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Project-Based Introduction to Engineering - a University Core Course

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Abstract

This paper describes a first year engineering course that is taken by both engineering and non-engineering students. The project-based Introduction to Engineering course, EAS107P, fulfills a university core curriculum elective. Although engineering students take the course during their first year, students from other majors typically elect to take the course later in their curriculum.

The focus of EAS107P is to have students experience the engineering design and problem solving process in a multi-disciplinary, team-based setting. In addition to learning about design, students develop an interest in the engineering profession and build a foundation of skills for future work. An additional expectation for engineering students is that they gain a basic understanding of engineering foundation topics, such as basic circuits, mechanics, and programming concepts. Students` understanding of these topics is enhanced as they are revisited along the "*Multi-Disciplinary Engineering Foundation Spiral*". Non-engineering students benefit by learning how to apply the engineering methodology to solving problems and by developing a greater understanding of how engineering contributes to society.

Students develop skills in problem solving, teamwork and technical communication through a series of projects that showcase the primary engineering disciplines. Each project emphasizes a different step or aspect of the design process, including computer simulation, optimization, and construction of physical models. Typical projects include the design, construction and testing of bridges based on the West Point Bridge Design program; development of characteristic curves for fuel cell system; building and programming robots to maneuver through an obstacle course, and solid 3-D modeling of puzzle cubes. For each project, pre- and post-tests are used to evaluate the student's increased understanding of concepts.

This paper provides details of the project modules and summarizes our experiences to date using this active learning style. Pilot versions of this course have been offered since Fall 2002 with positive feedback.

Introduction

Like many universities offering engineering degree programs, the University of New Haven (UNH) offers a first year engineering course that introduces students to the engineering profession, focusing on the design process and developing problem solving skills. Unlike many universities, both engineering and non-engineering students take this course. Non-engineering majors choose Introduction to Engineering as an elective course to fulfill the scientific methodology requirement of the current Core Curriculum at UNH. Historically, large numbers of non-engineering students take this course. The diversity of students in a particular class varies from section to section. It is not uncommon for freshmen engineering students to be in a class with sophomore, junior or senior non-engineering majors.

Evolution of Project-Based Version of the Course

Prior to the introduction of EAS107P in the curriculum, the structure of any particular section of EAS107 was dependent on the faculty member teaching the course. Some instructors used a traditional lecture style approach to teach the course while others combined lectures with activities such as computer-based simulations and projects. Typically, all classes involved some type of design project at the end of the semester that included the application of the design process and problem solving techniques introduced in the course. However, the variations in sections prevented faculty teaching subsequent courses from building on a common set of concepts and design experiences. Some of these differences are summarized in Table 1. This resulted in curricular inefficiency.

For this reason, a group of faculty members during the Spring of 2002 began discussing changes to the Introduction to Engineering course. These discussions eventually led to the revision of the first two years in the engineering curriculum currently underway at UNH. The new curricular approach, referred to as the *Multi-Disciplinary Engineering Foundation Spiral*, is a four semester sequence of engineering courses, matched closely with the development of students' mathematical sophistication and analytical capabilities and integrated with coursework in the sciences[1]. The Introduction to Engineering course, EAS107P, is one of two courses taken first semester of the Freshman year that forms the base for the *Multi-Disciplinary Engineering Foundation Spiral*. Concepts introduced in EAS107P related to basic electrical circuits, statics and programming are revisited in subsequent Freshman and Sophomore level courses, with increasing analytical sophistication, to reinforce and extend the student's knowledge, skill and familiarity with these concepts.

In the traditional course, through a series of lectures, students learn various engineering topics including the design process. Often the course culminates in a single design project. In contrast, students in EAS107P develop skills in problem solving, teamwork and technical communication through a series of projects that showcase the primary engineering disciplines. It is through these projects that students develop their first layer of skills and engineering concepts. Lectures are simply used on an as needed basis to provide background information on projects or to supplement information related to a particular project. Projects emphasize different aspects of the design process, including computer simulation, optimization, technical communication, and construction of physical models. In addition to the difference in modality, EAS107P approaches engineering design from a multi-disciplinary perspective. Multi-disciplinary perspective in this context means an understanding of issues and an ability to apply simple concepts from other disciplines[1]. Thus, an effort was made to include projects in the course of a multi-disciplinary nature, such as robotics and fuel cells. Secondary objectives include developing an interest in the engineering professions; and building a foundation of skills for future engineering work.

As highlighted in Table 1, there are differences in the topical content as well as modality used in teaching EAS107P and the non-project-based versions of this course. Whereas there are different styles used in the traditional course depending on the faculty member teaching that particular section, all sections of EAS107P use a uniform curriculum. Consistency in EAS107P is an essential part of the spiral curriculum, since subsequent courses in the spiral depend on certain engineering topical content being introduced in this course. In addition, the development of certain professional skills including time management, computer and presentation skills begins in EAS107P.

As the first course in the *Multi-Disciplinary Engineering Foundation Spiral,* EAS107P does not require students to have any engineering pre-requisite. This allows any university student with the math pre-requisite to enroll. The general coverage of engineering topics makes the course suitable for engineering and non-engineering majors.

Table 1: Summary of Various Versions of EAS107

	Traditional Lecture-based Course	Hybrid Course: Lectures with Activities & Projects	Project-Based Course
Topics Covered	• Engineering Profession • Engineering Design • Representation of Technical Information • Estimation & Approximation • Dimensions • Mechanics • Energy • Electrical Theory • Statistics • Engineering Economics • Ethics	• Introduction to Engineering Disciplines • Computing skills including e-mail, world wide web, word processing, spreadsheets, presentation graphics and information access • Professional expectations & ethics • Technical presentations • Statistical analysis • Creative problem solving	• Engineering Profession • Engineering Design Process/Problem Solving • Professionalism & ethics • Structures (Bridges) • Technical Communication (Solid Modeling) • Mechanics and Programming (Robotics) • Electrical Circuits and Chemistry (Fuel Cells)
Text Used	*Engineering Fundamentals & Problem Solving*, Eide *et al.*	*Engineering Your Future*, Oakes *et al.*	*Engineering Your Future*, Oakes *et al.* and handouts
Modality	Lecture-based Course, Design project at end of semester.	Lecture Course with computer simulations & virtual projects. Design project at end of semester.	Project-based Course, Lectures as needed

Course and Project Organization

Pilot versions of the project-based Introduction to Engineering course have been offered starting in the 2002-2003 academic year. Twelve engineering students took the initial offering of

EAS107P during Fall 2002. During Spring 2003, a single section consisting of both engineering and non-engineering students took the project-based course. The experience gained through the initial offerings of this course was then used to improve the delivery of the course. Two pilot versions of EAS107P were run during Fall 2003, one consisting of 18 engineering students and the other with 6 engineering and 6 non-engineering students. The Spring 2004 section of EAS107P will have a mix of engineering and non-engineering majors.

The three credit-hour course met twice a week for 1-½ hours, with one hour before and after class open for students to work on their projects. In addition, students are required to meet outside of class time to work on projects. Feedback from student evaluations along with our own experience with scheduling project presentations and teaching the course elucidated the need for additional class time. Thus, future versions of EAS107P are scheduled to meet for two 2-hour periods per week. The pilot versions of EAS107P offered in Fall 2003 were identically structured, allowing for students to easily make-up missed classes. The professors teaching the course collaborated in preparing each week's class.

An active learning style was used to teach the course. Thus, student participation was an important element of the class. Individual class periods consisted of a brief lecture to introduce concepts, followed by hands-on activities, with time allowed to work on projects. The first three weeks of the course centered on discussions and in-class activities related to the engineering profession, the design process and teamwork, followed by the projects. Cooperative learning methods were also used. For instance, instead of a lengthy lecture on the different engineering professions, students were required to choose and research a field of engineering, including a description of the field, the needs of society served, job opportunities, and areas of specialization. In addition, students were required to interview a person in that specific profession. Students submitted a written report on their research and interview, along with a PowerPoint presentation to the class. In this way, students learned from each other about the engineering profession.

For the majority of in-class activities as well as projects in the course, students worked in teams. There are various approaches used for determining team membership including random selection, creating teams of equal capability, student selected and those based on compatible personalities using the results of psychological testing such as the Myers-Briggs test[2]. Taking into account the mix of students who typically take the Introduction to Engineering course, and keeping with the objective to develop team-building skills, team membership was determined in the following manner. All students took a Jung Topology Test, which is a modified Myers-Briggs personality test. In the section of EAS107P with all engineering students, teams consisted of students with a mix of personality types. In the section with a mix of engineering and non-engineering majors, teams were assembled in a similar manner, with the exception that at least one engineering student was in each group. For both sections, team size was three per group.

During Fall 2003, the course was structured around four projects: namely, bridges, solid modeling, robotics and fuel cells. These projects varied in length from 2 to 3 weeks. There were certain course objectives that were common to all projects. For instance, common to all projects was the development of conceptual, analytic and technical skills. Each project module began with an introduction that focused on concepts related to the subject matter, followed in a subsequent class by an explanation of the project challenge. The project assignment write-ups identified the concepts included along with the analytical and technical skills needed for that particular project. Another course objective was the development of communication skills, both written and oral. Thus for each project, students prepared group written project reports, along with preparing and presenting their results using POWERPOINT. The exception to this was Project 2 which was the only project done individually by students. All of the group projects had an individual component. Typically students researched and prepared a 2-3 page report on some topic related to the project. Periodically, students individually assessed team performance. These assessments helped to identify for the instructor potential problems in the groups. Outlined in the following sections are the details for each project module.

Project Module 1: Bridge Building

The primary objective of Project 1 is to introduce students to the iterative nature of the activity that occurs when optimizing a design. Students gain experience working with constraints and criteria, and how these must be satisfied and balanced during the optimization of a design. In addition, students are introduced to the use of computer simulation models to aid them in the design process.

In the first class of this module, students are introduced to concepts related to structural systems and trusses, such as internal and external forces, reactions, compression and tension. Because of the limited mathematical sophistication of the students who are taking EAS107P, students gain more of a qualitative understanding of how to resolve forces for a structural system such as a truss. To aid students in their understanding, the John Hopkins Virtual Lab module on bridge design is used[3]. Using this program, students apply loads to various types of trusses and determine how the placement and magnitude of the loads impacts the distribution of compression and tension throughout the truss as well as the resultant reaction forces.

During the next class period, the project is introduced which involves designing a bridge to meet specified criteria; namely cost and safety. Initially, students individually design a truss bridge using the West Point Bridge Design program, such as is shown in Figure 1. As a team, groups of students choose which of their designs to optimize, based on lowest cost for a structurally stable bridge. Using cost versus cross-section curves generated in Excel, students begin to develop a qualitative understanding of the optimization process. Each team then constructs a physical model of their optimized bridge design using spaghetti and glue (Figure 2). Bridges are tested to failure with bonus points given to the team with the strongest design for a given weight. Testing occurs as part of the PowerPoint design presentations (Figure 3). Typically, students have one class period to work with the West Point Bridge Design software and another class period for construction of the bridge. Students are expected to work outside of class with their teams to complete construction of the bridges. The final class period for this project module is devoted for oral design presentations and testing of the bridges.

Project Module 2: Solid Modeling

Project 2 focused on methods of technical communication, including hand sketching and 3-D modeling to convey designs graphically to a client. Students gained experience in generating isometric views of an object using Autodesk Inventor®. An additional objective is for students to

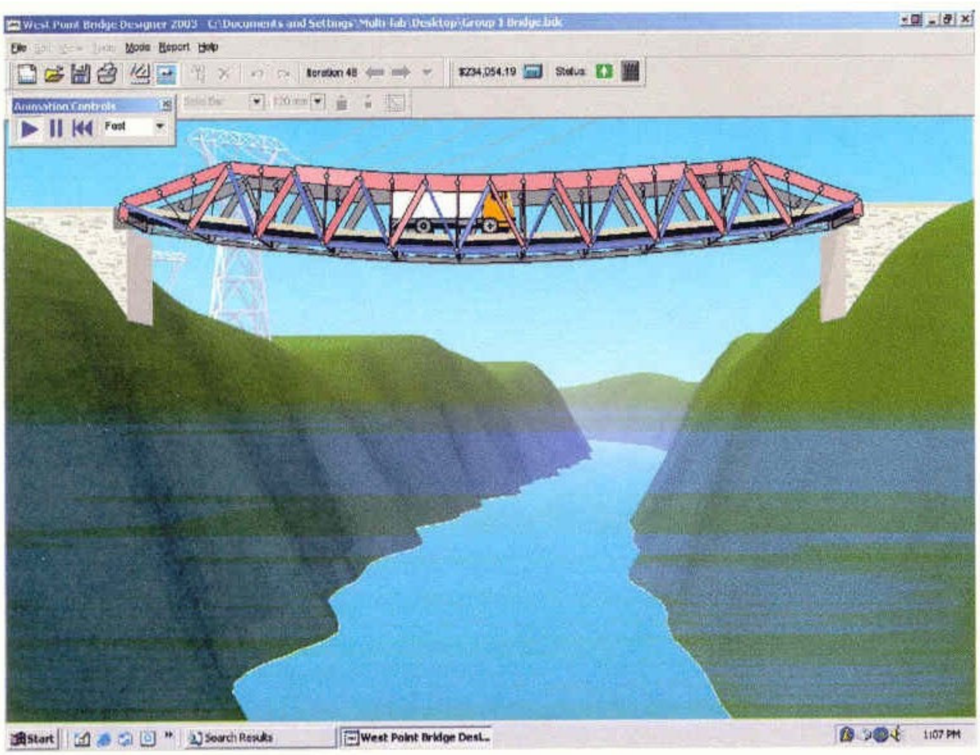

Figure 1: Bridge Simulation using West Point Bridge Design Program.

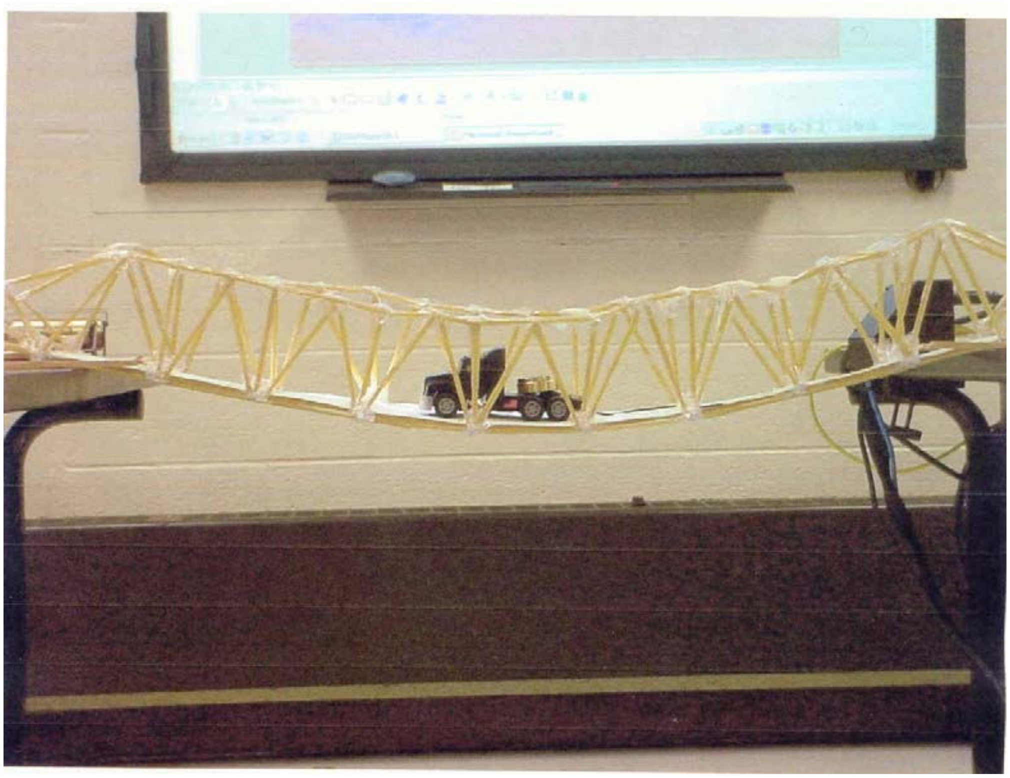

Figure 2: Bridge Constructed Using Optimized Design

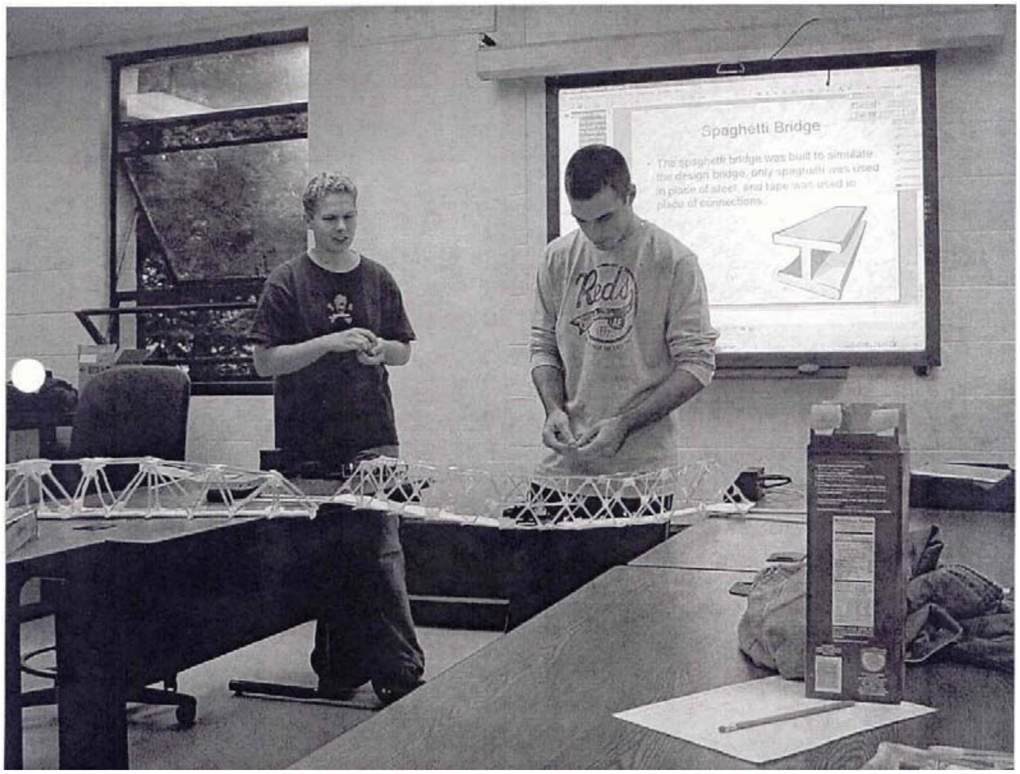

Figure 3: Testing of Bridge During Design Presentations.

apply the 5-step problem solving heuristic outlined in Fogler[4] to the design of a puzzle cube; namely, define, generate, decide, implement and evaluate. This is the only project in which students see the entire design process from beginning to end, including product realization. Unlike the other 3 projects, students worked individually during this module.

In the first class of this module, students are introduced to hand sketching techniques and gain practice through a series of exercises. After the initial exercises, students are instructed to design a puzzle cube consisting of 27 individual ¾ inch wood blocks that form 5 interlocking segments made up of 4 to 6 of the individual blocks. Note that this project is based on the Introduction to Engineering Design class introducing students to different aspects of design, used in Project Lead the Way[5]. Initially students hand sketch the design on isometric paper, and then physically build the puzzle to ensure that the design worked (Figure 4).

The next class period is an introduction to Autodesk® Inventor. During this class and the following class period, students use Inventor to generate 3-D views of individual segments, and then the fully assembled puzzle cube. Students are directed to test the puzzle cube design by having people assembly their cubes and record the time it takes for assembly to assess the puzzle "fun" level; for instance, whether the time was too long or too short. Students submit a project report explaining the steps used in the design of the puzzle cube. Individual oral presentations focus on reasons for a particular design.

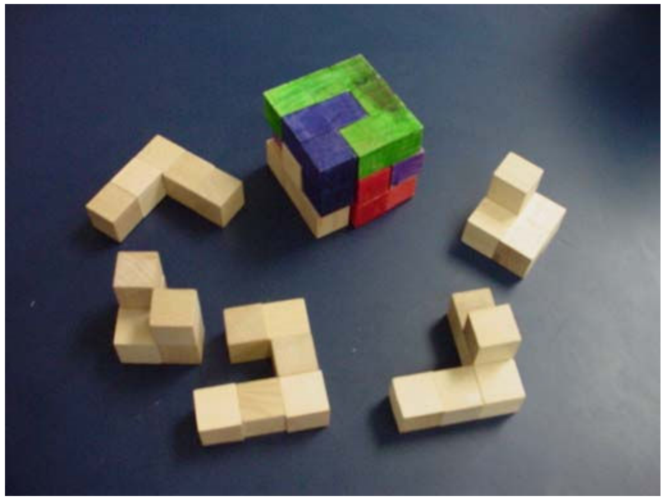

Figure 4: Puzzle Cube

Project Module 3: Mobile Robotics

An objective of Project 3 is to introduce students to the rapidly developing interdisciplinary field of robotics. Through this project, students are introduced to the basics of computer programming as they program their robots to perform a series of instructions, and to sensors, microcontrollers and basic mechanics.

The design challenge of Project 3 is to design a robot to be used in search and rescue missions where access is limited to small spaces. The design of the robot has to be as inexpensive as possible due to the likelihood of losing the robot during the mission, while still meeting the mission objectives. The ability of the robot to maneuver through space and around fallen debris is tested using a randomly assigned obstacle course. Student teams are instructed to build a robot using LEGO robotics kits and to program it using the ROBOLAB programming environment to autonomously navigate through a 20 by 3 foot obstacle course. Since cost is a design criterion, students determine a total cost for their robots using supplied LEGO parts price list.

Before students begin construction and programming of the robots, the initial class of this module focuses on components of mobile robots, beginning with mechanisms for making the robot move such as gears and motors. During the next few class periods, concepts related to speed and torque, gear ratios, motors, microcontrollers and sensors are discussed. Students are given time during these classes to begin construction of their robots (Figure 5).

Another two class periods focus on programming the robot using ROBOLAB. The programming environment used in ROBOLAB is based on LabVIEW. As such, students gain experience developing programming logic skills without focusing on syntax. Basic programming concepts such as conditions and control flow are discussed in class. A teaching assistant experienced with LabVIEW and programming assisted students both during class and designated work periods. Testing of the robots to maneuver through the randomly selected obstacle course is conducted as part of the design presentations.

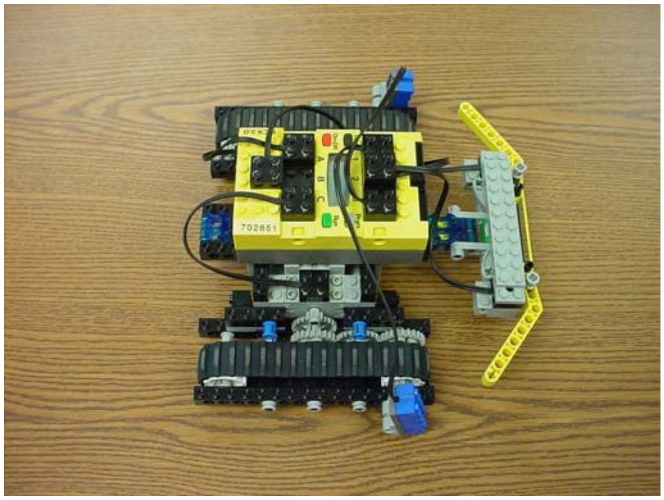

Figure 5: Robot Design

Through this project, students develop a qualitative understanding of gear ratios, motors and vehicle speed. In addition they begin to develop programming logic skills. Experience gained in this project allows them to determine motor speed, gear ratios, and resulting robotic speed and distance; minimum wheel/track torque levels for robotic motion; and total component cost.

Project Module 4: Fuel Cells

The primary objective of Project 4 is for students to explore the use of hydrogen technology using fuel cells. Students are introduced to the concept of sustainability in design and elements of basic electrical circuits, including parallel and series resistors.

In Project 4, students design a power supply system using a fuel cell system similar to the one used in class and illustrated in Figure 6 to power a device needed by an exploratory research team. This system consisted of a solar panel used to generate current for an electrolyser. The electrolyser unit is used to generate the hydrogen and oxygen needed for the fuel cell. Students randomly chose one of the following devices to power: laptop computer, GPS device, portable mass spectrometer, satellite cellular phone, short-wave radio, and LED lighting. To assist in the design of the power supply system, each team conducts a series of experiments using both an individual fuel cell kit (Figure 6) and a NP50 fuel cell stack system (Figure 7).

Before conducting any experiments, the first class of this module focuses on basic circuits. Concepts of power, energy, voltage and current introduced in the previous project on robotics are further discussed in this module, along with resistors. Kirchhoff's Voltage Law (KVL), Kirchhoff's Current Law (KCL) and Ohm's Law are presented. Students apply these conservation laws to the solution of simple resistive circuits in parallel and series.

The next class is a discussion of fuel cell technology. Students learn about how fuel cells work, specifically the oxidation-reduction reactions that occur, the various types of fuel cells, the components of fuel cells systems, along with the advantages and limitations of this technology.

During the next two classes, students conduct experiments and collect data. Two experiments

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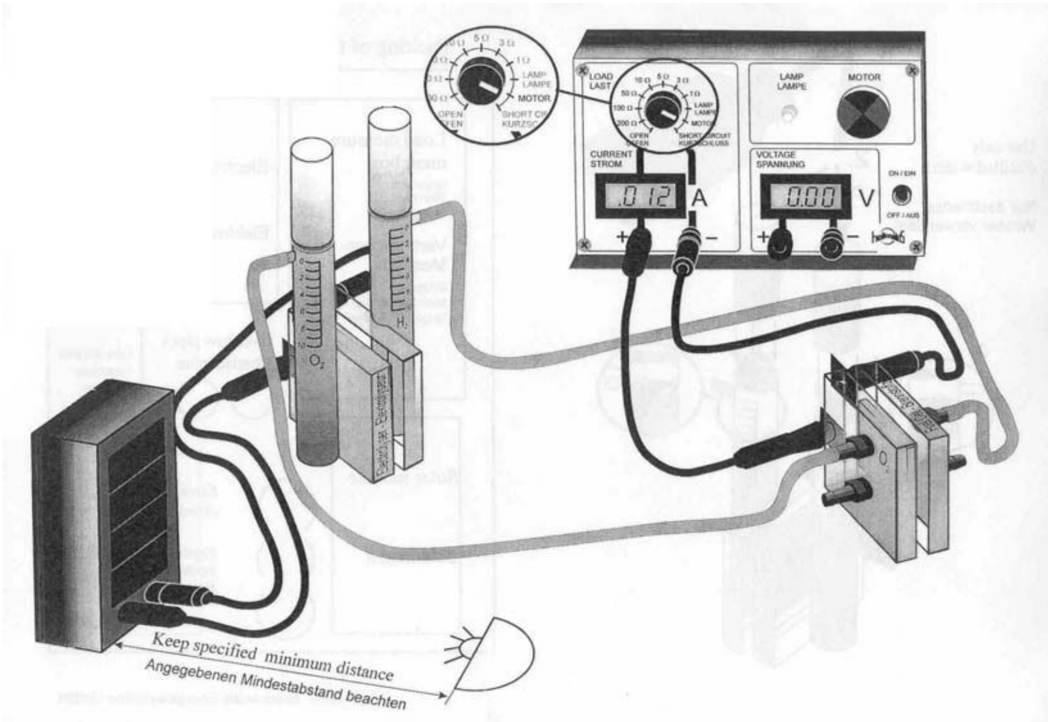

Figure 6: Electrolyser-Fuel Cell System

Figure 7: NP50 Fuel Cell Stack System

are performed using the individual fuel cell kits. These experiments focus on characteristics of the solar panel and electrolyser unit. One experiment involves determining the variation of solar panel output with angle to light source. In the other experiment, the efficiency of the electrolyser-fuel cell system is investigated. A single experiment is performed using the NP50 fuel cell stack system. In this experiment, the current is varied, and voltage, hydrogen flow and temperature measured. This data is then used to generate energy, current and voltage efficiency curves.

Unlike the other projects, Project 4 involves a number of computations. Students gain experience analyzing data using Excel. Because of the number of calculations needed to design the power supply system, as well as time constraints for completion of the project (last project of the semester), students are provided with detailed instructions, guiding them through data analysis and how to use the data to design the power supply system.

Class Evaluation – Outcome Assessment

Students were evaluated in class based on the four design projects, an individual design notebook/portfolio, homework, quizzes, and class preparedness and participation. It was expected that students attend all classes. Because the two pilot sections were identical in structure, this allowed for students to make-up classes if needed. Pre-tests and post-tests were used to assess whether student learning was enhanced using a project-based approach. The pre-tests do not count toward the students' grades, but the post-tests do. Although the intent was to give a pre-test for each of the four projects used, pre-tests were administered for only the bridge and robotics modules. In the pre-tests, concepts were first identified as key to the student's understanding of that subject matter, and were then focused on in the pre-test. As an example, a student's understanding of torque, speed, gear ratios and programming logic were identified as key concepts in the robotics module, and thus the pre-test contained questions related to these concepts. In all cases, students took post-tests for each module. Preliminary results show that the average improvement from pre-test to pos-test was 16% for the mobile robotics project and 21% for the bridge project. A summary of the results of these tests and this testing method is discussed in a paper by Daniels *et al.*[6].

Observations

Course evaluations and team assessments have provided us with valuable feedback regarding the course. Consistent with observations from non lecture-based courses[7], the project-based approach is appealing to students. A consistent comment by both engineering and non-engineering students in course evaluations is that the group projects and hands-on approach is what they liked most about the course. However, time management of groups specifically related to project deadlines was often cited as a concern.

When choosing core curriculum electives, many of the non-engineering students look to satisfy the core requirement with courses that are both enjoyable and easy. For those that elect to take the project-based EAS107P course, some withdraw during the first week once they understand the nature of the course. However, all of the non-engineering students who chose to stay did successfully complete the course. These students typically did as well academically as the engineers. This is particularly true of the upperclassmen who take the course, especially the Forensic Science students.

The dynamics of a mixed group of engineering and non-engineering students is worth noting. Initially, the non-engineering majors are fearful and concerned about getting involved and working with engineering students. These students tend to group with one another. This is one of the reasons why the teams consist of both engineering and non-engineering students, and are not simply chosen by the students themselves. As the students begin to work together, any concerns seem to disappear. Both the engineering and non-engineering students appear to benefit from this composition of the teams. The engineering students often help explain concepts and the calculations needed in some of the design projects to the non-engineering students. The non-engineering students who tend to be older often have better organizational skills which helps the freshman engineering students.

It is interesting to note that after the Fall 2003 pilots, non-engineering majors seem to have both heard about the course and are taking an interest in it. At the beginning of the Spring 2004 semester, some non-engineering majors enrolled in the project-based section of EAS107 rather than in other sections.

Experiences from the pilot versions of EAS107P seem to demonstrate that regardless of their majors students can have a fun and rewarding experience as long as the expectations and details of the project activities are clearly laid out. Based on student comments, this seems especially true for non-engineering students. Frustration for these students is minimized if they are given detailed instructions, even though they may not fully understand underlying concepts related to a project.

Conclusion

The project-based EAS107P course is an integral part of the *Multi-Disciplinary Engineering Foundation Spiral* curriculum at UNH. Students are exposed to the primary engineering fields through the variety of projects. The dynamics of this project-based course provides a valuable learning experience not only for engineering but non-engineering students.

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