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Multidisciplinary Student Experiences in a Liberal Arts Engineering Program

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Abstract

A two-semester senior undergraduate design sequence has been developed for an engineering program in a liberal arts college. The courses provide a wide range of design experiences including: study of structured design methodologies, individual and team projects, prototype construction, communication of design results, incorporation of industrial design problems, and experience in a multidisciplinary design environment. The first semester course uses individual projects proposed by each student as a means of developing an understanding of structured engineering design methods. The wide variety of individual projects initiated by the students provided a broad spectrum of engineering design problems for the entire class to study. The experience gained through individual design projects enables students to effectively participate in multidisciplinary team projects. Multidisciplinary design team experience is achieved in the second semester of the sequence. Student engineers are teamed with industrial participants with engineering backgrounds different from that of the students. Results are described from the first offering of this sequence to fourteen students at Hope College from the 1996/97 academic year.

Introduction

Engineering design challenges educators with the problem of incorporation of a diverse range of experiences into the engineering design course. Common elements considered essential to the capstone design experience include: use of formal engineering design methods, experience working in teams, prototype construction, contact with industry, and development of communication skills[1]. Recently, the ability to function on multidisciplinary teams has been added to the outcomes expected from an engineering education[2]. This growing list of expectations for engineering design experiences occurs simultaneously with a demand not to increase the credit hour requirements for completion of the undergraduate degree. The multidisciplinary experience has been achieved in a liberal arts engineering program through the use of industrially-sponsored design projects which place student engineers on design teams with industrial participants representing engineering disciplines that are different from those of the students. This approach to multidisciplinary experience is similar to design programs pursued in larger university-based engineering programs[3,4]. A distinctive feature of the program described here is the use of a first semester course which develops the individual design skills.

First Semester Course: Introduction to Engineering Design

In the first semester "Introduction to Engineering Design" course, each students proposed his or her own project to carry out during the course of the semester. This project served as the focus for the study of design methods. The students were encourage to develop a project which suited their individual interests. Guidelines were given as to what constituted an appropriate project. The project must involve the actual building of a physical object. It must be possible to complete the project in approximately 10 weeks. The project must involve some degree of innovation or creative development. While it was acceptable to build a new version of something that already exists, the student's design must incorporate original work of some type. The goal of this requirement is to avoid the putting together of a kit. To reduce the possibility of a cut and try approach to design, students must also commit to developing an understanding of the physical principles involved in any device that they build. The projects submitted by each student were reviewed for approval by the instructor and shop director. For those student who do not want to propose their own design project, the annual ASME Student Design Contest Design Problem served as a default project.

Course Structure

The structure and schedule of the course are summarized in Table 1. The course was broken into segments each requiring approximately two weeks. The first segment was a shop skills course conducted by the shop director and the course instructor. This was followed by a study of techniques for development of design requirements. The next set of topics covered the engineering design process. This view of engineering design follows that described by Dieter[5]. As each phase of the engineering design process was studied, students completed that portion of their individual project. A three week period was then allotted for construction of working prototypes. The relatively short construction period, preceded by application of structured design methodologies, is similar to the design course structure advocated by Ullman[6]. The final three weeks were devoted to preparation of design documentation and final presentations.

Table 1: Structure of the Introduction to Design Course.

Weeks	Topics
1-2	Machine Shop Course
3-4	Developing Requirements
5-6	Conceptual Design
7-8	Preliminary Design
9	Detail Design
10-12	Construct Prototypes
13	Written Technical Report
14-15	Final Oral Presentations

The course met three hours per week. Lectures described basic aspects of the engineering design process and design methodologies. In addition, each student had a half-hour scheduled meeting with the instructor every week to discuss progress and problems on the individual project. The instructor's time devoted to these meetings was offset by class time given over to student presentations which did not require instructor preparation. The course did not have a textbook. However each student was expected to purchase his or her own materials to complete the individual design projects. A budget of $50 to $70 for materials was recommended. Each student was allocated one hour of consulting time with the shop director. This could be used for advice on design decisions or aspects of prototype construction. The total time commitment of the shop director was 80 hours over the course of the semester including the shop skills course.

The facilities available to the students consisted of a 1000 square foot design laboratory equipped with a selection of basic hand tools. Students were also given access to the Science Division Shop which has a vertical mill, lathe, bandsaw, and drill press. To complete their prototypes, a number of students used other off-campus facilities and equipment which was available to them through their engineering internships or acquaintances in the area.

Individual Project Results

The individual projects proposed and carried out by the students during the Fall 1996 semester are summarized in Table 2. The projects span a wide variety of topics, and each reflects the individual interests of the student. Three students chose the default project: an entry for the 1996/97 ASME student design contest. Each of these three developed his own entry.

Table 2: Summary of Individual Student Projects.

Student Project Title	Aspect of Design Illustrated	Disciplines
Fog Lamp Extension/Retraction Mechanism	Use of Simulation Software	ME, EE
Vibration Damper for a Tennis Racket	Role of Experimental Testing	ME, Physics
A Simple Pendulum Clock	Understanding of Previous Work	ME
NASA Reduced Gravity Student Competition	Definition of Requirements	ME, Bioengr.
Toy Vehicle Positioning System	Assembly of Subsystems	ME, EE
Tree Climbing Assist Device	Safety	ME
Bicycle Camera Rack	Importance of Benchmarking	ME, Materials
Device to Measure Force in a Simple Truss	Role of Manufacturing Tolerances	ME, EE
The Portable Ladder Treestand	Tradeoff of Performance vs. Cost	ME
A Fishing Reel	Utility of CAD Solid Modeling	ME
Removable Automotive Subwoofer Speaker	Importance of Analytical Models	ME, EE
ASME Contest Entry: "The Pendulum"	Multiple Design Solutions	ME
ASME Contest Entry: "The Chariot"	Multiple Design Solutions	ME
ASME Contest Entry "The Lifting Tower"	Multiple Design Solutions	ME

Throughout the semester each student gave presentations to the class describing the status of the design project. Other students were required to respond with constructive criticism of the work. This afforded opportunities for the entire class to develop practice in design review, and to observe the experiences of other students. A problem in teaching undergraduate design is the limited experience base of most students. In this case, the variety of student initiated individual projects made it possible to have a number of on-going case studies of different aspects of the design process. Through the in-class design reviews, each student could see a different view of how the design process evolves.

One of the aspects of the design process illustrated by each project is included in Table 2. For example, one project involved the design of a fog lamp extension/retraction mechanism. An important aspect of this project was the use of Working Model™ dynamic simulation software to model the operation of the mechanism. This project provided an example of the use of analytical tools to facilitate evaluation of potential design solutions. Another student designed a device to dampen the vibrations in a tennis racket. While the mechanical construction of the device was relatively simple, extensive testing with an accelerometer was required to develop the device and test its performance. This situation illustrated how experimental testing can both guide design and establish that a design fulfills performance expectations. The need to survey and understand previous work done was demonstrated through a project which intended to build a simple pendulum clock. Even a simple pendulum clock is a complicated mechanism which involves a number of subtle design details. To avoid unproductive duplication of effort, the approach used by previous designs must be understood. Another student wanted to build a small toy electric vehicle which could be turned off by an infrared position sensor. To complete the project, different subsystems such as the electric motor, braking system, and the infrared detector were developed and integrated. This project provided an example of development of a new device from the a selection of existing components. The students were encouraged to create projects which would be useful to them after the course was completed. Some of the projects proposed were rather unexpected. The best illustration of this is a project to build a device to assist in climbing trees. In this instance, questions of safety became a major issue in the design process. One student proposed to develop a bicycle carrier which would hold a camera bag in a convenient and safe manner. This project demonstrated the need for careful benchmarking before proceeding too far into product design. By thoroughly surveying existing products, the student established that there were no products on the market which met his particular combination of requirements. The critical nature of tolerances in some designs was seen in a project to measure force in a simple truss system. The original project proposed to develop a seven-member truss from identical truss components. Early in the project, it became evident that the machining tolerances which could be expected would not permit assembly from pre-fabricated components. The design was revised to reflect more realistic tolerances. All of the projects had to consider cost as an important issue, however in one case the tradeoff of cost and performance was particularly evident. A student proposed to build a portable ladder-like device to allow a hunter to perch above the eye level of wildlife. The device was to be strong, yet portable and light weight. A major design decision was the choice between steel or aluminum for the ladder components. Relative cost of the two materials was the overriding factor guiding this decision. Another student proposed to build a fishing reel. This project illustrated how computer-aided-drafting and solid modeling can be an essential part of the engineering design process. Many of the projects did not require extensive analysis, an exception was a project to build a removable subwoofer speaker for use in an automobile. The design relied upon a variety of analytical models to design the shape of the enclosure and to specify the various properties of the speaker itself. Purchase of the speaker represented a considerable and irreversible financial commitment on the part of the student. This situation emphasized the careful use of accurate mathematical models in design. Three students chose to develop designs for the 1996/97 ASME student design contest. The basic problem was to develop a method to move a golf ball and two table tennis balls from a platform into a box. Power sources were limited to one small DC motor and a 1.5 Volt battery. Each student worked independently on his own design. The result was three different approaches to this problem. The variety seen in these three designs clearly illustrated to the class that design problems can have multiple solutions.

The multidisciplinary nature of many engineering effort was also evident from the student design projects. While all of the students considered themselves to be mechanical engineers, more than half of the student-initiated projects involved issues from disciplines outside of mechanical engineering. To complete these projects, each student was required to use material outside of his or her primary discipline.

At the end of the "Introduction to Design Course," the students learned the use of design methods. They completed an engineering design project including construction of a working prototype, preparation of a technical report and an oral presentation. This experience provided the background needed to later participate in a multidisciplinary team working on an industrially sponsored project.

Benefits of Individual Design Projects

The use of individual projects lead to a variety of benefits for students learning the design process. Students were able to have responsibility for all stages of the design process, possibly for the only time in their carriers. The process of carrying out all of the design stages provided each student with an unique perspective on the nature of design that may not occur in team situations. The construction of a working prototype can be a difficult and frustrating experience, since each student defined the requirements of the project and invested his or her own money, motivation to persevere through completion was high. Many engineering students enjoy hands-on activities and often develop some type of informal design experience before beginning college. The undergraduate curriculum rarely exercises or develops these skills. The individual projects drew from these previous informal design experiences but added an introduction to the structured design techniques. Lastly, the ability to observe how each student carried out an individual design effort provided the instructor with valuable information for later assignment of students to design teams.

Second Semester Course: Capstone Engineering Design

The second semester of the course serves as the capstone engineering design experience. Students work in teams on projects developed in cooperation with industry. A multidisciplinary experience was achieved by grouping the students with industrial participants from other engineering disciplines. In one case the project was conducted with engineering faculty representing different engineering backgrounds.

The projects conducted in the Spring 1997 Engineering Design Course are summarized in Table 3. One of the projects involved the design of a compartment for the interior of an automobile. This project was sponsored by a local automotive parts supplier. The task included determination of the dimensions of the compartment, design of a mechanism to open and close the compartment door, and selection of an appropriate latch. In addition to performance issues, safety, aesthetics, and cost were important concerns. The four student team members were mechanical engineers. The industrial sponsor provided the necessary expertise in materials engineering, and manufacturing processes.

Table 3: Multidisciplinary Capstone Design Projects.

Design Project	Disciplines Represented on Design Team	
	Students	Industrial or Faculty Participants
Automobile Interior Compartment Design	Mechanical	Materials, Manufacturing
Modification of Auto Interior Electrical Wiring	Mechanical	Manufacturing, Electrical, Industrial Design
System to Measure Torque about Human Knee in Reduced Gravity	Mechanical	Biomechanical, Mechanical, Electrical

The second project achieved a multidisciplinary atmosphere by teaming four student mechanical engineers with industrial participants who were manufacturing engineers, electrical engineers, mechanical engineers and an industrial designer. The industrial sponsor was also an automotive components supplier. The objective of the project was to increase the number of electrical conductors passing through a particular interior component with minimum impact on cost, appearance, or performance of the component. This particular components was one of the major product lines of the sponsor, and is located in a region of the vehicle with high customer visibility. Consequently the team included the input of an industrial designer in addition to the engineers.

The third project was unique opportunity for a senior capstone design project and required the development of a multidisciplinary engineering design team. A group of Hope College students submitted a proposal to the 1997 NASA Reduced Gravity Student Flight Opportunities Program. The objective of the proposal was to measure the torque about the human knee joint under conditions of zero gravity. Such information is needed in developing procedures and devices may increase astronaut productivity in performing manual tasks in space. The proposal was accepted by NASA, and a team of six students carried out the project in the capstone design course. In this instance expertise in biomechanical and electrical engineering was provided by members of the Hope College engineering faculty.

These projects illustrate one method of including multidisciplinary design experiences into the undergraduate engineering curriculum in a liberal arts engineering program. Provided that student has sufficient familiarity with the design process, it is possible to use the capstone design experience to create multidisciplinary engineering teams. Students may represent one engineering discipline while industrial participants or faculty advisors represent other disciplines.

Conclusions

A two semester course sequence which combines individual student projects and industrially-sponsored team projects encompasses the major elements considered essential to an undergraduate design experience. In a liberal arts engineering program the multidisciplinary design experience is achieved by placing students with industrial participants in different engineering disciplines. Success in the multidisciplinary environment is achieved by establishing familiarity with the engineering design process through an individual project.

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Bibliography

1.) Dutson, A. J., Todd, R. H., S. P. Magleby, and C. D. Sorensen, "A Review of Literature on Teaching Engineering Design Through Project-Oriented Capstone Courses," *Journal of Engineering Education*, vol. 86, no. 1, 1997, pp. 17-28.

2.) Criteria for Accrediting Programs in Engineering in the United States, Engineering Accreditation Commission, 111 Market Place, Suite 1050, Baltimore, MD 21202-4012.

3.) Nichols, S. P., and W. T. Fowler, "The Mechanical Engineering Design Project Program: An Interdisciplinary Approach," Innovations in Engineering Design Education, ASME 1993, pp. 271-274.

4.) Benedict, A. H., A. T. Moser, R. Murphy, and R. T. Skrinde, "The Use of Interdisciplinary Teams in Successful Senior Engineering Design Projects", Innovations in Engineering Design Education, ASME 1993, pp. 249-251.

5.) Dieter, G. E., *Engineering Design*, McGraw-Hill, 2nd Edition, (1991).

6.) Ullman, D. G., *The Mechanical Design Process*, McGraw-Hill, (1992).

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