Freshman Design Projects in the Foundation Coalition

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Abstract *- Many talented engineering students abandon engineering before taking a single engineering course. Herded into large sections of "pre-engineering" mathematics, chemistry and physics courses, many students prove themselves academically but walk away from engineering, disillusioned. Numerous schools have instituted freshmen engineering courses to retain some of these capable but disinterested students in the engineering program. Freshman engineering courses spark students' interest by showing students that engineers communicate, lead, and create as well as analyze. One of the most successful ways of showing first-year students the diversity of skills needed to practice engineering is through freshman design projects.*

The authors have each selected three of their favorite freshman design projects (a total of fifteen projects) and posted detailed descriptions on the web (www.foundation.ua.edu/projects). For those interested in learning a little background about the freshman programs in which these projects were used, please read on. This paper provides: a brief description of the freshman programs at each school (the schools are participants in the NSF-sponsored Foundation Coalition), short summaries of each project, and answers to frequently asked questions about freshman design projects.

Introduction

The authors are participants in the NSF-sponsored Foundation Coalition. Many of the educational goals of the Foundation Coalition parallel the educational goals of freshman design projects. The FC concentrates on the first two years of engineering education and stresses curriculum integration, active learning and teamwork, technology-enabled learning, and assessment.

Now in its sixth year, the FC has developed and implemented freshman design projects for each of the past five years. This paper synthesizes joint experiences of the FC freshman-engineering faculty from five of the FC schools (Arizona State University, Rose-Hulman Institute of Technology, Texas A&M University, Texas A&M University at Kingsville, and the University of Alabama). The faculty experiences are communicated via examples and a discussion of the elements of successful freshman design projects.

Literature Review

Many schools have instituted freshman engineering courses containing design projects. A review of the papers presented at the last two FIE conferences indicates the popularity of freshman design projects and shows the diverse approaches faculty at different schools use to implement freshman design.

At the University of Colorado [1, 2], Lehigh University [3], SUNY-Binghamton [4] and the University of Wisconsin [5], freshman students design and build. Students really enjoy working with their hands to actually build something. Two of the programs [1, 5] stressed the importance of having students interface with real "clients" (often handicapped people). By working for real clients (rather than engineering professors), the students learned that problem definition is a large and difficult part of the design process [1].

SUNY-Binghamton [4] has replaced three traditional courses that primarily teach skills rather than content (computer programming, graphics, and English composition) with one integrated course. The new course uses design projects as the context for learning the traditionally-taught skills. The design projects also facilitate learning other skills not traditionally taught such as solving open-ended problems, working in teams, and giving oral presentations.

Faculty at several schools have tackled the challenging problem of defining design, a prerequisite to measuring a student's progress learning design. Sheppard and Jenison [6] provide a list of qualities expected in a design engineer and propose a method of categorizing how we teach design. They categorize freshman design courses at several schools based on the educational objectives (product vs. process) and on the pedagogy (individual work vs. teamwork).

Faculty from three schools in Washington (Tacoma Community College, Washington State and the University of Washington) [7] have developed a list of student competencies for design. They have listed criteria for measuring each competency and provided examples for evaluating student progress in a particular competency. The paper's authors recognize that learning design requires some trial and error on the part of students and suggest ways teachers can build a supportive environment for the students to learn the process of design.

Karl Smith [8] divides the design process into three intellectual steps: (1) formulate the problem, (2) build a conceptual model, and (3) analyze and draw conclusions. Model building, according to Smith, is the key intellectual process students must learn to be effective designers. The course format (pedagogy) is a combination of problem-based learning and formal cooperative learning.

Students for a new freshman-engineering course at North Carolina State [9] were selected randomly. Students in the new course, which stresses open-ended problem solving and group work, had significantly more confidence about problem solving than their counterparts in the traditional curriculum. A unique course at the University of Virginia [10] includes non-engineering students as well as engineering students. The course emphasizes invention and design and included.

Arizona State [11] has done what many of us are afraid to do. After training their students all semester on a series of team design projects, they gave the Physics final in a team project format. The students performed poorly on the exam. "Freshman university students have spent twelve years honing their study skills for success on standard 50-minute written examinations. Those skills are largely a disjoint set to the skills required for success on the final project exam. … and for achievement in the post-university engineering environment."

The paper's authors also state, "Our experience indicates that project-based learning is indeed a viable and very useful means of instruction, but that its use is decidedly hindered by a lack of classroom-proven projects, learning plans, and assessment tools. Currently these must be largely developed from scratch. A database to draw upon in choosing projects and assessment methods would greatly facilitate the use of project-based learning." [11]

Projects on the Web

Detailed descriptions of fifteen of our best freshman-engineering projects are presented on a central web site (foundation.ua.edu/projects). Each project is presented in a common format and includes all of the information needed for the reader to implement the project. Information such as educational objectives, required resources, project timeline, student deliverables and grading procedures are presented for each project.

Paper Overview

The first section of this paper provides a brief background on each of the FC freshman engineering programs. This furnishes a context for the projects and will clue the reader about if and how a project should be modified to fit the reader's freshman engineering program. In the next section, each author briefly describes freshman projects on his campus and comments about specific highlights or low-points concerning the projects.

The next section of the paper presents frequently asked questions (FAQs) and answers about FC freshman design projects. Many of these questions center on aspects of team work. How do you grade team projects? What do you do about team members who don't participate? There is no one correct answer to many of these questions. Each author responds to each question, with similar answers grouped together.

In the last section of the paper, the authors take a step back and discuss freshman design projects in the context of engineering education. What are we, as engineering educators, trying to accomplish with freshman projects? A list of educational objectives for freshman design projects is presented and discussed. Interestingly, only one of the educational objectives concerns learning material, the remainder of the objectives concern practicing skills or providing experiences.

Freshman Engineering Programs at FC Schools

The Foundation Coalition, now in its fifth year, was organized around four thrusts: curriculum integration, cooperative learning/teamwork, computer-aided learning and assessment. Two of the schools had experience with curriculum integration prior to formation of the FC: Rose-Hulman had a freshman program in which physics, mathematics, chemistry, computer science, and engineering were integrated into a single 12-hour course. Texas A&M had a series of sophomore courses which integrated engineering science topics into a common theoretical framework using conservation principles. Also, Arizona State had prior experience with cooperative learning and teamwork.

The FC emphasis on curriculum integration and cooperative learning/teamwork directly impacts the freshman design projects. Topics for the design projects frequently come from current topics in the students' Physics, Mathematics and Chemistry courses. This is not possible in a normal freshman year engineering curriculum because although all students eventually take Physics, Math and Chemistry, not all students have taken or are taking these courses. Also, students receive instruction in how to be an effective team member.

The freshman year programs at each FC school are summarized in Table 1. All of the programs incorporate the same FC thrusts of curriculum integration, cooperative learning, computer use, and assessment but the curricula varies from school to school because of differences in student population and individual preferences of faculty. For example, Physics is delayed at the University of Alabama and Texas A&M-Kingsville to give capable but poorly prepared students a semester to catch up with the other students.

Table 1. FC First-Year Curriculum

School	First Semester/Quarter (Hours)	Second Semester/Quarter (Hours)	Third Quarter (Hours)
Arizona State University	Freshman Composition and Rhetoric I Calculus I Physics I Engineering I- Models, Design Concepts, Projects	Freshman Composition and Rhetoric II Calculus II Physics II Engineering II- Models, Design Concepts, Projects	
Rose-Hulman Institute of Technology	Calculus I (5) Chemistry I (4) Introduction to Design (1)	Calculus II (5) Chemistry II (4) Physics I (4) Introduction to Programming and Problem Solving (2) Introduction to Design (1)	Calculus III (5) Physics II (4) Statics (4) Engineering Graphics (2) Introduction to Design (1)
Texas A&M University	Calculus I (4) English I (1) Engineering I (3) Physics I (4)	Chemistry (4) Calculus II (4) English II (2) Engineering II (2) Physics II (3)	
Texas A&M University - Kingsville	Chemistry I (4 hr), Analytical Geometry (3 hr) English I (3 hr) Engineering as a Career (2 hr) Computer Based Graphics/Design (3 hr) or a discipline specific engineering course	Calculus I (3 hr) Physics I (4 hr) English I (3 hr) and/or Chemistry II (4 hr) and/or Discipline specific engineering course (3 hr)	
University of Alabama	Engineering I (3) Calculus I (4) Chemistry I (4)	Engineering II (2) Physics I (4) Calculus II (4) and/or Chemistry II (4)	

Arizona State University (ASU*)*

The freshman program combines and integrates material from introductory courses in calculus, physics, English composition, and engineering, normally taught in a stand-alone format. The calculus used in this course was based on the "Harvard reform model" and includes a review of functions, the derivative, the definite integral, differential equations, and application of these topics to physics and engineering problems. The physics is traditional in that the first semester is mechanics-based, with emphasis on kinematics, dynamics, conservation principles, rotational motion, while the second semester is electromagnetics based, with emphasis on wave phenomena, electro- and magnetostatics, and electric circuits. In the English composition classes the students learn the use of rhetorical principles with readings from the philosophy of science and engineering case studies and to organize and develop ideas for both technical and general audiences

The engineering class serves as the backbone of the integrated coursework. In the engineering class, the students learn to develop critical thinking skills through the exposure to design concepts, the development of computer models, and the construction of engineering projects. The projects incorporate the calculus and physics that have been learned to date in the class. The integrated course also employs considerable use of computers in an active learning environment that stresses teaming and other quality tools.

Rose-Hulman Institute of Technology (RHIT)

RHIT has offered the Integrated, First-Year Curriculum in Science, Engineering and Mathematics (IFYCSEM) since 1990. IFYCSEM integrates topics from the courses listed in Table 1 into a year-long sequence of three twelve-credit courses. IFYCSEM students meet for nine lecture hours and nine laboratory hours each week. They take a three-hour exam every two weeks on which questions are drawn from every discipline which students have been studying.

Summative assessment using carefully matched comparison groups show that IFYCSEM students are retained at a higher percentage and have a higher GPA than their counterparts in the matched comparison group.

Students work on a major project each quarter. In the Fall Quarter, students work on a creative development project. In the Winter Quarter, students work on modeling or design project which places more emphasis on the analytical capabilities students are developing in their mathematics, chemistry and physics courses. In the Spring Quarter, students select from a list of projects generated by the members of the interdisciplinary faculty team. Projects range from creating computer games to developing better processes for making plastics to developing a magnetic rail gun. At the end of Spring Quarter, student teams present their projects in a poster session. Through the projects students develop their ability to work in teams and appreciate the relevance of science and mathematics in the practice of engineering.

Texas A&M University (TAMU)

The integrated freshman program has been delivered for four years at TAMU. Since the onset of the project, chemistry, calculus, English, engineering, and physics have constituted the core courses taken as part of the program. Initially, only calculus-ready students were admitted into the program, but a pre-calculus tract has since been developed. While all courses are taught in an integrated fashion and involve the use of active/collaborative techniques and teaming, students receive individual grades for each class.

The evolution of the program after it was first delivered includes:

1) moving and integrating mechanics and electricity & magnetism into the first two semesters;
2) rearranging the calculus sequence to support the teaching of both semesters of physics;
3) adding a physics/science laboratory experience to the first semester; and
4) restructuring the English component from two, 2-credit-hour courses taught over the academic year to a 1-hour course followed by a 2 hour course the second semester.

The change in English was not done for any pedagogical reasons, but rather to balance teaching loads in anticipation of scaling up to accommodate all incoming engineering freshman. In addition, a pre-calculus track has been developed which allows students who need preparatory math skills to participate in the program, albeit one semester out of phase. These students begin their freshman year taking a 1-credit-hour engineering course, pre-calculus, chemistry, as well as any elective courses. This is followed by two semesters that mimic the integrated sequence for calculus-ready students in structure and presentation with chemistry omitted.

Texas A&M University –Kingsville (TAMUK)

The Freshman Year Integrated Engineering Curriculum (FYIEC) at Texas A&M University-Kingsville has been offered since fall 95. In line with the goals of the Foundation Coalition, the FYIEC curriculum was designed to incorporate changes in four major thrust areas: curriculum integration, technology-enabled learning, cooperative/team learning, and assessment, evaluation and dissemination. Traditional first year courses in Science, Engineering, Math, and English, have been modified such that topics are delivered based on a predefined sequence which emphasizes basic skills and thematic concepts (rather than discipline boundaries), problem solving strategies and design. Classes are taught in a high-tech active learning mode that facilitates the use of computers and cooperative/team learning. A variety of assessment methods are used including regular feedback from students during the semester.

Several unique activities of the program include: integrated exams, hands-on design projects, problem solving sessions outside class, and ethics panel discussions. Other unique activities include: a shadow day in which students shadow an engineer for a day from local industry and engineering firms, electronic journals, and use of portfolios for student and program evaluation and assessment.

University of Alabama (UA)

The FC freshman year has been taught at UA since the Fall of 1994. For the first two years of the program, physics was included in the first semester. In years three and four, physics has been taught in the second semester of the freshman year. There are advantages and disadvantages to this change, the primary advantage being that under-prepared but capable students (e.g. from small rural high schools) had a semester to catch up with their better-prepared peers.

Over half of entering UA freshmen engineering students are not ready for calculus (based on a math placement test administered during summer registration). The UA freshman program has included (in years three and four) an FC pre-calculus course. This math class covers the standard pre-calculus math topics (functions, etc) but emphasizes problem solving and is linked to a pre-calculus engineering class and the FC chemistry class. These students work design projects that do not require calculus.

Design Projects

Each of the authors describes their favorite three projects below. These projects are described in more detail at the following web site: foundation.ua.edu/projects.

Arizona State University (ASU)

The faculty feel that the projects: (1) allow the students to use and demonstrate their innate creativity, (2) challenge the students to reach for lofty intellectual goals, and (3) let the students participate in the successful completion of a good design plan.

The students feel that the projects are the most valuable part of the integrated first year program. This is demonstrated very clearly by the written comments the students attach to the university course evaluation forms. Naturally, the students think the projects are fun, but nearly all also mention that:

(1) the projects reveal the connections among the four subject areas vividly,
(2) the reporting process is challenging and interesting, and
(3) they discover some of the wonder and excitement that comes naturally from doing creative work.

The Bungee Jump The goal of this project is to have the students apply physics and calculus to the design and construction of a bungee-drop apparatus. The "passenger" at the end of the bungee cord is a raw egg, and the drop takes place at the top of the track stadium. The students are able to take an analytical approach to this project because of their increased understanding of analytical physics and calculus. Modeling is carried out by defining the free body diagram for the motion of the egg, finding the net acceleration on the egg, and then using Euler's method of integration to solve the equations of motion for the egg on a spreadsheet. The students measure the elastic properties of the bungee cord material, determine the departures from Hooke's Law behavior, and get an empirical expression for the cord elongation as a function of applied force. In the free body diagram, they consider the forces due to air drag, gravity, the cord's tension, and damping within the cord itself. In the modeling phase, the students devise a drop that would provide maximum free fall without decelerating the egg more than three times "g." The students are shown the boom from which the egg will be dropped and have to design an attachment/release mechanism for their egg. On the day of the drop (no practice runs here), the students specify the length and number of bungee cords, set up the release mechanism, and carry out the launch. The launch is recorded on videotape, and the students digitize the tape and compare the performance of their design (maximum deceleration, closeness of approach) with that predicted by the model.

The Seismometer The goal of this project is to design and construct a sensitive seismometer that will allow the team to examine mechanical vibrations transmitted through the earth. The seismometer has to be sensitive enough to detect minute ripples in the earth produced by someone walking across a room. In essence, the seismometer must employ mechanical oscillatory motion (a pendulum) to measure seismic waves traveling through the earth and electromagnetics to convert the mechanical motion to electrical energy. The electrical energy is then amplified and examined on the classroom PC's.

The mechanical portion of the seismometer is to be built with parts from an Erector Set. The students are given magnet wire to fashion a multiple turn coil and small permanent magnets to build a compact transducer. The induced voltage output of the coil goes to a team-designed and built op-amp circuit, and finally to the data acquisition board on the PC for display and analysis.

The Analog Computer The goal of this project is to design and construct a "mathematical instrument" that employs op-amps to solve linear differential equations. The students once again combine the current physics topics (RC circuits and op amp electronics) and calculus topics (differential equations) with engineering problem solving skills. Like the seismometer, this project permits the students to design, build, and test an actual scientific instrument.

The students first design and simulate the op-amp integrators with SPICE circuit simulation software. They then construct a series of op-amp integrators that can be connected to act as a differential equation solver, or analog computer. The output of the analog computer can be sent to a data acquisition board on the PC for display. The students can analyze the operation of their analog computer and compare the results with analytic and numerical approaches learned in Calculus class.

Rose-Hulman Institute of Technology (RHIT)

Students develop very creative approaches working on the projects and are very enthusiastic about opportunities to demonstrate their ideas and to see the ideas of other teams. Students learn about working together. After the poster session for Spring Quarter projects in the student union, faculty remark on the very good quality of the student projects.

The projects help students see the connections between mathematical/scientific concepts and the practice of science and engineering. Students discuss these connections in their written journals, which develops a deeper level of understanding. Also, some students grow in their understanding of the value and process of mathematical modeling.

Fizz Soda pop drinks have fizz which is considered a desirable property. Define fizz in such a way that it is possible to measure. Develop one or more techniques to measure the change in fizz of an opened pop over time. Prepare a mathematical model to predict the behavior of fizz and compare the behavior of fizz for two or more brands of soda pop.

Modeling Esoterica, Inc. has developed some powerful mathematical modeling tools. To help market the tools, a series of application notes (reports) must be developed to demonstrate the capabilities of these tools. Your team has been assigned the task of developing an application note (report). The application note will contain:

- a description of a physical process,
- a description of quantity or quantities which change over time,

- a description of an apparatus to measure the selected quantity (quantities),
- two or more mathematical models (e.g., differential equations, functions, which predict the measured behavior of the quantity (quantities)),
- graphs showing how well the models predict the behavior, and
- a comparison of two or more examples of the physical process

At least one of the mathematical models should be based on physical principles: Newton's laws of motion, conservation of mass, conservation of charge, etc. That is, you should explain why one particular form of the model was chosen. Additional models may be constructed solely through empirical methods, for example, curve fitting.

Falling Water Powered Vehicle Potential energy is stored in a pop can full of water 1.00 m above the ground level. Convert the potential energy into kinetic energy to propel a wheeled vehicle across smooth ground. An appropriate the vehicle will have at least three wheels, a mass of at least 100.0 grams and remain in continuous contact will the ground. Prizes will be awarded for greatest distance and for most creative design.

Texas A&M University (TAMU)

At Texas A&M, two major projects have been developed and are used as part of the freshman integrated program. The first project, which is assigned during the last half of the first semester, is short in duration (generally 3 to 4 weeks) and is specifically aimed at preparing students to begin thinking like engineers. The project also provides students with a teaming experience wherein all team members perceive themselves to be equal contributors. The second project is considered to be a whole semester project and requires the students to use knowledge gained throughout the academic year in the areas of calculus, chemistry, English, engineering, and physics. In both cases, the project grade constitutes a portion of the student grade in all of their courses. Details of each of the projects are described below.

Rubber-Band Powered Car This project provides the a freshman engineering student with a "hands-on" experience, as well as introduces them to the concept of engineering economics. Students are expected to demonstrate the ability to work as effective members of a technical team, use basic energy concepts developed in calculus and physics, and produce a written document, in the form of a standard report. The report details the design process and includes any necessary technical drawings and supporting calculations.

Students are supplied with all necessary construction materials (a corrugated cardboard box; rubber bands; paperclips, and a section of _" dowel-rod) and are given specific design constraints by which they must construct their vehicle. Examples of these constraints include: 1) the vehicle must have a minimum of 3 wheels, all of which must support the total weight of the vehicle (both with and without cargo); 2) the vehicle must have a "rubber band type engine" which is enclosed within the body of the vehicle and expends its energy over time; and 3) the vehicle must satisfy geometric constraints such as minimum top, side, back, and frontal projected areas, as well as a maximum height and length.

Students teams compete against one another based upon the performance of the vehicle in terms of speed (computed over some fixed distance), maximum distance traveled, available power (distance/time to pull a fixed weight), and endurance (time the vehicle can be kept moving). In addition, the students are judged for creativity and originality in order to promote innovative thinking in their design process

Ping-Pong Ball Launcher This is a semester long integrated project involving concepts learned in calculus, chemistry, English, engineering, and physics. Each team of students is responsible for preparing a project proposal, developing the design itself, and writing a final report (in the form of a multi-media presentation). For this project, students are made aware that a significant portion of their project grade is based upon their ability to perform the appropriate analysis for both the proposal and the final report.

This project entails designing, analyzing, constructing, and reporting on a launcher that will propel a Ping-Pong ball, in flight, for any arbitrary distance between one foot and 35 feet. The Ping-Pong ball must impact the target point with the highest degree of accuracy (where the term accuracy is mathematically defined for them). The students participate in an oral proposal phase, wherein the faculty teaching team evaluates the merit of the design, as well as the preliminary analysis, before the teams can begin constructing their launcher.

The students are evaluated on their oral proposal, their multi-media final report, and their demonstration of the functionality of the design via an accuracy measurement, as well as creativity. In the past, students have designed spring-loaded launchers, compressed gas launchers, catapults, pendulums, and other similar devices as the foundation for their design concept.

Texas A&M University –Kingsville (TAMUK)

The T-shirt logo design is a non-technical way of introducing students to the engineering design methodology. Students like it because they get to actually wear a T-shirt. The T-shirt has the best logo design that represents the integrated curriculum they are participating in. It gives a sense of belonging. The weather balloon and rocket powered car are excellent ways of illustrating the integration of math, science and engineering. These projects also require students to build a prototype. The students enjoy the hands-on approach and have a lot of fun.

All projects emphasize English and oral communication skills with a standard report format. This is particularly good because juniors and seniors often do not know how to write adequate design reports. With these first-year projects, students are introduced to report writing early on in their education. Students practice teamwork with these projects and are involved in a healthy competition amongst themselves.

T-shirt Logo Design This is the first design project given to students in the First Year Integrated Engineering Curriculum at Texas A&M University-Kingsville. It provides a simple way for first year students to apply and learn the engineering design methodology (described in *Engineering Design and Problem Solving module of the Engineer's Toolkit: A First Course in Engineering*). Students are given the charge of designing a logo to disseminate the First Year Integrated Engineering Curriculum. In the past two years, the best logo has been sent off for printing on T-shirts given to the students and faculty and staff in the program.

Weather Balloon Design This is an interdisciplinary design project given to second semester students in the First Year Integrated Engineering Curriculum. The project clearly allows students to see the application of forces, velocity, acceleration, derivatives, numerical integration, and ideal gas law. It also uses Maple to show students its applicability in generating solutions to complex differential equations. The design methodology emphasized is the one described in *Engineering Design and Problem Solving module of the Engineer's Toolkit: A First Course in Engineering.* Students are given the charge of designing and building a prototype of a weather balloon that carries CO2 measuring equipment to an altitude of 5 km above sea level.

Rocket Powered Vehicle An interdisciplinary design project given to second semester students in the First Year Integrated Engineering Curriculum. The project allows students to see the application of forces, acceleration, derivatives, numerical integration, and transformation of stored chemical energy into kinetic energy via a chemical reaction (rocket). Maple is used so that students can generate numerical solutions to a differential equation governing the motion of the rocket-powered car. The design methodology emphasized is the one described in *Engineering Design and Problem Solving module of the Engineer's Toolkit: A First Course in Engineering.* Students are given a model rocket engine with all its specifications and given the charge of designing and building a prototype of a rocket powered vehicle that should travel up 9 ft on a 20 degree ramp.

University of Alabama (UA)

One of the primary goals of the UA design projects is to give students a taste of what it's like to be a practicing engineer. Students are assigned three design projects per semester, each project representing a different discipline of engineering. Students write a report and give a presentation for each project. Students are graded on how well they follow the design process.

Power Distribution System Design Students locate transformers and power lines for a typical subdivision using information from the local power company (typical household energy demands and transformer capacities, for example). This is a great first project because it uses simple technical concepts (entering students have a wide variety of math and science knowledge) and beautifully illustrates the design process. Students list constraints, develop design criteria, generate several alternate designs, and select the best design alternate. When selecting the best design, students must compare design alternates against criteria with numeric data (e.g. cost) and criteria without numeric data (e.g. safety and ease of maintenance). At the end of the project, an engineer from the local power company presents his or her design (which generates an avalanche of "How did you…" and "Why did you…" questions from the students).

CNG Tank Design for Personal Vehicle Students design a cylindrical steel tank to hold compressed natural gas to power one of their teammates' cars. The tank must fit in the trunk of the car and hold enough CNG to power the car for 150 miles. This is a good second project because it exercises basic technical skills and links with a current Chemistry topic. Students calculate the required tank size using the ideal gas law, demonstrate the tank will fit in the trunk using orthographic sketches, and design the tank using trial and error with a spreadsheet. The design calculations require many unit conversions, a weakness of most engineering students.

Stream Pollution Remediation Students develop a mathematical model for the concentration of a pollutant (phenol) in a small stream next to three industrial plants. They then use their models to develop a proposal to reduce the pollution to acceptable levels. The final presentation is a mock public hearing with four engineers: an engineer from each of the three industrial plants and a fourth engineer representing the state environmental agency. After briefly presenting their plans to reduce stream pollution, the "engineers" challenge each other's plans and defend their own plan.

Frequently Asked Questions about Freshman Design Projects

Engineering faculty are usually impressed by the quality of the freshman design projects and frequently ask questions about the projects. Some of the more common and interesting questions are presented below. Where possible, the answers represent a synthesis of the individual answers from each author.

What is the purpose of the design projects?
Simply put: design projects allow students to emulate practicing engineers. First-year projects have several

simultaneous educational purposes, (see Section IV of this paper for more discussion on the educational goals of the projects). The projects provide opportunities for students to:

- see both the constraints and limitations as well as the chance for creativity in the engineering design process,
- work on and develop strategies for attacking problems where there are multiple satisfactory answers,
- work on problems where answers are developed over days and weeks instead of minutes,
- practice working in teams over several weeks,
- understand connections and relevance among science, engineering and mathematics and their future career goals.

How do you evaluate the projects?

Faculty evaluate projects on the basis of status meetings with students, written progress reports, oral progress reports, final oral reports, final written reports or poster session presentations. Individual progress reports can be used to help faculty understand the individual contributions of different team members. Faculty either assign percentage scores to reports or indicate competencies demonstrated in the various activities. Activities include: completion of the design, meeting the design goals, staying within the design constraints, completion of an analytic or computer model, comparison of experimental and theoretical results, analysis of results, written presentation, and oral presentation of process and results.

How much faculty time does it require to facilitate and manage student projects?

It depends. At RHIT, faculty typically commit 4-8 hours per week depending on the number of students, the scope of the projects, and their own individual interest. The amount of time required at the end of the term to grade final written and oral reports is usually substantial. At ASU, faculty spend approximately one third the time of a senior design project, or perhaps the same time as an extended undergraduate laboratory (in other words, not an excessive amount). At UA, faculty must plan the projects carefully so that students can successfully complete the projects in four weeks. Faculty spend between 20 and 40 hours preparing a project and approximately 10 hours evaluating a project (oral and written reports). Minimal faculty time is required during a project as faculty intentionally provide the students scant guidance once the project has started.

How do you develop the ideas for your projects?

The current physics and calculus topics determine the general area and scope of any project. Faculty talk with other faculty at their own institution and others. They exchange project ideas at conferences. They search the literature and the Web for ideas. The exact idea for the project springs forth from that place where all creative ideas emerge.

How do you choose the teams?

At RHIT, faculty assign teams in the Fall Quarter since students don't know each other. Residence proximity, gender, and academic heterogeneity are factors which are considered. Typically, faculty assign at least two women on teams of four in recognition of the difference in communication styles.

At ASU, the teams are chosen by random selection at the start of the first semester. Teams are reformed after the conclusion of each design project. In the reforming process, we seek input from the students, requesting information about work schedule, residence location, and people with whom they would enjoy working. We combine this information with standard strategies about achieving team diversity to assemble the teams.

At UA, faculty assign teams twice each semester. For the first set of teams, shy students (based on the Meyers-Briggs Personality Inventory) are grouped together. This technique accelerates the rate at which these students learn to participate in the group decision-making process. Throughout the school year, teams are formed with a mix of academic abilities (based on SAT scores initially and then course grades) for fairness.

What do you do with students who don't participate?

At RHIT, in cases where the lack of participation by one or more students on a team can be documented, then the grade assigned to these students is substantially lower than the other members of the team. If faculty recognize problems earlier in the term, possible penalties are clarified for every member of the team and then students make their own decisions about their degrees of participation.

At ASU, we ask the students to carry out a self-assessment. They have N dollars to divide among themselves, based on participation in the project. Those students who receive less than N/4 receive a lower grade.

At UA, one method of encouraging all team members to participate is to have students give their final presentation in pairs. Students are told ahead of time that they will each give _ of the presentation and that the first presenter will be decided by a coin flip immediately before the presentation. The evaluators can direct questions to either student at the end of the presentation.

What happens to a team that does not complete a design project successfully?

All of the teams always have a constructed device at the end of the project period, but not all work with precision, repeatability, accuracy, etc. (Some bungee drop systems let the egg to slam into the ground, others stop the egg 5 meters above the ground). The students are graded on the design process, their analysis, and their ability to interpret the results in view of their predictions.

Are the logistics of carrying out a project in the class difficult?

Not particularly - it just requires some organizational skills and an ability to set and carry out a schedule.

Are the projects expensive to carry out?

Not particularly - finding sources of low cost or reusable materials and parts can be a daunting task at times, but the students, who have very limited funds in general, can be very resourceful and are often the best sources for items for the projects.

Conclusion

Developing and implementing a successful freshman design project is much different than preparing and delivering a good lecture. For one thing, it's usually more work. So why bother? Anyone who has watched students grab hold of a project and immerse themselves in it knows the answer. Skeptics might ask, "Do students learn any math, science or engineering in design projects or are freshman design projects "candy" with which we bribe students to stay in engineering?" YES!

Students usually rate design projects as their favorite part of the freshman curriculum. They also say design projects are very time consuming, but they elect to commit substantial time to these projects. Many features of design projects entice students to invest time. Design projects encourage students to be creative, to be self-directed, to work together with other students and to be professional. For example, students usually don professional attire (suits) for their end-of-project presentations. Students are drawn to design projects because they get to act like real engineers!

A skillfully designed project assignment grabs students' interest but also develops their professional skills, broadens their perspective of engineering, and leads them to learn technical material. Multi-faceted learning is one of the beautiful aspects of design projects. It is difficult, however, to keep track of all the possible types of learning when designing the project assignment. One method, which can give the project designer more control over the types of learning on a project, is to write down a set of learning objectives for the project and evaluate student performance on the basis of these objectives.

The educational objectives of each project described in this paper are listed in the project's description on the web site. A synthesis of the objectives for all projects is given below. Students working on engineering design projects:

1. get an early hands-on engineering experience
2. improve teamwork skills
3. practice written and oral communication
4. learn how to set up and solve open-ended problems
5. apply math, science and/or engineering principles to solve practical problems
6. see how math, science, and engineering subjects integrate when designing
7. can select a project which closely matches their interests and establish closer connections to a discipline of their choice

Of the goals above, only Goal 5 is aimed at learning technical material (the primary goal of most mathematics, science and engineering courses). Other goals concentrate on either developing skills (2, 3 & 4) or providing experiences (1, 5 & 6).

The first goal is a carrot to encourage students to stick it out through the math, science and engineering science courses until they reach the discipline-specific courses, which (hopefully) will teach them to design. Goals 2 through 4 develop skills employers want but find lacking in many of our graduates. Goal 6 strives to let students see the "forest" of engineering practice before they get immersed in the "trees" of topic-segregated engineering courses. And finally, Goal 7 (which applies to projects that allow students a choice of topics) helps students select an engineering major by allowing students to explore in some depth a topic of interest.

The FC schools collect qualitative assessment data on design projects through student journals. The journal entries help professors adjust the workload, clarify project deliverables and tune the level of guidance.

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