Problem Solving and Design in the Freshman Year: The Foundation Coalition

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Abstract

A pair of courses, GES 131 and 132, form the two semester engineering component of the Foundation Coalition's integrated freshman year at The University of Alabama. The courses use engineering design and problem solving processes to present a more realistic, interesting, and useful introduction to engineering. The overall goals of the Foundation Coalition (curriculum integration, teaming & active learning, technology enabled education) are introduced and developed within the overall framework of problem solving and design.

Each course is organized around several four-week-long "design projects" that are integrated with current topical material from the mathematics, chemistry, and physics courses. The design projects give students a taste of "real-world" engineering and develop the students' problem-solving skills. Students use teaming, active learning, and technology extensively in these courses. Details about specific exercises and common student problems are discussed in the paper.

Introduction

The National Science Foundation has responded to the call for engineering education reform by establishing several "coalitions" of schools across the country. The University of Alabama has been part of the Foundation Coalition (Arizona State University, Maricopa Community College District, Rose-Hulman Institute of Technology, Texas A&M University, Texas A&M University - Kingsville, Texas Women's University, The University of Alabama) since its inception in 1993. As implied by its name, the Foundation Coalition (FC) is attempting to begin the reform movement at the "foundations" of the engineering curriculum, i.e. at the freshman and sophomore years. The three main "thrust" areas of the FC are

1. curriculum integration,
2. teaming and active learning,
3. technology enabled education.

We believe that a thorough implementation of these three concepts in the freshman and sophomore years will substantially improve the engineering education of our students.

At The University of Alabama, the first semester FC freshman curriculum consists of a 13 semester hour set of four courses,

- CH 131 - Chemistry for the Integrated Curriculum (3 credit hours)
- GES 131- Foundations of Engineering (2 credit hours)
- MA 131 - Calculus for the Integrated Curriculum (4 credit hours)
- PH 131 - Physics for the Integrated Curriculum (4 credit hours)

Some details about the chemistry, mathematics, and physics courses are available in (1). A companion set of courses (132's) are offered in the Spring semester. We initially offered the suite of courses in the 1994-1995 academic year to 36 students. Currently, we are offering the course to two sections with a combined enrollment of 62.

Curriculum Integration

Each of the GES (engineering) courses is organized around three to four week long "design projects" which are integrated with current topical material from the mathematics, chemistry, and physics courses. For example, the first project used a surgical tubing powered "sling-shot" device to "launch" golf balls. The students were required to use their projectile motion equations from physics to predict the settings required to hit a specified target with one "shot." Other instances of curriculum integration occur in the following design projects:

- size a compressed natural gas tank (CNG) for an alternatively fueled vehicle (uses ideal gas law from chemistry and physics),
- size a cylindrical tower to support an elevated water tank in earthquake country (uses simple harmonic motion concepts from physics and mathematics),
- evaluate the environmental effects of industrial waste water discharges into a stream (uses mass balance and rate equations from chemistry),
- invent a new polymer and develop a marketing plan (uses material properties concepts from chemistry).

The project descriptions for some of these design projects are given in a later section. The descriptions and some results from many of these design projects are also available on the World Wide Web at http://foundation.ua.edu in the University of Alabama section.

Teaming and Active Learning

Students are involved in teams throughout the freshman year. These teams remain static across all courses, i.e. students are in the same team for physics lab that they are in for the engineering design projects. Teams are rotated once a semester. A major concern of the FC is to get the students to recognize the benefits of teaming as early as possible. In this light, we identified the following "first day" teaming exercise.

1) Draw a map of the United States to scale, showing the borders of all of the states
2) Label the states
3) For each state, write down the:
   - state capital and one other city
   - names of a famous man and a famous woman associated with the state
   - something else for which the state is famous
4) Write on a sticky note 5 things you know now but didn't know before about the U.S.

We gave the students 45 minutes to work on this problem. At the conclusion we conducted a spot-check of the information generated by different teams for several of the less-well-known states. Students said they completed much more of the map as a team than they would have as individuals, which is exactly what we hoped they would say. The purpose of this exercise was to demonstrate the benefits of teaming.

Technology Enabled Education

The availability of low cost personal computers provides the opportunity to incorporate modern technology into the engineering curriculum at the freshman year. Our FC students use the Maple package extensively in their mathematics courses for both numerical and symbolic problem solutions. Chemistry, physics, and engineering use spreadsheets (Excel) extensively to generate numerical and graphical solutions and to report laboratory results. Students use a word processor (Word) for formal written communications, including lab reports in chemistry and physics and design reports in engineering. Presentation software (Powerpoint) is used for the oral presentations following each design project.

FC students use e-mail for informal communication between students and faculty, including weekly electronic journal entries. Our FC students are encouraged to gather information for use in their design projects through use of Internet access software (Netscape). We also introduce (in the second semester) a programming language (FORTRAN) for solving problems not easily solved using spreadsheets.

Problem Solving Skills

We have observed the freshmen working math, chemistry and physics "word" problems and observed that many of the students lacked a general-purpose problem-solving strategy. Specifically, many of the students skipped the problem set-up phase and plunged straight into the solution phase, usually grasping the first equation which came to mind. We introduced a four-step problem-solving strategy:

1. clearly define the problem,
2. state assumptions and constraints,
3. formulate a solution, and
4. test or evaluate the solution.

Using topics from math, physics and chemistry, we drill the students on a series of increasingly more difficult problems.

We believe that the student's lack of a problem solving process is an impediment to their success in the freshman calculus, chemistry, and physics courses. One of our major goals for the engineering course in the FC program is for students to develop a problem solving strategy modeled on the design process.

As we did with teaming, we introduced our problem solving strategy after first motivating the students about the need for such a strategy. The following exercise demonstrated to the students why a problem strategy is useful.

Problem Solving Exercise #1

Each pair of students was given a 12 ounce can of cola and a ruler and asked to determine the surface area and the volume of the can. The answers were written on the board and discussed. Many students had difficulty with unit conversions and significant digits. Very few of them recognized that they "assumed" that the can was a uniform right circular cylinder in order to solve the problem. The tremendous variation between answers and the low number of correct answers clearly demonstrated the need for a problem-solving strategy.

In-class Problem Solving Exercises

During the first few weeks of the engineering class, the students are asked to solve a series of problems. Since our class meets for two consecutive hours twice a week, we can use a significant portion of the class time for such activities. A mix of both team and individual exercises are used. Students are taught to use the spreadsheet program Excel as a tool for solving problems by numerical computation (especially "trial and error") and by graphing. Typical in-class problem solving exercises are shown below.

Problem Solving Exercise #2

> "Design a tank to hold 1,000,000 L when full. The tank will have a cylindrical base and a hemispherical top. Construction costs are $400/m^2 and $500/m^2 for the cylindrical and hemispherical parts, respectively. Design

the tank radius and the height of the cylindrical base to produce the least expensive tank."

This problem was used to introduce the utility of spreadsheets in solving simple problems. Many of the students used a trial-and-error process, while others used a more direct, exhaustive search process. Several of the students struggled with unit conversions (cubic meters to liters), and the use of radius vs. diameter in the area and volume calculations. Most of the students expressed very little intuitive "feel" for the approximate magnitude of the solution. This same problem was used later in the semester as a "min/max" problem that can be solved analytically by the use of derivatives.

Problem Solving Exercise #3

"Bama Ball Painters provides a custom ball painting service. They paint all sizes and types of balls ranging from golf balls to basketballs to huge inflatable beach balls. The president of the company wants an easy way to estimate how much paint will be required based on the diameter of the ball. You have been asked to provide a graph of paint required (gallons) vs. ball diameter (centimeters). Some customers are more technically sophisticated, so you should also develop an equation for estimating the paint requirements as well (an 'eyeball' fit of the data to a line will be sufficient)."

This problem was intentionally selected to introduce the use of logarithmic scales. The ball diameters were given from 5 to 300 cm, with paint volumes ranging from 0.005 to 19 gallons. This problem also emphasized "integration" with chemistry and physics laboratory exercises which required the students to plot data on logarithmic scales.

Design Projects

The first two of the design projects used in the Fall 1995 semester are discussed below. Each project also had several short, in-class exercises associated with it. These short exercises were intended to guide the students through the steps necessary for successful completion of the project. However, we deliberately avoid a "cookbook" approach to problem solutions by our selection of exercises that differ in some respects from the project.

Design Project #1 - Golf-Ball Launcher

"A local civic group is sponsoring a golf 'hole-in-one' contest. Each contestant is given one try (no practice shots) and the location of the hole will not be announced until the day of the competition. Due to an oversight, the rules do not stipulate that the golf ball must be "launched" with a golf club. Your friend builds a golf-ball launcher but needs help controlling it. Another friend has volunteered his video equipment and computer, if it will help. You form a team for the competition and work out the following plan:

1. Set the launcher in a known configuration, release the ball and video tape the flight of the ball.
2. Capture the video in a digital form for use by the computer (using an Intel Digital Video Producer board).
3. Pick off the horizontal and vertical positions of the ball frame by frame (using the Vidshell physics program).
4. Correlate the launcher configuration with the trajectory characteristics.
5. Repeat steps 1 through 4 for several other launcher configurations.
6. On the day of the contest, learn the location of the hole (distance and elevation), calculate a trajectory which will put the ball in the hole, set the launcher to produce the desired trajectory, win the contest and split the prize money!"

This project, which was based on a similar freshman project at Arizona State University, coincided with the topic of projectile motion in the physics course. Though it was not a real "design" project, students experimentally verified an analytical model (the trajectory equations) and then used the model to predict the trajectory needed to hit the target. One of the in-class exercises required the students to develop an Excel spreadsheet that could predict an initial velocity and launch angle to hit a specified target. Most of the student teams were able to use the process described above to come "reasonably" close to the target on the "contest" day. However, only two of sixteen teams actually hit the target. Difficulties with experimental repeatability kept most of them from obtaining a successful launch.

Design Project #2 - Alternative Fuels for Transportation - Natural Gas

The second design project integrates material from both chemistry and physics with an engineering application. The project as presented to the students was:

"Your client, the local newspaper, has several contracted individuals that deliver their newspapers in rural areas. The new publisher believes that by operating several cars on natural gas, the paper can both save money and become more environmentally friendly. The client will base their decision on a combination of estimated savings from lower fuel costs (simple payback period), and your ability to justify all other assumptions made regarding this process. The design goal is to select CNG tank size(s) for an automobile used to deliver newspapers along a rural route in Alabama. Specifically, select the inner and outer diameters and the length of the tank so that it will fit in the trunk of the selected automobile."

The first in-class problem solving exercise associated with this design project required the students to review some basic geometric relationships and the ideal gas law:

> "Size a hot air balloon that will lift your team members and a 200 lb (890 N) gondola with a 25% safety margin"

We used this exercise as an opportunity to review the engineering design process before the students began their second project in detail. At least one member of each team knew that the concept of buoyancy was a relevant principle in the problem solution. Most teams also discovered that the balloon cloth weight was an important parameter that they did not know. After a few other small difficulties (for example the safety margin does not apply to the entire hot air weight), all of the teams were able to generate an acceptable solution.

The second in-class exercise associated with this design project required the students to create an Excel spreadsheet:

> "Given the amount of gasoline to make the delivery route, find the amount of natural gas required and determine the compressed volume of this quantity of natural gas."

The students were also asked to plot the tank outer diameter vs. inner diameter from the maximum stress equation given in project description.

The third in-class exercise for the CNG project was to further develop the project spreadsheet:

> "Given the inner diameter and length of the tank as inputs, calculate the inner volume of tank (in^3 and m^3), outer diameter of the tank (inches and cm), and the weight of tank (pounds or newtons)."

After this in-class exercise, the students were able to successfully complete the design project in a relatively short period of time.

Observations

Students enjoy working together and using computers to solve "practical" problems. Advantages of incorporating active learning, teaming, technology, and design include:

- students enjoy learning,
- students help each other learn,
- learning is more balanced (students learn through discussing, graphing, building, etc. as well as listening),
- students are very computer (technology) literate and catch on to new programs quickly,
- students can develop problem-solving skills and confidence,
- students learn to work effectively in teams.

As our experience with these teaching methods grows, disadvantages of these methods have come to light. These include:

- students do not necessarily trust each other (they need good initial team building exercises),
- lack of individual accountability on team assignments ("slack" students receive team grade but fail to learn and cause resentment among teammates),
- lessons incorporating active learning must be carefully planned to meet the lesson objectives (or else the class disintegrates into a study hall),
- more responsibility for learning is placed on students (and some students do not have the necessary maturity)
- some deliverables are required each time you have teams working during class.

Over the last several years, we have observed that many engineering students have problems with basic algebra, geometry, and trigonometry skills. By exercising these skills in the context of engineering design projects, we hope to improve our student's ability to use them outside the math classroom. Many students are also not thorough in their approach to unit conversions and significant digits. We deliberately use both the SI and English systems of units to force students to exercise and develop this fundamental skill.

References

1. Parker, J., D. Cordes, C. Laurie, A. Hopenwasser, J. Izatt, D. Nikles, "Curriculum Integration in the Freshman Year at The University of Alabama - Foundation Coalition Program," Proceedings of the Frontiers in Education 25th Annual Conference, Paper #4A11 Atlanta, GA, November, 1995

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Joey Parker is currently an Associate Professor of Mechanical Engineering at The University of Alabama, where his teaching responsibilities include control systems, instrumentation, and senior capstone design. He has been involved with the Foundation Coalition effort at Alabama since 1993, and currently serves as the coordinator of the freshman year program. He received his B.S.M.E. degree from Tennessee Technological University in 1978, and his Master's and Ph.D. in Mechanical Engineering from Clemson University in 1981 and 1985, respectively. Dr. Parker's experience includes three years with the Badische Corporation (now BASF) as an R&D engineer and three terms as a NASA/ASEE Summer Faculty Fellow at the Marshall Space Flight Center. His research interests include microcomputer applications, industrial automation, electro-mechanical actuators, and I.C. engine control.

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Jim Richardson is an Associate Professor in the Civil Engineering Department at the University of Alabama. He teaches structural analysis, bridge design, and senior design courses as well as freshman engineering for Foundation Coalition. Dr. Richardson received his B.S. in Civil Engineering from the University of California at Davis in 1978 and his M.S. and Ph.D. in Civil Engineering at the University of Nevada Reno in 1982 and 1987, respectively. Dr. Richardson's work experience includes three years with Civil Engineering consulting firms. His research interests in include bridge design and structural dynamics.

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David W. Cordes is an Associate Professor of Computer Science at The University of Alabama. His primary research and teaching interests focus in the area of software engineering. Recent activities have centered on the development of formal testing methods for object-oriented software. Specifically, techniques that promote the incremental development and testing of software are being
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