Engineering Design in the Freshman Year at The University of Alabama - Foundation Coalition Program

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Abstract

A pair of courses, GES 131 & 132 (Foundations of Engineering I & II), form the two semester engineering component of Foundation Coalition's integrated freshman year at The University of Alabama. These courses replace two existing freshman engineering courses which are devoted to computer programming (FORTRAN) and engineering graphics. In order to present a more realistic and interesting introduction to engineering as a profession, the courses focuses on the engineering design process.

Both courses are organized around four three-week long "design" projects. The projects are selected from a variety of areas, covering the breadth of engineering disciplines taught at UA. The design projects also complement the current subject matter of the integrated math, chemistry, and physics courses. For example, while both physics and chemistry are introducing the ideal gas law, the engineering project involves the design of a CNG (compressed natural gas) tank for an automotive application. Each design project requires a team report, in written and (sometimes) oral form. The students are introduced to a variety of computer tools to aid their presentation of reports, such as word processors, spreadsheets, and presentation packages. Student access to the Internet (for data collection) and e-mail (for communication) is also provided.

This paper provides an in-depth examination of the first of these two courses. It includes a brief overview of the relationships that exist between the integrated courses in the freshman year, a detailed examination of the nature and scope of the design projects included within the course, and feedback from both faculty and students on the merits of the approach.

Introduction

The National Science Foundation sponsored Foundation Coalition (FC) consists of a group of schools (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) attempting to improve the basis or "foundations" of engineering education. The FC program is focused on three concepts for improvement: curriculum integration, human interface issues (teaming, active learning), and technology enabled education. In our FC program, the first year mathematics, chemistry, physics, and engineering courses are integrated to take advantage of topical redundancies and provide additional student motivation for difficult material. Our goal with curriculum integration is for students to understand that mathematics, chemistry, and physics are not simply hurdles that they must leap to enter engineering, but are the foundations upon which engineering build. A consideration of human interface issues, such as active learning and teaming, offers the potential to greatly increase student understanding and retention of new material. Our FC program provides numerous occasion for students to work in two or four member teams, from their chemistry and physics labs to their engineering design projects. Active learning strategies that have been used include short, in-class recitations, five minute "brainstorming" exercises, and anonymous student feedback through the "plus/delta" technique (students use a "post-it" note to indicate either a positive or "plus" aspect of the class or an aspect that could be improved, i.e. "delta," and place the notes on the classroom door as they leave). The widespread use of modern computer technology in the freshman year is a significant component of our FC program. The incorporation of symbolic mathematics programs, such as Maple, along with reform calculus concepts, has revolutionized the instruction of calculus for our FC engineering students. Additional uses of computer technology are introduced in the next section, which details the new engineering course component of the freshman year of the FC program.

GES 131/132 - Foundations of Engineering I & II

Two new two-credit hour courses, GES 131 and GES 132, were created to provide the engineering component of the freshman year FC program. Our overall focus in GES 131 and 132 is on the engineering design process and how knowledge from the basic sciences and mathematics is used to solve engineering problems. Each of these courses is organized around four three-week long design projects. These projects were selected to cover the breadth of engineering disciplines taught at The University of Alabama, and to integrate with the math, chemistry, and physics courses as closely as possible. Students spent five to six hours per week in class (for two credit hours) with few outside assignments. The students used about half of the class time to work in teams on their design project solutions and reports. Several miscellaneous topics (sketching, word processing, spreadsheets, teaming skills, etc.) were introduced during the remaining half of the class time.

A major goal throughout GES 131 and 132 was for students to understand the engineering design process, and how it is used to solve real problems. We believe that this is best accomplished by having students actually do design problems, which may be over- or under-specified, or even ill-defined. No formal, rigid definition of engineering design and the design process was used. Instead, the description of the engineering design process that we presented to the students on the first day of class was fairly generic:

- identification of the problem to be solved,

- overview of relevant (background) information,

- establishment of the basic goal(s) of the design,

- iterate through the following tasks until an acceptable solution is identified,

- identification of constraints placed upon the design,

- development of solution(s) to the design problem,

- review and evaluation of the solution(s) with respect to basic goals and constraints,

- formal presentation of the design problem and its solution.

It was frequently pointed out that in an academic environment, the professor usually does the first step for the students, but in the "real world" it is often the most difficult! After discussing the importance of creativity in generating a multitude of alternate solutions, we started the students on their first design project.

Design Project #1 - Classroom Layout and Organization

The room in which class was held (East Engineering 111) had been renovated to incorporate computers (one for every two students, arranged around the periphery of the room) with movable tables and chairs in the interior. We deliberately positioned the tables and chairs in a poor arrangement before class to motivate the first design project:

"Identify a preferred layout for the tables and chairs in East Engineering 111"

Since the students were new to the team oriented format of the FC program, some basic guidelines for the design were given:

- students will use this room for both traditional lecture and team-oriented activities,

- teams will consist of no more than four individuals,

- the design should work for a class of up to 36 students,

- the computer tables around the sides of the classroom are fixed, and cannot be moved.

The teams were given the latitude to design one single formation that was applicable to both a traditional lecture-style classroom or a combination of both a traditional lecture-style layout plus an arrangement that permits teams to work effectively. The first design project was a relatively simple exercise requiring little outside work. The emphasis of this project was on:

- teams and teaming skills,

- learning styles and methodologies (students were given the Myers-Briggs Type Indicator personality exam),

- developing familiarity with the computing environment.

When looking at the basic problem statement, others might wonder whether this is really a design problem, or just a pointless first-week exercise. We stressed the aspects of this problem that do indeed relate it to actual design problems (factory layout), and the fact that there are multiple solutions (none are ideal), readily identifiable constraints (table size and shape), and a need to "sell" the final design to the entire class.

Since this was the very first design exercise, there was no attempt to relate to current topics in math, chemistry, or physics. An interesting observation about this design project is that the final student solution was one that had not occurred to the four engineering professors that had originally designed the tables and classroom layout!

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

Natural gas is becoming an increasingly attractive fuel for many transportation uses. Fuel costs are significantly less than with gasoline, abundant reserves of natural gas are available in the U.S., and significantly lower emissions are possible due to the simple chemical structure of natural gas (primarily methane). The combustion characteristics of methane are similar enough that unmodified gasoline engines may be successfully operated using natural gas. The primary disadvantage of natural gas as a transportation fuel is the fact that it is a gas, and thus has a low density, and is often stored in a compressed state. The ideal gas law (from both chemistry and physics) can be used to determine the mass of natural gas stored at any given pressure once the volume and temperature are known. The second design project description was:

"Select compressed natural gas tank size(s) for a car/light truck application."

The students were given some initial assumptions (the ideal gas law applies, tanks are hollow cylindrical shapes made of steel, a formula for calculating outer diameter based on pressure).

Several other constraints exist for this problem. Ideally the students "discover" as many of these as possible during one of their teaming exercises (fuel consumption rate, desired range, trunk space available for tanks, refueling stations and CNG availability, added weight and volume of tanks). Given that all of our students have a great deal of experience with automobiles, most were able to discover these constraints and successfully complete the second design project.

Design Project #3 - Kinetics - Catalytic Converter For CNG Automobile Exhaust

Automobile exhaust contains significant amounts of air pollutants such as carbon monoxide, nitric oxide (NO), and hydrocarbons. Catalytic converters promote chemical reactions which turn these compounds into relatively harmless carbon dioxide and nitrogen. Laboratory studies have shown that the rate of reaction (from chemistry) can be written with a dependence on temperature. A simple material balance (chemistry) for NO across a differential slice (mathematics) of the converter will lead to a solution equation that gives the concentration of NO as the exhaust gas flows through the converter. The catalyst pellets are porous spheres of alumina with the costly noble metal rhodium dispersed on the surface. The design problem presented to the students was thus:

"Design a catalytic converter that will help a CNG-powered engine meet the current U.S. federal emissions limits for NO."

The solution equation for this problem was given to the students and was easily implemented on a spreadsheet. Unfortunately, the students were told to use the weight of the catalyst (rhodium) in the equation, instead of the weight of the combined catalyst and alumina pellet. This misunderstanding caused the design project to be much more difficult than anticipated, since acceptable solutions based on emission reduction required unreasonable quantities of expensive rhodium. The problem was further compounded when the course instructor (the first author) left town for a three-day workshop at a critical point in the design project. Ideally, the students should have focused on the following design considerations:

- What problems occur when the engine is cold at startup? How can you solve them?

- Is it reasonable to assume the converter behaves isothermally?

- For the same size converter shell, how could you change the catalyst to increase the conversion of the NO? Does this create other problems?

- Look under a car (use proper safety precautions!) and sketch out the exhaust system. Why is it arranged this way?

Design Project #4 - Design of a Water Tower to Resist Earthquakes

In this age of "high" technology, the design of buildings and bridges to resist earthquakes is coming under increasing scrutiny. There are no records of large earthquakes in Alabama, but large devastating earthquakes have occurred in the south (near Memphis, Tennessee and Charleston, South Carolina). Traditionally, structures have been designed to resist vertical loads: the weights of materials and people which occupy the building. Earthquakes, however, cause lateral dynamic loads on structures. A key to understanding how earthquakes affect structures is the concept of resonance: if a structure's natural frequency coincides with the predominant frequency of the earthquake, the ground motions will be amplified in the structure. Engineers use a response spectrum to determine how much the ground accelerations are amplified in the structure by resonance. Structures such as buildings and bridges are usually analyzed as a system of oscillators which involves complicated analyses. An elevated water tower, however, can effectively be analyzed as a single oscillator (simple harmonic oscillator from physics). The mass of the oscillator is the mass of the water in the tank and the stiffness of the oscillator is the bending stiffness of the support pedestal. The project is to do a preliminary design of a proposed new water tower:

"Design an elevated water tower to be located on a 50-foot-tall hill in Memphis, Tennessee."

The students were given a list of design constraints from their "client" (minimum volume of tank

minimum and maximum pressure in water main at bottom of hill, maximum allowable stress for steel), as well as some practical design guidelines to get them started. The students were also encouraged to use a spreadsheet and a trial and error process. The students were also encouraged to consider the following in their presentation to the "client":

- Will other tank heights or diameters work? What effect does the tank shape have on the natural period of the structure?

- Will other tower heights work? What effect does the tower height have on the natural period of the structure? on the earthquake force at the center of mass of the tank? on the stress at the base of the tower?

- For a given tower diameter and wall thickness, show the result of changing the tower height on the natural period of the structure, on the force at the center of mass of the tank, and on the stress at the base of the tower. Plot the results over the range of permissible tower heights (based on water main pressure requirements) using 10 foot increments in tower height.

Observations

The sections above presented a short outline of the design projects used in the first semester course, GES 131. Since this was a completely new course in a new program, a great deal was learned about how to operate such a program. Some of our observations about the course are listed below.

- Students felt more comfortable with concepts that were introduced in their science courses first, then used in a design problem. Since many of the students felt that they did not have a good high school preparation in physics, this is not surprising.

- Providing the correct mix of helpful background information without making a "cookbook" analytical problem is difficult. Most students have been conditioned over the years that all problem statements in an academic environment contain exactly the correct amount of information. These old habits are hard to break. and many of the students are very resistant.

- The faculty had the luxury of having the design project originator give the initial project description to the students, since we had only one section of 36 students. As the program grows, this will be difficult to accomplish. Educating engineering professors about design projects in areas other than their own research specialty may prove to be one of the largest challenges to the success of the FC program.

- Most students need a great deal of structure, i.e. intermediate goals, particularly during the first few design projects. Determining the correct amount of structure to provide, without hampering the creative aspects, is a difficult challenge for this type of program.

- All of the grades for the projects were based on team reports (both oral and written) with equal weight for the quality of the solution and the quality of the report. The use of team grading for the projects (about half of the total grade) generated some complaints about team member effort and participation. We plan to use regular team self-evaluation in the future to help overcome this problem.

As with any new program, there were both positive and negative aspects to our initial attempts to implement design in the freshman FC program. Some student feedback to the specific question "How do you feel about your experiences with the GES design projects?" is given below.

"The GES design projects answer the question: ‘Am I ever going to use this?’ The design projects incorporate as fully as possible the information that is taught in the lectures and the information learned in the labs and recitations."

"The GES design projects were a good idea, sometimes they seemed a little too underspecified, sometimes a little too overspecified. The water tower project I think was ideal."

"To be honest I really hate the GES projects because your success depends too much on your team member’s participation unless you are able to do the whole thing yourself."

"The design projects taught me the kind of the things to expect when I get a job. However, on a few of the projects, I felt that we were not given enough information to do the project."

"I think that they are the best part of the foundation. They are the closest thing to real engineering that we have done.."

"The design projects feel like they are over my head. As a freshman, I don’t think I have learned enough classroom material to solve a project."

"I think the GES design projects have given us a good idea of what projects in future classes will be like, and how we will need to present ideas to future employers. The projects have been fairly interesting and challenging."

Conclusion

The first offering of The University of Alabama’s Foundation Coalition freshman level engineering course has been described. The intent of the course is to capture the student’s interest in engineering while motivating their parallel studies in mathematics, chemistry, and physics. Four small, three-week long design projects have been described in detail, along with both faculty and student observations about the course. Based on student and faculty response to date, the authors believe this course sequence represents a significant improvement over the traditional freshman engineering program.

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