2006-1360: REVISION OF A FIRST-SEMESTER COURSE TO FOCUS ON FUNDAMENTALS OF ENGINEERING

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1. Introduction

The first semester of a student's academic career is always very important, and it may be even more important for an engineering student. From increasing academic rigor to increased freedom to make important life-affecting choices, the first semester of an engineering program holds great opportunity to change a student's life. Along with this high degree of importance comes a high degree of flexibility, because there are many different ways in which a first engineering course can be structured and taught. Each of these different philosophies has its benefits and liabilities, and optimizing the first-semester engineering course is still a very active area of curricular research.

In this paper, we will first present an overview of the many different philosophies being used to teach first-year engineering students are programs throughout the country, highlighting the rationale for each. Next, a summary of the previous first-semester programs at Valparaiso will be presented, along with a discussion of the revision process that took place over a period of many months. Finally, we will describe the resulting course, which was taught for the first time in the fall semester of 2005, including an assessment of its effectiveness and lessons learned for future improvement of the course.

2. Philosophies in First-Year Engineering Education

Several very different approaches to teaching first-year students have emerged over the past several decades. Each of them has merit, and each has arisen as a result of real needs of first-semester students. Although the following analysis is far from comprehensive, it does provide an overview of the different philosophies being applied to the education of first-year engineering students.

Traditionally, first-year engineering courses at some universities[1] have been similar to other "freshman orientation" courses in other disciplines that focus on academic survival skills such as time management, studying for exams, and balancing work and social life. Such courses do not explicitly focus on engineering topics, but provide engineering students with skills that will be valuable to them throughout their academic and professional careers.

Another traditional approach for first courses in engineering is to provide students with knowledge of the different engineering disciplines necessary to select a major and, eventually, a career. Courses at universities such as Vanderbilt[2] and Purdue[3] provide such background knowledge, helping their students to make an informed decision about their choice of major. Frequently, such courses are designed in a modular structure, such that students can complete different modules and different hands-on projects based on their particular interests. Enabling students to make an informed choice of major was one of the most important learning objectives of the first-semester engineering course at Valparaiso University until 2004, and it is still a secondary purpose of the course.

Because engineering drawing and visualization skills are so important to engineering students, some universities either require or have required all first-semester students to take a course in those topics.[4] Such a course provides a balance of useful skills that will serve at least some students (especially mechanical and civil engineers) in their future courses, and it helps students to develop visualization skills that benefit them in advanced calculus classes. Still other programs [4,5] devote at least a part of their first-year program to instilling in students the ability to use computational tools to solve engineering problems. From spreadsheet skills to high-level language programming, such skills will be important for all disciplines, but especially so for electrical and computer engineering students.

The introduction of ABET Engineering Criterion 2000 created many new expectations on engineering programs, and many of those programs responded by changing their introductory courses. Many universities [4-10] increased the emphasis on engineering design and engineering analysis in this first course, including the introduction of hands-on design projects to be completed by individual students or teams of students. Some universities created courses that explicitly attempted to increase their students' teamwork skills[11], while others sharpened their focus on improving their students' problem-solving skills[5] and creative and critical thinking skills[12]. Perhaps the most difficult mandate of EC2000 is that students be able to work effectively in multidisciplinary teams, which has led preeminent universities such as Purdue to create courses that explicitly build interdisciplinary connections in their students' minds.[13]

Many emerging philosophies in first-year engineering education have grown out of fundamental pedagogical research that supports a holistic approach to engineering education. For example, a great deal of work has been done to investigate and confirm the usefulness of learning communities, which are being implemented at several universities.[5,14] Other universities, such as Texas A&M and the Air Force Academy, are working very hard to provide their students with an integrated curriculum that combines engineering, mathematics, and science into one course sequence that helps students to much more effectively see the interconnections among those topics.[15-17]

Another important area of pedagogical research that has benefited first-year courses is development of a student-centered structure in which the instructor is more of a guide than a source of knowledge. Courses at universities such as Virginia Tech and Bucknell have created such an environment in which in-class hands-on projects are used to illustrate the material, holding the students' interest and helping them to more effectively learn important engineering concepts.[18-21] Still others have used students' natural inquisitiveness to help them develop the skills necessary to investigate, model, and analyze very complex systems.[13, 22-23]

Although some of these philosophies do appear to be mutually exclusive, an optimal first-semester course would benefit from adopting the best characteristics of each. By balancing these different philosophies, it may be possible to design a course that is more effective than any one philosophy could have been. We have attempted to design such a balanced course, modeled after work done at Purdue University [5], that helps students to learn the fundamentals of each engineering discipline and build interdisciplinary connections among those disciplines, and we do so through a balance of traditional lecture and hands-on laboratory and design experiences.

3. First-Year Engineering Education at Valparaiso University, 1984-2004

Twenty years ago, first-year engineering at Valparaiso University consisted of four basic courses that introduced the principles of computer programming, engineering graphics, thermodynamics, and statics. First-semester sophomores took two common courses that covered dynamics and electricity and magnetism. After three semesters, students chose their major and focused future coursework on that area. This became a problem, since it was difficult to get in all of the necessary discipline-specific courses in just five semesters. A major curriculum revision reduced the common curriculum to only one semester and introduced a freshman engineering course.

Our initial freshman engineering course, called "Exploring Engineering," was created in 1992. The primary goals of the course were to introduce the students to engineering, to help them to choose a major, and to develop basic computer literacy. The course consisted of two large lectures (attended by every student in the class) and one computer lab (in sections of 20 students each) every week. Three of the lectures were devoted to each of our four majors: civil, computer, electrical, and mechanical engineering. Other topics of importance to our students were interspersed between the lectures. These included study skills, time management, graphing, statistics, ethics, and engineering careers. Engineering alumni frequently spoke about their careers and provided valuable insights to the new students. At the beginning of November, students were asked to choose their engineering major and attended six special class meetings in which students performed hands-on projects in their selected discipline.

The course was an efficient way to present information to the students, but the favorite part of the course for the students was the three-week workshop at the end of the semester. Evaluations always said, "Why can't the whole course be more like these workshops?" In 2002, we modified the course to allow more hands-on projects. Instead of three lectures, each major was given six lectures and three two-hour labs, significantly reducing the programming component of the course. The labs allowed all students to work through significant projects in civil, electrical/computer, and mechanical engineering. The remaining lectures covered many of the previous general topics such as problem solving, ethics, and careers.

The revised course dealt with one of the weaknesses of the original course, but still included the large lectures. Faculty did not like to give these lectures since it was very hard to connect with the students in a large lecture hall. Students did not like to attend the classes, and it was very easy to go to sleep in them. Furthermore, the perception of the students was that the course was easy and that engineering was not going to challenge them as much as their math or physics courses. Based upon these concerns, a major course evaluation was planned for the 2004-205 academic year.

4. The Revision Process

A Freshman Engineering Syllabus Committee was formed in November of 2004. The committee consisted of the department chair and an additional representative from each department, plus the freshman engineering coordinator. This committee began by reviewing the course evaluation for the existing course in order to obtain more complete information about the students' perceptions. They also brainstormed several different possible models for a freshman engineering course ranging from no change to a more traditional lecture course to a studio-lab course. A total of nine models were presented to the freshmen for their feedback and were extensively debated in the committee.

Several criteria emerged from the discussion:

- Students should not have to select their engineering major before they arrive on campus.
- The course must continue to include a lab/project component.
- If possible, the large lectures should be eliminated.
- The teaching load credits for the course should not be significantly increased.
- The course should emphasize the interdisciplinary nature of engineering.

From this input, the nine initial possibilities were reduced to the five shown below, each of which would correspond to a total of three credit hours:

Option 1: Large lecture two days a week and small labs once a week. Three weeks spent on each engineering major. (Current model)

Option 2: Large lecture, recitation, and small labs each once a week. Similar content to option 1.

Option 3: Two studio labs a week. Some lecture presented at the beginning of each lab. Would cover the engineering fundamentals that every engineer should know.

Option 4: Three studio lectures a week. Some lecture and then group projects/homework. Similar content to option 3.

Option 5: Five-week one-credit general lecture course followed by three different nine-week two-credit lecture/lab courses specific to the disciplines. Each student would take the general lecture and one of the discipline-specific units.

The "studio lab" idea would give students and faculty an opportunity to blend lecture and lab time, introducing a topic in lecture, then moving seamlessly to a lab project and then back again, if necessary, for a classroom discussion of the results. One advantage of Options 1 and 2 is that the freshmen would meet with their entire freshman class and could begin to build camaraderie. It was decided that Options 3, 4, and 5 could still do this by adding an evening Engineering Seminar with guest speakers and some of the more general topics. The biggest concern with the options was the teaching load credit. Any option but the first two seemed to increase the teaching load.

After much debate, it was decided to choose option 3. The course would meet twice weekly for two hours with a maximum of 24 students/section. The slightly larger class size would help to keep the teaching load credit reasonable. It was agreed that the material would cover "What Every Engineer Should Know," the topics from each discipline that are considered to be fundamental. The department chairs submitted lists of topics that they felt should be included. These were condensed into 28 possible topics. The entire engineering faculty was asked to rank these topics and based on this a few were eliminated.

The committee next spent several months reviewing the literature and asking the entire faculty for ideas about good projects to illustrate the various topics. Each topic was fleshed out to an outline. A book was chosen, although it was not possible to find one that included all of the desired topics.

In April, a proposal for summer work was made and faculty were recruited to prepare the lessons for each topic, with over half of our faculty participating. The committee continued to meet weekly through out the summer to review the topics as they were completed, and to revise them as needed.

5. Teaching First-Year Students the Fundamentals of Engineering

The primary goal of the new structure for the first-year engineering program at Valparaiso University was to expose students to topics that were considered fundamental to all engineering disciplines in a small class setting with an emphasis on experiential learning. The secondary goals of the revised course were to provide an opportunity for students to explore the engineering disciplines offered at Valparaiso; to develop basic teamwork, problem solving, and computational skills; and to discover the increasingly multidisciplinary nature of engineering. It was decided that the structure of the new program that would best achieve these goals was a combination of two classes. The two classes were GE100: Fundamentals of Engineering, which was a bi-weekly studio lab, and GE 199: Engineering Seminar, a weekly seminar series focused on areas of interest for first-year engineering students.

The primary component of the first-year program, GE 100, was a studio lab that met twice per week for two hours. Each section of the course was taught by a single dedicated faculty member. Because it was desirable to have students meet in a small class setting, a sufficient number of sections were offered in order to maintain a maximum class size of twenty-four students. Generally, these sessions met in a typical classroom setting, and when possible in-class exercises and hands-on experiments were conducted in that classroom. However, when necessary and/or beneficial for the students' experience, the class would convene or move to other spaces, such as computer labs and specialized laboratories. In addition to the faculty member, two upper-class engineering students served as mentors and attended all studio lab sessions. The mentors' primary responsibility was to assist the faculty in answering student questions during in-class project and labs.

Each studio lab session was considered an individual module and was a combination of lecture, in-class projects (ICP), demonstrations (D), computer labs (CL), and/or hands-on laboratory experiments (L) that were developed by faculty throughout the College of Engineering. Generally, the modules were not prepared by the faculty teaching the class and were often topics beyond their particular area of expertise. Therefore, the instructors would meet the day before the module was to be taught, providing an opportunity to discuss the material and to review and/or perform the experiments and in-class projects planned. These meetings maximized the likelihood that students in different sections would have a similar experience.

The academic calendar allowed for a total of twenty-eight sessions, and the topics covered are listed in Table 1. The table

1. Engineering Analysis (L)
2. Engineering Design (L)
3. Probability and Statistics (L)
4. Teamwork (ICP)
5. Library Research (ICP)
6. Engineering Communication
7. Accuracy and Precision (L)
8. Voltage and Current (L)
9. Power and Energy (L)
10. Mechanics - Statics (ICP)
11. Material Properties (L)
12. Mechanics - Dynamics (ICP)
13. Structural Engineering (CL)
14. Transportation (D)
15. Digital Logic (L)
16. Electromagnetic Fields (D)
17. Motors (L)
18. Manufacturing
19. Pneumatics (L)
20. Environmental Engineering (L)
21. Fluids (L)
22. Vibrations (L)
23. Thermodynamics (L)
24. Heat Transfer (ICP)
25. Programming (ICP)
26. Project Management (CL)

Table 1 Studio lab topics.

also indicates the type of exercises (ICP, D, CL, or L) that accompanied the lesson material. It should be noted that two studio lab sessions were reserved at the end of the semester for group student presentations based on research the students performed on emerging topics in engineering.

The order of these 26 topics was determined using two criteria. The first criterion was that the topics should be presented in a logical sequence and allow for students to build on and use the skills gained in previous sessions. The second criterion was that a sufficient number of topics related to each engineering discipline be presented prior to students declaring their major during spring registration, which occurred after approximately twelve weeks.

A typical studio lab session would consist of approximately 45 to 60 minutes of new material, with the balance reserved for projects and labs. New material was presented using PowerPoint slides that were prepared by the faculty member who developed the lesson. The use of this media provided a reasonable guarantee that similar content would be provided for each section. The exercises varied from topic to topic. Examples of hands-on and computer labs included: design of a pneumatic arm and hand to pick up objects, determination of the optimum amount of coagulant for removal of suspended solids from drinking water, the measurement of the power and energy requirements for typical electronic equipment, and development of a project schedule for a construction project using Microsoft Project. The in-class projects were generally designed to improve students' problem solving abilities. Example projects included: analysis of static and dynamic systems, teamwork exercises, and development of basic computer programs.

For example, the session on fluid mechanics included a lecture component in which the importance of fluid mechanics was first explained, and then the principles of energy conservation underlying the Bernoulli equation were described. The equation itself was presented, and several examples were worked in class to illustrate its application. Finally, the class conducted an experiment measuring the distance a jet of water traveled under the pressure from a fixed height of water and the volume of water exiting the jet in a fixed amount of time. These results were then compared to each other and to values predicted using the Bernoulli equation, and students wrote a short laboratory report and memo describing their results as homework for the next class.

The second component of the first year program was the first-year engineering seminar, GE 199. All students enrolled in the College of Engineering and in GE 100 were required to attend a one-hour engineering seminar one evening each week. The goals of the seminar course were to expose students to engineering professionals, provide guidance on developing their academic skills, provide opportunities for students from all sections of the GE 100 course to meet each other, and provide an opportunity for students to meet faculty not teaching GE 100. A total of fourteen seminars were scheduled during the first year. On six occasions, an accomplished graduate from Valparaiso University spoke to the students. The topics for these seminars typically included a discussion of the presenter's career path, non-engineering career opportunities available to students with engineering degrees, career lessons learned, entrepreneurship, and details of specific projects. In addition to presentations from prominent alumni, faculty members gave four seminars on such topics as study skills, time management, preparing resumes, study abroad, co-op and internship opportunities, engineering careers, engineering societies, and engineering as a vocation.

6. Assessment of the New Course Structure

At the completion of the course, every student in every section was asked to complete an in-class course and instructor survey. Of the 97 students enrolled in the five sections, 88 completed and returned the survey. Each question was asked using a five-point semantic differential scale with "Strongly Disagree" and "Strongly Agree" as the antonyms to anchor the "1" and "5" responses. The weighted mean of each question was calculated, generating a response that ranges from a worst case of 1 to a best case of 5. In response to four of the general learning objectives for the course, students responded as follows:

"I am able describe in general terms the various fields of engineering and how they relate to each other."	3.89/5.0
"I can effectively communicate results graphically and in writing."	4.10/5.0
"I can work effectively in a team."	4.16/5.0
"I can solve technical problems using an effective problem-solving strategy."	3.73/5.0

Figure 1 shows the students' responses when they were asked about their ability to explain the fundamental principles of the engineering subjects covered in the course:

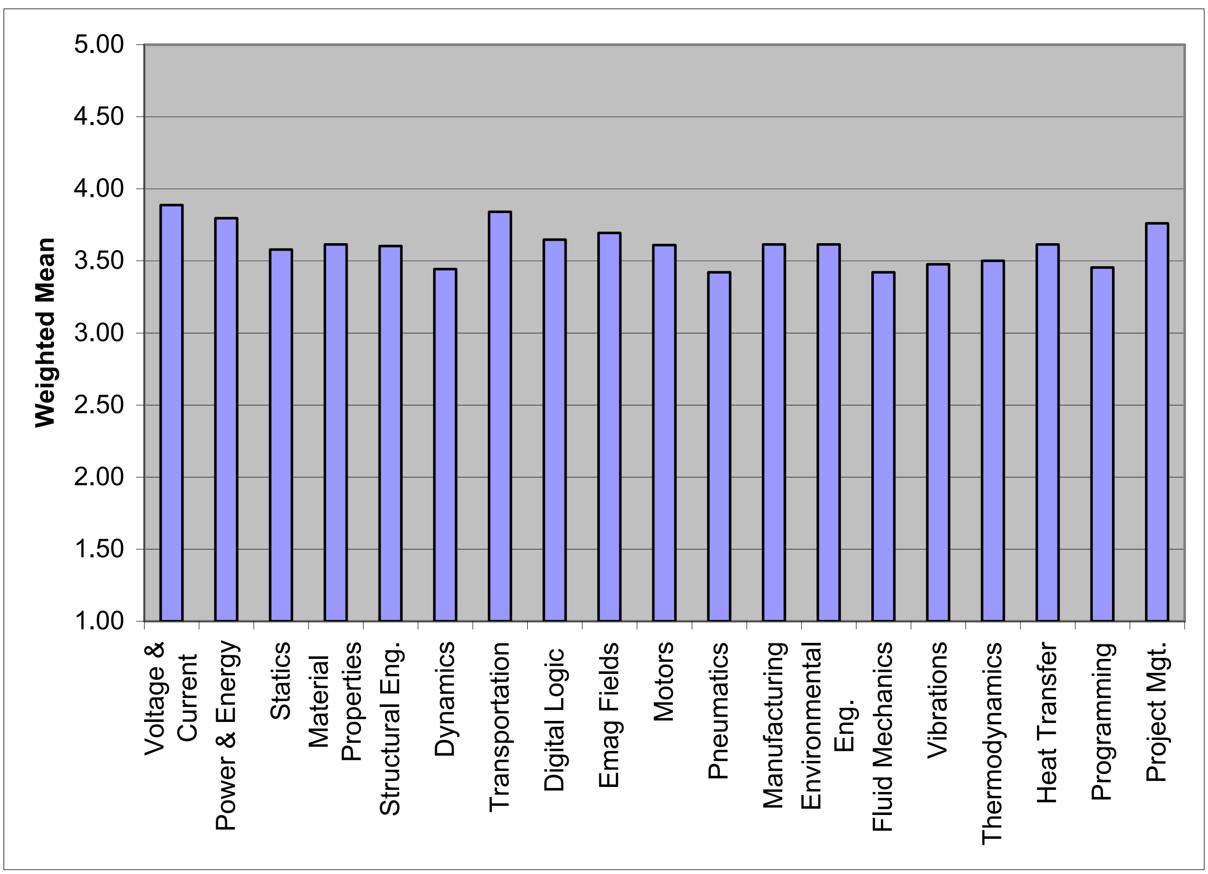

Figure 1. Self-Assessment of Technical Learning Objectives

Nearly every one of these ratings is between 3.5 and 4.0, suggesting that the students were moderately confident of their abilities in each of these areas, but that there is room for improvement in all of them.

When asked whether they had sufficient information to make an informed decision about their major, students in the new course responded with 3.31, compared to 3.89 the previous year. This decrease is to be expected, since helping students make an informed decision was one of the most important learning objectives of the previous course and is only a secondary objective of the new course structure.

When asked about the degree of difficulty of the course (with 1 being "Too Easy" and 5 being "Too Hard"), students in the new course responded with 3.10. This can be compared with the response from the previous year, which was 2.81, suggesting that students felt the new course was more difficult than the previous course. When asked to assign an overall rating to the quality of the course (with 1 being "Unsatisfactory" and 5 being "Excellent"), students responded with 3.07. This can be compared to the rating of 3.34 assigned by students in the previous year, suggesting that students were slightly less satisfied with the new course than they were with the previous course.

It is important to note that student evaluations are affected by a wide variety of variables, not only the course structure and material. Especially for first-year students, there seems to be a natural tendency to assign more positive ratings to easier courses. Since both the faculty and the students themselves feel that the level of difficulty of this course increased as a result of the changes made, this could explain part of the reason for the drop in student satisfaction. Still, there is room for improvement in the course, and the next section will address the lessons learned and plans for improving the course in subsequent offerings.

7. Lessons Learned

Having completed one year of the new course structure, the faculty have determined that there are several areas where opportunities for improvement exist. These opportunities exist in the overall course structure, course content, and method of presentation.

During the first year, five sections of the GE100 studio lab were offered. All sections of the class were taught on the same day, which required that two sections be taught in the evening. While offering the sections on the same day provided the benefits of only having to prepare course and lab materials for one day, and simplified the process of scheduling rooms, it did receive some negative feedback from the students in the sections that met between 4 p.m. and 8 p.m. In addition, students seemed to lose focus during the second hour of the session, regardless of the class time and/or activities. As a result of these observations and feedback, the faculty have decided to offer the course in four, one-hour sessions per week rather the two, two-hour sessions.

Although there was positive feedback on seminars presented by the alumni, students were less positive on several of the other seminars. Therefore, the faculty will consider reducing the number of seminars from fourteen, with most or all being presentations from practicing engineers. In addition, the faculty feel as though there was insufficient faculty representation at these seminars. Therefore, greater emphasis will be placed on having all engineering faculty attend the seminars and provide an opportunity for faculty to mix with students.

In general, students were satisfied with the overall content of the course. However, students did feel that some topics were too broad to be covered in a single session. Slight modifications to the scope of some of the course materials already developed should address this issue for many topics. The faculty have also determined that several topics will not be covered in the second iteration of the course. This will permit some topics that were determined to be too broad for a single period to be covered in more than one session. In addition, students did not always make the desired connections between topics. Of course, due to the variety of topics covered, some degree of discontinuity will inevitably exist. However, a careful review of the topic sequence will be completed prior to the second offering of the course. This should allow for a better sequencing of lessons and allow an opportunity for faculty to specifically address the connections that exist between individual topics.

There are also several areas related to method of presentation where opportunities for improvement exist. In general, the students did not like the textbook that was selected for the class. Although the textbook did cover a significant portion of the topics in the class, students did not feel as though the book added significantly to their understanding. The faculty will consider not requiring a textbook and providing course materials they have developed themselves.

The changes made to this course increased the teaching load required of the faculty involved, because the large lecture sessions were replaced by smaller seminar labs. As such, it would be very resource-intensive to scale this course to a larger university with more than a few hundred first-year engineering students.

The opportunity to redesign a first-year program is both a rewarding and time intensive endeavor. The reward exists when a course is developed that will greatly enhance a student's understanding of fundamental engineering principles and sparks student interest in their chosen careers. However, these rewards do not come without significant effort and buy-in by the faculty. Although a significant number of faculty members participated in the development of the course materials, the time commitment required by the faculty teaching the course for the first time was significantly greater than anticipated. While this time commitment should decrease with future generations of the program, it is imperative that those involved with a similar process be aware of the significant time commitment required by such an undertaking.

8. Conclusions

Having an excellent first-year engineering course is a priority at Valparaiso University. The time spent evaluating current and previous courses, reviewing possible models, considering material, and preparing the course demonstrates this importance. The new course allows students to learn about diverse areas of engineering, which will not only help them to choose their major, but will also make them better engineers. It demonstrates the interdisciplinary nature of engineering, and it gives the students opportunities for hands-on learning relating to these areas of engineering.

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