Integrating Engineering Design Projects and Economic Case Studies in a First-Year Course

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Abstract

The paper describes the set of engineering design projects and economic case studies used in our first-year course, "The Fundamentals of Engineering and Computer Science." The organization and goals of the course, and the criteria for selection of both short- and long-term design projects, are presented. Projects/cases reviewed include a portable ramp for handicapped access, a system to monitor traffic on a pedestrian bridge, a Newcomen steam engine, a computerized weather station, repair of a sinking warehouse, mechanization of agricultural processes in Third World countries, and cost/benefit analysis of alternative fuel use. Over the course of the year student work generally exhibits significantly increased understanding of the elements of open-ended problem solving and increased creativity in the engineering design process. Most students find the course work to be interesting and relevant but very challenging, and there is some concern about continuity in the team-taught, modular curriculum.

Background

In the last five years, the Engineering and Computer Science Programs at Union College were extensively revised as part of a study financed by the General Electric Fund. One result is a first-year curriculum that includes a new common course, “The Fundamentals of Engineering and Computer Science.” The course is being offered for the third time in the 1998-99 academic year. The catalog description of the course is provided in Appendix A; the course (ABET 2000) objectives and performance measurements are detailed in Appendices B and C.

Union College offers undergraduate degrees in Civil, Computer System, Electrical, and Mechanical Engineering. Material from each of these disciplines is incorporated in the first-year course. The course includes basic lecture material with extensive handouts, reading assignments (from texts listed in Appendix D), economic case studies, and laboratory exercises that prepare students for the culminating design project.

Course Organization and Administration

The course is a one-year, three-term sequence taken by all majors in engineering (civil, computer systems, electrical, mechanical, and undecided), computer science, and industrial economics. The course schedule is the standard four hours of classroom meetings and one three-hour laboratory each week. These time periods are used for lecture, studio, and laboratory time as appropriate for the course modules. At the beginning of the year the modules are two to four weeks long and include short-term design projects and case studies. Later in the year the course module is eight weeks long and includes a long-term design project.

Each offering of the freshman course has involved a multidisciplinary team of faculty [acknowledged at the end of the paper] who administer, teach, evaluate, and modify it. Faculty from computer science and economics work with faculty from the traditional engineering disciplines in the design of the curriculum. A key course objective is to introduce students to open-ended problem solving and the design process. Each of the 3-week modules (e.g., mechanics, small engines/power conversion, instrumentation/digital logic) is aimed at preparing students to complete a group design project at the end of the course.

Each time that the course sequence has been offered, a number of changes have been made. This process of modifying the course is directed at improving the connections between topics and integrating the design project material into the whole course. The faculty team uses a real-time process to monitor course outcomes and generate feedback to the team. The engineering design, communications, and teamwork skills that the students are developing are also critical to the successful administration of the course by the faculty team. The selection of design projects is a complex decision that can divert the faculty team from their on-going task of course coordination and improvement.

Course Material Selection

The following criteria are used to select laboratory exercises, case studies, and design projects for the course. Ideally, the projects should stimulate the students' disciplinary interests, provide a common background experience as a prerequisite for upper-level courses, and introduce students to critical aspects of the design process (e.g., tradeoffs among design objectives and sensitivity to design parameters) and the socioeconomic context in which design decisions are made. From an administrative perspective, the projects should offer enough design variations to accommodate multiple teams of students and to facilitate modification for subsequent course offerings (at both the freshman and upper levels).

Recurring Short-term Design Projects and Case Studies within Course Modules

Project 1. The Newspaper Frame

The first class meeting includes a construction competition using newspaper and duct tape. The students work in groups to design and build a frame with maximum load-bearing capacity. Among the constraints imposed are that the frame surround a balloon which is popped and removed before test loads (cans of soda) are placed on the frame. A follow-on assignment is a report by each member that (1) compares the design process used by the team with the design process that is described in the textbook [Ferguson, 1993] and (2) evaluates the effectiveness of the group's design given the outcome of the testing of all of the frames. This introductory exercise is based on material from the workshop, Integrating Design into the Engineering Curriculum, presented in Dallas by Dr. Charles M. Lovas. The students observe that the frame designs are all different. In follow-up discussions the instructors remind students that future design projects will require choices among alternatives. Those choices may be based on their engineering studies but some will be made with incomplete information. Variations on the space frame have been used in other years. For example, the project may be to design the tallest tower (capable of bearing a minimal load) or the strongest bridge. It is easy to modify the project so that old designs that are on display can not be duplicated in the next year.

Project 2. The Sinking Warehouse

The first course module on mechanics is based on the case of a small warehouse built in a rural setting and used to store rolls of paper for printing companies. Because the structure had been built over a former municipal waste landfill, the warehouse foundation sank and shifted as the waste material compressed. Two consulting engineers make a presentation to the class about their investigation into the warehouse structure problem. One speaker addresses the warehouse beam and post design and the other talks about the soil and foundation under the warehouse and the potential danger from high concentrations of methane gas. Their presentation provides an example of teamwork in an engineering task. The speakers present four possible repair approaches and their estimated costs over the useful life of the structure.

The structural repairs range from (i) replacement of the misaligned portions of the slab and exterior walls, removal of landfill materials, and installation of a gas venting system to (iv) a "bandaid" approach of recurrent shimming and anchoring of wall panels and monitoring of methane gas infiltration. Considering the durability, cost, and safety and environmental consequences of the alternative repairs, students are asked to determine how the structural problem with the warehouse should be addressed. This requires present value calculations of cost (using spreadsheet software), analysis of the sensitivity of the cost outcomes to key parameters (inflation rate, interest rate, and structure life), and consideration of the tradeoffs among cost, durability, and other criteria of evaluation. Students see that the decision depends crucially not only on the cost parameters but also on the company's willingness to incur higher (projected) costs in order to achieve higher levels of safety and durability of repair. Although the students are encouraged to work through the analysis in teams, a written report with the final recommendation and full documentation is required of each student.

Paralleling the case analysis is a laboratory exercise that involves measurement of the load-carrying capacity of a soil sample with varying degrees of compaction. Included in this lab is a demonstration of how the load-carrying capacity is degraded by a sponge buried below the soil surface, analogous to the municipal solid waste beneath the warehouse.

In addition to showcasing a team of practicing engineers, this module introduces students to the concepts of forces and vectors, the problem of life-cycle costs and cost tradeoffs in design, the issue of liability in building siting and construction, and experimental techniques for data acquisition, display, and analysis

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Project 3. Small Engine Redesign and Use of Alternative Fuels

A small engine module includes reverse engineering, internal combustion cycles, power measurements, and emissions testing.. In the initial laboratory exercise, the students are asked to disassemble a small internal combustion engine, measure and draw the piston, and reassemble the engine. Emphasis is on the geometry of the piston, the cylinder and the connecting rod. The students can compare the piston to the text drawing of a Ford model A piston. They use a spreadsheet to calculate and plot the cylinder volume versus the crank angle. The plot of volume versus angle is also revisited in a later software design exercise on interpolation. The students are shown how the horsepower of the engine can be modified by altering the bore (and the piston size) and by installing different jets on the carburetor. The engine's speed governor is used as an example of feedback. The principle of feedback is found in other parts of the course as the students see it used in the iterative design process and in digital circuits for flip-flop memory elements.

In a case study, the students must evaluate the desirability of mechanizing some agricultural production processes (e.g., pumping irrigation water) in Third World countries by introducing small internal combustion engines as a substitute for labor. Given the cost, power output, durability, and fuel efficiency of various engine designs, students must evaluate the alternative approaches, make a recommendation, and consider the sensitivity of the decision to the price of gasoline, local labor costs, and projected engine life. For example, students initially compute the cost per horsepower-hour of utilizing alternative small engine configurations and compare those to the cost of human labor, at "base case" values of $2.00/gallon gasoline, $.45/hour wage, and an engine life of 600 hours. Then spreadsheet programming is used to re-evaluate the costs at as the key cost parameters vary. It becomes clear to the students that the appropriate technology application does depend on the price and availability of local resources.

A second laboratory exercise is a bench test of the engine to measure its power output and emissions when it is fueled (1) by regular gasoline and (2) by gasoline reformulated with oxygenates like ethanol. This demonstration is the backdrop for a case study of the U.S. Environmental Protection Agency's proposed requirement of oxygenated fuel use by automobiles in metropolitan areas. Students must evaluate the benefits (reduced morbidity) and costs (including engine redesign) of alternative fuel mixtures, make a policy recommendation, and evaluate the sensitivity of that recommendation to uncertain damage function parameters and the price of ethanol. Data is provided (based, in part, on the laboratory measurements) on the volume of emissions of unburned hydrocarbons (and resulting ozone concentration) for three different ethanol-gasoline fuel blends (0%-100%, 20%-80%, and 50%-50%). The costs of ethanol use and the estimated reduction in health-related costs of exposure to atmospheric ozone are then computed and compared (using spreadsheet software) for the various fuel blends. The case illustrates the parallels between engineering design and social policy design and the socioeconomic context in which engineering design necessarily occurs.

Term-Long Design Projects

Project 4. The Wheelchair Ramp

This is an eight-week project to design, model, and document a wheelchair ramp for handicapped access. The specifications require that the designers be aware of the ADA guidelines which are available on the Web. The ramp is intended for use at a residential site during a convalescent period. Thus, the ramp must be modular and portable so that it can be built in the shop, moved to the site for assembly, later removed from the site, and stored for future use. A specific campus building is selected as the site for the ramp. The student design teams are asked to produce (1) the design specifications, (2) a parts list (including cost), and (3) the instructions for ramp assembly and disassembly. Tradeoffs in the design process among cost, durability, portability, and aesthetics must be made explicit. After the designs are presented, one is selected and ultimately constructed by a faculty/student team.

Project 5. The Whipple Bridge Monitor

This is a year-end eight-week design project. Students investigate the remote monitoring of traffic on a campus footbridge. An outside speaker presents the history of the design of the 1847 cast iron bridge by Squire Whipple and the student project which moved the bridge to our campus. The task is to develop a system to record pedestrian traffic and environmental data at the footbridge and to transmit the data via a Morse code RF transmitter to a receiving station across the campus. The system is powered by a battery and a solar panel and uses the digital counter developed in a previous digital circuits laboratory. The use of the digital counter in two parts of the course provides important linkage for the students and economizes on course development time for the faculty.

Project 6. The Weather Station

This is a year-end eight-week design project. The goal is to develop a weather station that collects data for a computer database and provides weather data for a Web page display. In the design of the weather station, the students incorporate temperature sensors and the digital counter studied in an earlier digital hardware module. Because the weather station consists of a modular set of sensors, it can be augmented or upgraded as the project is reused. In addition to the temperature sensor, commercial sensors for humidity, and rainfall were purchased. Students designed, fabricated, and calibrated a wind speed sensor was fabricated. Currently, the students have formed a club that is looking after the weather station and continues to develop it. Because there are a number of commercially available weather stations and components, the students must continually assess the relative merits of buying or building the components.

Project 7. The Newcomen Engine

The Newcomen engine is an atmospheric pressure steam engine that was a precursor to the James Watt design. The design is well-documented in books and is described on the Web. Early designs used manually activated valves, and so a working model is simple enough to be constructed in an eight-week period. The design challenges center on the selection of materials and components. Many are available at the local hardware store, but the piston and cylinder are designed and sent out to subcontractors (e.g., our machine shop). The students have observed the piston and cylinder in the internal combustion engine and now must adapt the design to the steam engine. The final demonstration of the working model provides an impressive student design group presentation.

Course Assessment

Student response has generally been favorable to the set of design projects and related economic case studies developed for the first-year course in engineering science. Because students are required to apply fundamental concepts and analytical/experimental techniques from the course modules and to consider the social and economic context in which engineering decisions are made, the work is very challenging to all and quite daunting to some. The focus on development of open-ended problem-solving, team-building, and communication skills is appreciated by most students. Though the projects clearly stimulate student interest and creativity, some perceive a lack of continuity in the modular curriculum. The most challenging pedagogical task in a course of this type is reinforcement by the faculty team of the conceptual, analytical, and methodological linkages among the projects and modules.

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Appendix A: Catalog Description

Fundamentals of Engineering and Computer Science Fall, Winter, Spring A three-term, three-course-equivalent, integrated instructional module required of all engineering and computer science students in the first year with the following objectives: to define engineering and the engineering sub-disciplines; to provide instruction in oral, written, graphical and computer communications skills appropriate to engineering; to provide an introduction to engineering design through case studies and comprehensive design projects; to develop team-building skills in conjunction with both engineering and non-engineering students; to introduce the concepts of professional ethics, environmental consequences, economic considerations, and public safety and welfare as engineering design factors; and to provide introductory basic instruction in traditional engineering science areas such as engineering mechanics, computer science, engineering materials, thermodynamics and electrical science. The year-long sequence involves lectures and recitations as well as laboratory instruction, team projects and external speakers.

Appendix B: ABET Objectives

With respect to ABET Engineering Criteria 2000, Program Outcomes and Assessment, this course addresses the following outcomes:

- an ability to apply knowledge of mathematics, science and engineering;
- an ability to design a system, component or process to meet desired needs;
- an ability to function on multi-disciplinary teams;
- an understanding of professional and ethical responsibility;
- an ability to communicate effectively;
- the broad education necessary to understand the impact of engineering solutions in a global/societal context;
- a knowledge of contemporary issues;
- an ability to use the techniques, skills and modern engineering tools necessary for engineering practice.

Appendix C: Performance Measurements

Student progress in achieving the desired objectives and outcomes for this course module are monitored and measured through use of some or all of the following:

- maintenance and submission of a laboratory notebook which contains the original data recorded during the laboratory sessions;

- periodic quizzes and regular examinations designed to demonstrate mastery of basic concepts, the ability to conceptualize and synthesize a formal problem statement and algebraic mathematical model from a verbal description of a physical situation, and the ability to solve elementary engineering problems;
- completion of an assigned project, requiring both a written report and an oral presentation, dealing with an open-ended problem that entails consideration of environmental impact, economic factors, and resource allocations;
- satisfactory completion of a comprehensive final examination designed, at least in part, to demonstrate the student's ability to solve specific, individual problems amenable to closed-form solution;
- organization and submission of a portfolio containing a comprehensive representation of the student's work in the course.

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