing success of this type of project in the course. While such projects take significant faculty time for development and require
scheduling of laboratories for freshman class use, it is believed that freshmen students are a valuable resource well worth the effort.

Table 1
Competitive Concrete Strength Test Mini-project

Overview of Concept:

Normal Portland cement concrete is composed of four ingredients: gravel, sand, water, and Portland cement. Since the Portland cement is not produced with a strength variable, it is up to the mix designer to proportion the four ingredients in order that the proper strength and workability is achieved. Many tests have been performed over the years in order to establish criteria affecting compressive strength of cured concrete as pertaining to ingredient proportions. These tests have confirmed that certain ratios of ingredients do significantly alter the compressive strength of the hardened concrete.

Project Objective:

To provide students with a basic understanding of the importance of material properties and mix proportioning when performance criteria such as compressive strength is of interest. Through this active learning project students will explore how different variables affect compressive strength, economy, etc.

Project Methodology:

Teams will combine Portland cement, gravel, sand, and water to mix a small batch of concrete. Three cylinders will be formed from the mix (using orange juice cans as casting forms). Careful records of the amount of ingredients used will be kept for later data analysis. One day after casting, the cylinders forms will be stripped, specimens will be marked, and placed in a suitable curing environment. After ample curing time has elapsed, teams will use a testing machine to load the cylinders in compression until failure occurs. Load and cross-sectional will be used to calculate material strength.

Evaluation of Results:

Competitive aspects of this project include collaboration of team members to determine how to combine mix ingredients to produce the highest compressive strength of small laboratory prepared concrete test cylinders. Each team’s compressive strength value will be based on the average strength of three test cylinders. The team with the highest average compressive strength wins and other teams are ranked in order of their cylinders’ corresponding strengths. Data from the entire class will be combined to further analyze and discuss mix versus strength relationships.
Table 2
Changes in Mini-projects

<table>
<thead>
<tr>
<th>Topics</th>
<th>Current Course Exercises</th>
<th>Proposed Changes</th>
</tr>
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<tbody>
<tr>
<td>Surveying</td>
<td>Use of 3-d terrain models to help in reading engineering plans and to prepare a topographic map</td>
<td>No major changes</td>
</tr>
<tr>
<td>Structural</td>
<td>Spreadsheet analysis to optimize configuration and member design of a wooden truss</td>
<td>Develop a new team exercise that requires construction of a model bridge (e.g., a linguini bridge)</td>
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<td></td>
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<td>Develop a new lab exercise to load model truss for evaluation of reactions generated by moving loads</td>
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<tr>
<td>Geotechnical</td>
<td>Analysis to evaluate soil type and cost implications of footings and pile design</td>
<td>Develop a new team exercise that requires load testing of model piles in the laboratory</td>
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<tr>
<td>Hydraulics</td>
<td>Plotting data from flow over a v-notch weir (includes lab session)</td>
<td>Have students take some measurements in the laboratory</td>
</tr>
<tr>
<td>Environmental</td>
<td>Determination of pipe flow for a storm sewer system from adjacent surface runoff areas</td>
<td>Modify exercise to analyze on-campus drainage areas that can be easily observed on a class field trip</td>
</tr>
<tr>
<td>Transportation</td>
<td>Evaluation of an example roadway alignment and calculation of stations, grades, and bearings</td>
<td>Develop a new team exercise that requires students to re-design a local parking lot circulation and layout</td>
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<tr>
<td>Construction and Testing</td>
<td>Preparation of an itemized construction cost estimate for a storm sewer system</td>
<td>No change to exercise involving the construction cost estimate.</td>
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<td></td>
<td></td>
<td>Add team exercise on test strength of concrete cylinders (see Table 1)</td>
</tr>
<tr>
<td>Office Layout</td>
<td>Competitive team project to develop a conceptual engineering office layout for a new 75-ft by 75-ft stand-alone building</td>
<td>Enhance to more fully incorporate peer evaluation, presentations, selection process, team ranking and in-class debriefing discussion.</td>
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</table>

References


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