

Smart Cars and Freshman Engineering

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Abstract

The engineering programs at Union College draw heavily upon its two-century old tradition in the liberal arts, believing engineering to be an appropriate part of a liberal education for an increasingly complex technological world. Founded in 1795, Union College has a long tradition of innovation in its science and engineering programs. It was among the first college to offer chemistry (1809), to create a bachelor's degree in science and mathematics (1822), to establish a degree program in engineering within a liberal arts context (1845), and to establish an Electrical Engineering department (1895).

The introductory engineering course described in this paper was designed to help entering freshman engineering students make the transition to college level work, and to offer liberal arts students an exposure to engineering that would help fill their breadth requirement. The theme chosen to accomplish these goals is "Smart Cars." The students are introduced to the engineering areas in which they can major at Union College (mechanical, electrical, and computer) in three ways. First, in two lecture hours per week, the students study traditional analytical areas such as unit systems, energy conversion, electric circuits, computers, and control systems. Second, in one three-hour design studio each week, the students carry out hands-on design exercises. The basic principles of design are taught, the role of ethics is introduced, and the students form competitive teams that build devices that utilize course principles. Following the "Smart Cars" theme, a head-to-head end-of-term team competition involves building a powered and controlled model vehicle. Phases of the design and construction process (such as choosing gear ratios) are tied to lecture topics. The third part of the course takes advantage of Union College's location in a high tech geographical area. External lecturers are invited to make presentations on leading edge technologies consistent with Union's Converging Technologies initiative (nanotechnology, bioengineering, mechatronics, and pervasive computing). These lectures are intended to motivate and excite interest in modern engineering and technology rather than convey testable material. The integration of these elements - basic principles for several disciplines, teaming, ethics, hands-on design experience, and inclusion of non-engineering majors—are all consistent with ABET Criteria 2000 for undergraduate engineering programs.

Introduction

This paper discusses the evolving development of an "Introduction to Engineering and Mechatronics" course given to first term students at Union College, Schenectady, New York. The main aspect of this course is its organization into a three-part format – small group lecture sessions, team design projects, and presentations of leading edge technologies by working

engineers - around a unified theme: “Smart Cars.”

In this paper we will describe: 1) the problem definition for the course in the context of Union College and its educational goals; 2) the course’s design requirements; 3) some alternative concepts for meeting those requirements, and the concept selected; 4) the detailed design of the course; 5) a learning outcomes assessment, and 6) a discussion of challenges for the future.

A useful way of categorizing typical introduction to engineering courses has been presented by Sheppard and Jenison.¹ One dimension contrasts teaching students as individuals versus grouping them in teams. Another dimension contrasts content (such as the traditional engineering content of kinetics and dynamics, energy, electrical circuits, information and so forth) versus process (in particular, the process of design). On this map, the Union College Introduction to Engineering and Mechatronics course combines the teaching of content on an individual basis with the teaching of process on a team basis. Students are grouped in sections of about 20 under a single instructor. The instructor teaches them analysis in two one-hour sessions a week in the traditional lecture-discussion mode. The same instructor also teaches the same students in a three-hour design studio once a week, in which the students form teams, typically composed of three students, to carry out a design project leading to a term-end competition. In addition, once a week the students from all course sections meet together in a large lecture hall for one hour to hear a presentation by a practicing engineer about a leading edge technological field.

A main challenge that emerges from such a combination is balancing the first two elements. Ideally they would support each other, with analysis providing a rationale for evaluation of design choices. In practice, this synergism is difficult to achieve. Synergism also tends to be overshadowed by the fact that the students find the design studio a lot more enjoyable. (The reaction of a current senior when asked what she recalled about the course as taught three years ago is illuminating: “there was a design competition that was really fun, and (pause), oh, yeah, there was also an instructor who projected Power Points with lots of words on them onto a screen.”)

We have attempted to infect the lecture part of the course with some of the excitement and direction of the design studio by organizing it around a theme related to the design challenge: the theme of “**Smart Cars.**” The standard topics of engineering, from unit systems through energy, electrical circuits, and information and control are exemplified by systems found in the automobiles of today and tomorrow.

Problem Definition

The problem that Union College’s Introduction to Engineering and Mechatronics course is designed to solve is to help students make an early and informed decision about whether or not they find engineering an exciting career path and have both the interest and the capability to pursue an engineering degree. This problem is, in large part, set by the nature of Union College as an educational institution. Founded in 1795, it is a small, predominantly liberal arts college with a total enrollment of 2000. About 15% of these students are engineering majors. Within engineering, Union offers degrees in Mechanical Engineering, Electrical Engineering, and Computer Engineering, and is developing new interdisciplinary programs in Converging

Technologies that emphasize emerging areas such as nanotechnology, pervasive computing, mechatronics, and bioengineering.²

About 100 incoming freshmen annually express an initial interest in engineering. Many, however have only a vague idea of what engineering is and whether engineering is the right field for them (indeed, many list their majors as “engineering, undecided”). At Union students are asked within the first year to confirm an engineering choice, or switch to another program. Similarly (though much less often), liberal arts freshman transfer into engineering.

To help students make these decisions, an introduction to engineering course should give the student an idea of the essence of an engineering career. At the same time it should offer relevant challenges of a sufficiently demanding nature so as to give the student a taste of the problem solving methods and work habits needed to be a successful engineer. It should also provide guidance for improving those problem solving skills and the work ethic.

In addition to being an entry-level course for engineers, this course is also available to liberal arts students seeking to fulfill their general education requirement. While only about ten percent of the students in the course currently meet this description, their presence adds emphasis to the need for presenting engineering as a human endeavor as well as a profession.

Design Requirements

In addressing the problem outlined above, the following design requirements were identified. First and foremost, strengths already exhibited by the course should be retained. As discussed in earlier papers by Wilk, et al., and Hedrick,³ these include: a) using an interactive teaching style to monitor student progress and modify the pace based on frequent student feedback, b) introducing a problem solving strategy in the presentation of all course material, c) offering a weekly review session that students are encouraged to attend, d) providing the students with a textbook specifically designed to accompany this course, and e) instructing the students in the skills and advantages in forming student study groups. Additional design requirements include the following.

- Because Union College is on a trimester system, and the Introduction to Engineering and Mechatronics course must be presented to the students in the first trimester, the course must be ten weeks long.
- Because all students in any one year should be subjected to as nearly as possible the same basic educational (course) experience, and there is a natural turnover in faculty from year to year, the course should be “professor-proof.” That is, content, instructional methods, and grading rubrics should be specified in advance and kept uniform across all sections.
- The course must impart both hands-on design experience and minds-on problem solving skills, in about equal proportions.⁴
- Because of the presence of the liberal arts students as described above, the course must not require mastery of calculus.
- The course must be a “success” as described by, e. g. Pomalaza-Raez and Groff.⁵ That is, it must, in their words, “provide students with sufficient computer and personal development skills and help them develop the right mental attitude conducive for academic success.” One measure of success is freshman retention rate. Union has had a retention

rate significantly higher than the 20-50% reported in other studies.⁶ In 2001 more than 90% of declared freshman engineering majors from 2001 continued as engineering students in 2002.

- The course must be accessible to students under-served by their high school science and math preparation, while remaining interesting and challenging to those students who were well prepared by their secondary schools.

Alternative Concepts and Concept Selection

There is an extensive literature on alternative concepts for introductory engineering courses.⁷ These include traditional lecture-and-problem courses aimed at mastering problem-solving skills, more general problem solving courses aimed at teaching a particular problem solving method, courses aimed at developing creativity, “technology dissection courses” based on taking apart and analyzing current technology based products; and design courses leading to a team competition. Another option less often implemented is an “engineering-in-life” course tapping engineering expertise from the local industries.

Drawing on these alternatives, selection of a course concept has proceeded in an evolutionary manner for more than a decade. That evolution has been based on a “fitness criterion” featuring three major parts. First, the course should be sufficiently enjoyable and challenging as to encourage retention of already declared engineering majors. Second, the course should serve a filtering and feedback function, appraising students of how their current skills stack up against others in engineering and providing them with guidance for improving those skills. Third, the course should fulfill an informational function, enabling students to better understand the essence of science and engineering.

Those three criteria have led to a course at Union College with three main components: 1) a one-hour lecture session that the students attend twice a week, dedicated to interactive inculcation of engineering concepts and problem solving skills; 2) a three-hour design studio that the students attend once a week, dedicated to hands-on design projects that lead to a final student competition; and 3) a one-hour “common lecture” that the students attend once a week at which a practicing engineer describes a leading edge technology (e.g., recent advances in nanotechnology, fuel cells, bioengineering, etc.) that motivate and excite the students.

To prevent the three parts from becoming a smorgasbord, a unifying theme that bridged the material was chosen: “Smart Cars.” Thus the lectures exemplify engineering concepts and problems by applying these concepts wherever possible to issues related to the modern automobile. The design studio competition focuses on development of a vehicle designed to achieve a specific competitive purpose. And the common lectures, while not exclusively automotive in nature, are dedicated to issues of modern leading edge technologies in the fields of energy, transportation, computers, information, mechatronics, bioengineering, and material science.

Detailed Design

The design of the course has proceeded along three parallel tracks, corresponding to the three components described above. A continuing challenge, which will be discussed later, is to

increase the synergy between those components.

The design of the lecture sessions have been captured in a textbook manuscript that has evolved over the past four years. Entitled “Exploring Engineering: An Introduction to Engineering and Mechatronics,” it implements the smart cars theme in eight chapters, with the goal of covering them at the rate of one per week (leaving time for start up, a midterm exam, and end-of-term review). Students are responsible for everything in the text’s 142 pages, and an additional 26 pages of appendices provide reference material in greater depth. The contents of the text are:

- Chapter 1 Key Elements of Engineering Analysis
- Chapter 2 How to Solve Problems and Spreadsheet Analysis
- Chapter 3 Energy: Kinds, Conversion and Conservation
- Chapter 4 Chemical Energy of Fuels
- Chapter 5 The Automotive Drive Train
- Chapter 6 Electrical Circuits
- Chapter 7 Control and Binary Logic
- Chapter 8 Implementing Control with Computers: The Automotive Fuel Control System.

Throughout the text, examples drawn from automotive engineering provide a thematic thread. Where possible, social and political implications of various topics (e.g., the role of carbon dioxide emissions in possible greenhouse warming) are introduced. For example, in discussing the energy content of fuels, the story of the U.S. government’s ill-fated “Partnership for a New Generation of Vehicles” is discussed.

Developing a course text manuscript enabled instructors to devote an increased portion of ‘lecture’ sessions to discussion, interaction, and problem solving. In support of this increasingly interactive approach, the instructors all taught their classes a problem solving technique called the “Need – Know – How – Solve” approach. This method is similar to many described in the literature and will not be detailed here. Its main purpose was to wean the students away from a “plug-into-the-equation” approach. The method emphasizes that correctly defining the problem and envisioning possible answers (including the measurement units in which the answers must be expressed) are the most important steps toward problem solving success.

The design studio begins with a presentation of a “design process” consisting of the following elements: 1) carefully define the problem to be solved, 2) determine the design requirements and limitations, 3) generate numerous alternative solutions (i.e., brainstorming), 4) select a solution that best meets the needs of the problem, 5) prepare a detailed design, 6) defend the design to supervision (i.e., course instructors), 7) construct a device based on the final design; 8) evaluate the performance of the final product (i.e., test) and, 9) write a final design report.

The first two weeks of the design studio consist of “ice breaking” hands-on team exercises (e.g., building a tower from minimal materials, designing apparatus to transport a simulated radioactive “waste ball”) that accustom the students to accurately defining a problem and determining design requirements. The third week introduces brainstorming techniques (e.g., no one is allowed to criticize another student’s ideas), and the fourth week focuses on techniques

used to select a final solution (e.g., Pert charts). The fifth week is devoted to engineering ethics wherein real engineering case studies involving ethical issues are discussed. The students are then assigned to permanent 3-person teams. During the remaining five weeks of the term, they use the material presented during the first half of the course to solve the problem of designing, building, and testing a mechatronics device that will win a competitive game (this is the “problem”). The conditions and rules are clearly posed by the course instructors and are the same for all sections. A Q&A web site allows the students to ask questions about the contest and the questions and answers are then shared with all the students (one faculty member is assigned the task of being the official rules master). The contest objective is changed each year to prevent students from copying previous entries.

In line with the course theme, the competition involves designing a vehicle, a sort of remote control car (though, for practical reasons, electrically powered by wire rather than batteries) that accomplishes a competitive task along the lines of robotic basketball, soccer, or other familiar sport. This is where “mechatronics” formally enters the course. Each student team is issued a standard box of components, including electric motors, gears, and various construction materials. They are required to use only these components in their final design.

This year’s competition involved designing a robotic device that would deposit 3-inch diameter balls into an 8-inch circular tin pan placed in the center of the field of play, and then push the tin pan as far as possible toward the opponent’s goal line. Both the number of deposited balls and how far the tin pan was pushed downfield contributed to the scoring. This contest was chosen to encourage the students to employ key engineering ideas discussed during the course. These included velocity (getting to the tin pan fast), torque (ability to push the tin pan, especially against the opposition of another vehicle pushing in the opposite direction), and control (making the vehicle steerable in order to approach the tin pan from a direction different than that of the opponent).

The students were required to prepare a design proposal in order to “earn” the standard box of components from which they built their design. They were also required to maintain a “design notebook” that contained all information relevant to the design (calculations, meeting minutes, brainstorming ideas, Pert charts, etc.) that was graded at the conclusion of the course. They also had to meet various graded design milestones, including a performance test of their completed device. Finally, they were required to submit a final design report summarizing the experience, including drawings and other information sufficiently detailed that the device could be reproduced from information contained in the report.

Finally, in a weekly common hour, professional engineers addressed the entire 120-person student enrollment about career paths in current leading edge technology projects. Topics included “The Fuel Cell Automobile of the Future,” “Mechatronics,” and “New Materials from Nanotechnology.” This segment of the course drew on both Union College alumni and the technology resources of upstate New York’s Capital Region. These include General Electric Power Systems and the GE Global Research Center, Lockheed-Martin, General Motors, high tech mid-size corporations such as Intermagnetics General, Plug Power, Albany Molecular, and MapInfo, and educational institutions such as Rensselaer Polytechnic Institute and the University

at Albany, and (soon) the east coast laboratory of Sematech and the U.S. research lab of Tokyo Electron, Ltd.

A future goal is to link more fully the three components of the course. When this happens, educational value seems greatly amplified. For example, in this year's course, the lecture session analysis of gear ratios occurred in the same week as the design of gearing for the student's competition vehicles. By this coupling, two results were achieved. Performance of the students on an exam question regarding gear ratios was much better than last year. In addition, more competitive teams made explicit strategic choices regarding gearing their designs for either speed or torque, as opposed to merely applying an arbitrary gear ratio.

Performance Evaluation

Performance of the course was measured in four ways: by its effect on retention, by exam scores, by its effect on student problem solving performance, and by student reaction.⁸

Regarding performance on exams, continuity has been provided throughout the course by keeping the general level of the final examination consistent over the past few years. Average student scores on the final exam have steadily improved, from 67% in 2000 to 85% in 2001 to 87% in 2002. Indeed, there is some concern that the exam is too easy as we improve the learning outcomes.

Regarding effect on student problem solving, the measurement is more crude, and the results more equivocal. The final exam is a conventional exercise in solving standard engineering problems (e. g., calculating the kinetic energy of a moving body, determining a gear ratio, finding the current and power for a circuit of given voltage and resistance values, and so forth). One might ask whether performance on such an exam is affected at all by the teaching in the lecture session of the course or is entirely predetermined by the student's previous preparation. To test this in at least a crude way, in the first week of the course a "units quiz" was given. This was a quiz on the material in first chapter of the course text that was purposely not covered in lecture by the instructors (to get students to become accustomed to being responsible for material not presented in class). While ostensibly a quiz on whether the students read and understood the first chapter of the text, it was also a test of whether the students came to college equipped to carry out really basic mathematical and geometrical operations needed to succeed in engineering. These operations can be basic indeed, including the ability to find the area of a rectangle or a circle, a skill a surprising percentage of the incoming engineering students find challenging.

During the course, students were graded on whether or not they did the weekly homework. This, and the units quiz, gave two dimensions of "input" that can be compared to the "output" performance on the final exam. For two of the course's sections, the average final exam scores for each of four input categories were tabulated. While the sample is small, the results at least suggest that doing the homework helped students with poorer preparation catch up with those better prepared, and that there also might be a small improvement in performance due to homework preparation even among the better prepared students.

Average Final Exam Scores for Students by Category of Pretest Performance and Homework Performance (Number of students in each category is in parentheses. Total number of students = 40)

	Low Pretest	High Pretest
Low Homework	76% (4)	88%(9)
High Homework	87% (12)	91% (15)

Finally, student reactions to the course were compiled through an end-of-year written survey. Results are excerpted in the table below. Briefly, they confirm that a majority of the students believe the course is attaining its educational learning objectives of introducing students to the field of engineering, and improving their design, teamwork, and technical communication skills.

Topic	As a result of this course I can now do this:			
	Very Well	Well	Poorly	Not at All
1) Design concepts				
(a) I am able to carry out the design of a simple system.	40.7%	50.0%	7.8%	1.5%
(b) I am able to define the five basic steps in the design process.	36.1%	59.8%	4.1%	0.0%
(c) I understand basic manufacturing and project scheduling.	28.1%	50.0%	18.8%	3.1%
(d) I have carried out several design projects during the course.	36.7%	54.1%	9.2%	0.0%
(e) I have an appreciation for the role of ethics in engineering.	33.0%	53.6%	11.3%	2.1%
2) Teamwork concepts				
(a) I can identify the skills required for good teamwork.	59.8%	38.1%	2.1%	0.0%
(b) I can identify the characteristics of good teams.	57.3%	38.5%	4.2%	0.0%
(c) I have completed exercises requiring a team effort.	54.6%	44.3%	1.0%	0.0%
3) Technical communication skills				
(a) I can complete a sketch and a drawing of a simple system.	36.7%	49.0%	12.2%	2.0%
(b) I have prepared written design reports during the course.	33.0%	60.6%	5.3%	1.1%
(c) I have organized and delivered oral presentations of design work to a group of peers during the course.	36.8%	52.6%	6.3%	4.2%

Conclusion and Challenges

In conclusion, the authors emphasize that the results described in this paper are part of an evolutionary process, and that the course itself remains a work in progress. If it is to continue to

be successful, it should always be a work in progress. The performance assessment described above indicates that it is achieving its principal learning objectives: helping students make an early and informed decision about whether or not they find engineering an exciting career path and have both the interest and the capability to pursue an engineering degree. The course's performance in its secondary role, as a liberal arts elective has so far eluded our measurement efforts since this was the first year this option was available.

Experience has also suggested several areas in which the course can be improved. First, the inclusion of significant mechatronics instruction remains to be achieved. Second, while students are instructed in and carry out extensive exercises in spreadsheet use, they have not yet "bought into" the advantages of routinely using spreadsheets and other computerized tools in engineering calculations. Third, use of the Internet as an information source for this type of course is as yet rudimentary. Fourth, implementation of the uniform problem solving technique can be improved. Finally, coordination between the weekly content of the lecture portion of the course and the design studio can be improved.

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The final design studio competition.