Int. J. Engng Ed. Vol. 16, No. 4, pp. 351–361, 2000
Printed in Great Britain.

0949-149X/91 $3.00+0.00

A New Approach for an Interdisciplinary Senior Elective for Electrical Engineering and Electrical Engineering Technology Majors in Electric Vehicle Applications*

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In this paper, we describe a new approach to introducing electrical engineering students to a new area in electrical engineering and electrical engineering technology education. In this project which was funded by the Department of Education, we have utilized 'only-as-needed' and 'just-in-time' philosophies in the course design. The course is taught by the two sponsoring departments. The paper details the topics, the laboratory experiments, the laboratory facilities, and computer activities that are included in the course. It also describes how a comprehensive design project is used to promote integration of knowledge in diverse topics such as batteries and energies, DSP and fuzzy controllers, power electronics, solid-state high-power devices, and data acquisition. The paper also describes the role that industry plays in the development, its assessment of the course, and means of dissemination.

INTRODUCTION

THIS PAPER describes an innovative course that integrates electrical engineering (EE) and electrical engineering technology (EET) students in a common classroom and laboratory setting. The course is a senior technical elective for both majors and focuses on the design of instrumentation and control for electric vehicles. The course contents were selected to provide students with a spectrum of design methodologies that cover power electronics, computer simulation, data acquisition, digital signal processing, neural networks and fuzzy logic, electromagnetics and energies, and microprocessor control. Each of these topics would normally be covered in greater depth in standalone courses, and students would normally be required to take more than 15 semester credit hours of technical courses in order to experience the design methods taught in those courses. By using an 'only as needed' method, we can give students the opportunity to experience design methods from the above mentioned technical areas by introducing them only as needed to complete the laboratory design assignments.

A full-scale propulsion system of a commercially available electric vehicle serves as the focal point of the design methods selected to promote the integration of knowledge [1]. Integration of knowledge is accomplished by asking students to incorporate a diverse range of design methods into their laboratory work, demonstrating to students that knowledge from different technologies is not separated by invisible walls. The selection of the electric vehicle is a timely and motivating choice since students have become familiar with electric vehicles through the media.

This paper details the technical contents of the course, the laboratory experiments, and the laboratory facilities that feature a full-scale propulsion system that was donated by General Motors. Finally, we will describe how the course has led to a major effort to offer additional advanced courses in the area of hybrid electric vehicles to students in electrical engineering, mechanical engineering, electrical engineering technology, and mechanical engineering technology.

INNOVATIVE FEATURES OF THE NEW COURSE

The new course is a complete departure from traditional EE and EET senior electives in the design of the course, the instructional team including the use of industry scientists, the process for

* Accepted 11 November 1999.

selecting the course contents, and the assessment and dissemination of the course.

The innovations that were designed into the course include the following:

- The course uses an industrial model, where students work in integrated design teams composed of EE and EET students.
- It provides students with a highly motivational, hands-on, design-oriented experience, centered on a full-scale, commercial propulsion system provided by General Motors.
- It provides students with experiences with a variety of software, including LabView to provide data acquisition to monitor high voltages, currents, temperatures, and pulse width modulation (PWM) waveforms for the different phases of an inverter-controller experiment setup, PSpice for computer simulation of the propulsion system, and assembly language programming for the TI controller.
- Collaborative group techniques are used to facilitate teamwork, especially since the course integrates EE and EET students who have not worked together in prior courses. Traditionally, EE and EET seniors do not take senior elective courses together for the following reasons. On a majority of the campuses where EE and EET programs both exist, they are housed in separate departments. Collaboration is not part of the tradition and thus not easily accomplished. Another reason for the separation of students is the difference is mathematical preparation for the two groups of students. The motivation for developing a course that can be taken by EE and EET is to provide students from both majors with experiences in working on interdisciplinary teams, while learning a body of material that is mutually beneficial. Since EE Department and EET Department are housed in the same school on our campus, the faculty already know each other and have worked together on committees. The progression to working together on course development was easily made.
- The course uses the principle of attached learning [2], where all topics are attached to a real-world, hands-on, course project.
- Topics are scheduled for just-in-time delivery to increase student motivation. That is, each new design method is followed immediately with a design-oriented laboratory experiment. Furthermore, topics are selected on an only-as-needed basis so that all learning is seen to be relevant and not learning for the sake of learning.

The instructional team

There are several reasons for team-teaching the course. The primary reason is the diversity of topics that are included in the course. No one faculty member has sufficient experience in all of the topics to teach it alone. The second reason was to make students from each department comfortable with the course since this was the first course that was designed across engineering and technology departments. It was developed by faculty members from the EE department and the EET department, with the lead faculty member housed in the EE department. Topics for the course were divided among the participating faculty according to their areas of expertise. Each topic was taught by the person who developed the materials for that topic. The instructional team include industry research scientists who participate not only as guest lecturers but also in the development and supervision of design projects.

Selection of course contents

Innovations in the selection of the course contents are the following:

- Instead of selecting a particular topic and pursuing it in depth as most electives do, the development team decided to select a wide spectrum of state-of-the-art, design-oriented methods that can be applied to the design of electronic subsystems for instrumentation and control of electric vehicles. Figure 1 shows the different topics covered in the course. In this way, students gain design experiences that would normally be seen in more than fifteen credit hours of technical courses.
- Students are asked to integrate knowledge gained through design laboratory experiments in the execution of a course design project.

Dissemination of the course

A web site containing the complete notes for the course has been developed (URL:http://www.engr.iupui.edu/electricvehicles). Thus anyone interested in adopting the course will have complete access to them. Dissemination was built into the development of the course by forming a consortium of four universities to share in the development of the course. Each member of the consortium received a propulsion system from General Motors. Finally, presentations on the development and assessment of the course were made at the ASEE 1998 [3].

The course can be disseminable at different levels so that any school can follow:

- *Disseminating the concept of the university/industry linkages.* The success of the course depends upon the participation of industry, and selling the idea of a university/industry partnership should not be difficult as long as there are related industries nearby since it is a win-win situation. There are mutual benefits for this partnership that attract institutions to adopt the model.
- *Implications of equipment needs on dissemination.* Equipment needed for the program is commonly available at a nominal cost. There are two kinds of equipment that must be available for the program to be adopted. One is a propulsion system, and affordable components with service and technical consultation are available at a reasonable rate. Solectria, for example, quotes

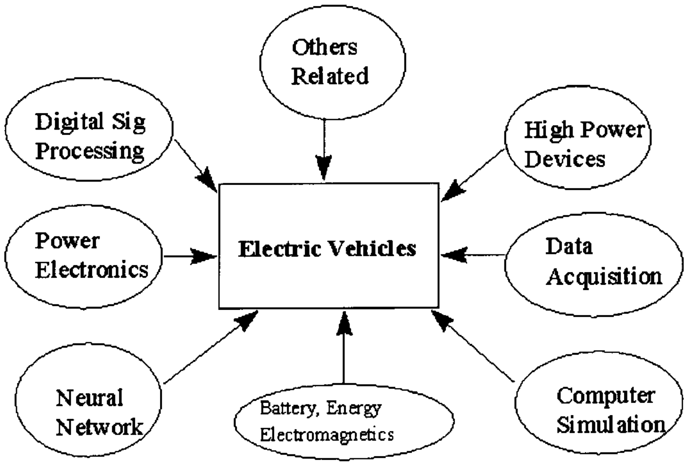

Fig. 1. Concept of integration of knowledge.

a 20 kW propulsion system, which is sufficient for educational courses, for $6,000, including the motor, inverter, and controller. The second kind involves hardware/software that is normally readily available in comprehensive engineering and technology programs. For example, common CAD software such as PSpice for low and high power component simulation and data acquisition software/hardware such as LabView (educational price for 24 channels is $6,200) for monitoring high power voltage and current waveforms from a propulsion system, are commonly used in engineering and technology programs across the country. Texas Instrument DSP hardware development system is needed for motor control and can be purchased at an educational price under $2,000.

In order to disseminate and assess the course, a university consortium has been formed to promote the immediate and active dissemination of the course. Four universities across the country have agreed to join the consortium and teach the course on their campuses. The WWW is used to distribute the course materials and laboratory experiments to students and to university partners. A comprehensive assessment of student satisfaction and student learning has been performed through student satisfaction surveys and exams designed to assess learning outcomes and critical thinking.

WHY FOCUS ON ELECTRIC VEHICLES?

The electric vehicle was selected as the test bed for the application of design methods because of its timeliness because so many different design technologies can be attached to it. The timeliness aspects of the choice is related to public acceptance. For public acceptance of electric vehicles and other variants such as the hybrid electric vehicle (HEV), their performance, reliability, safety, and cost must become more attractive. Thus the electric vehicle provides us with a wide range of applications, where hands-on, concrete, relevant design experiences can be developed to motivate students to learn. Experiments and projects can focus on the battery and charging systems, electric motor of several types, regenerative breaking, DC-to-DC converters to drive the air-conditioning system, and the power electronics subsystem. Design of instrumentation and control can make use of techniques from several domains, including power electronics, computer simulation, data acquisition, digital signal processing, neural networks and fuzzy logic, electromagnetics and energies, and microprocessor control. Figure 2 shows a block diagram of an electric vehicle, illustrating the different subsystems that are studied in this course.

PEDAGOGICAL FEATURES

The pedagogical features of the course are:

- 'just-in-time' delivery of information;
- 'only-as-needed' selection of course contents;
- 'integration of knowledge' philosophy.

The first two features were selected to produce a course that would motivate students to learn by making knowledge relevant to the task at hand. The concept of 'just-in-time' delivery refers to the process of delivering lectures 'just-in-time' for immediate application. Just-in-time delivery minimizes time lag between learning and applying. Using 'just-in-time' delivery, students are not asked to learn something with a promise that 'you'll need this later in the course'. Lectures and experiments are structured so that students put new knowledge into practice almost immediately. The only-as-needed selection of course contents eliminates the selection of topics that are interesting but devoid of practical applications. The third feature, integration of knowledge, is one of the campus principles of general education, and this course helps students master the principle and recognize that the imaginary walls that separate

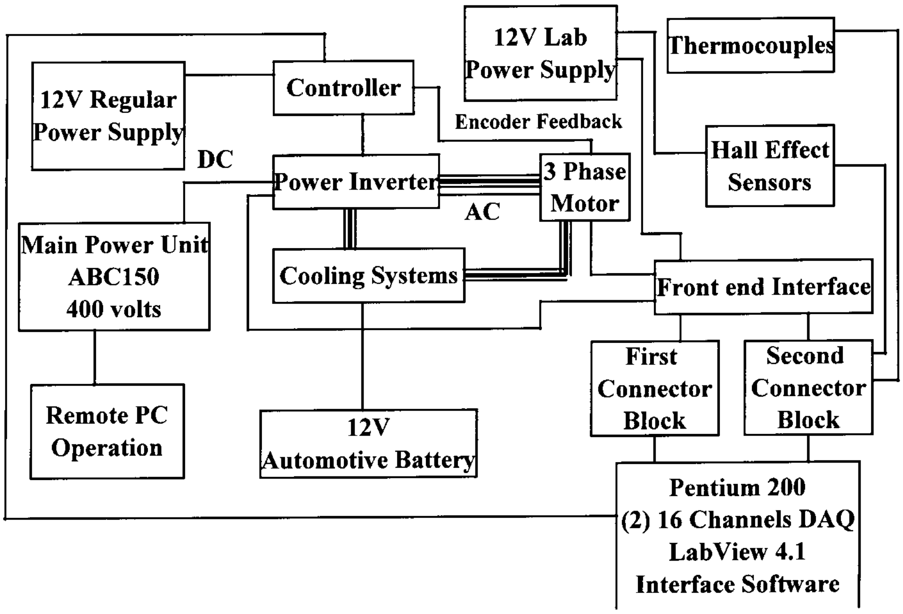

Fig. 2. Block diagram of the electric vehicle showing data acquisition.

conventional courses are mere artifacts of conventional curricula. Integration of knowledge is not the same as project-oriented studies. Integration of knowledge described here refers to the process of taking seemingly unrelated knowledge, such as knowledge of DSP methods, knowledge of power electronics devices and design techniques, and knowledge of microprocessor controllers and applying all three in an experiment or on a project. In traditional courses, students pursue a narrow topic deeper and deeper, and the knowledge is self-integrating.

THE TECHNICAL ASPECTS OF THE COURSE

The technical emphasis of this course is to design and realize instrumentation and control of electric vehicles in the most economical manner. TI microcontrollers are used to implement high efficient PWM for motor control using peripheral devices such as A/D and D/A converters, analog or digital filters, and position encoders. For data processing, digitization, quantization, and control algorithms are obtained from look-up tables or mathematical models developed by the students. LabView software is used for monitoring the different components of the EV system for safe handling of high voltages and currents by virtual instrumentation. LabView is also used to emulate and replicate all input and output signal activity of a given device. Advanced emulation will be developed by sending the actual converter system output signals to electric motor training devices for actual mechanical operation. For high power and low power devices, computer simulation is used to simulate power devices such as IGBTs. Other data acquisition systems are used in the course for low power accessories and for high DC power from a high energy power supply. The weekly schedule of the contents of the course are presented in Table 1.

LABORATORY EXPERIMENTS

Ten experiments have been developed for the course and are described in Table 2. The experiments cover applications such as battery charging, virtual instrumentation, simulation of power electronics and propulsion systems, controlling a full-scale propulsion system using TI microcontrollers, and testing and measurements.

ROLE OF INDUSTRY IN THE COURSE

The role of industry in the course can be summarized as follows.

Development of the course

- They provided the school with a state of the art propulsion system from General Motors' EV1 electric vehicle.
- They provided the School with the ABC150 battery charging system.
- They assisted with the installation and setup of the physical facilities that house the equipment.
- They supervised our students who designed the cooling system for the motor.
- They assisted us in setting up and testing a hardware and software data acquisition system to be able to monitor high voltages and currents inside the propulsion system.
- They provided parts for the propulsion system needed for repair.
- They instructed the students about safety issues.

Table 1. Contents of the course

Week	Topics
1	Course policy Course introduction: historical background, environmental issues, requirements, challenges, unique capabilities over internal combustion, variable speed drives; keys of improvement, battery charger architecture, lab facility
2	Types of motors and their applications in electric and hybrid electric vehicles. Motor requirements for drives DC motors Induction motors Synchronous permanent magnet motors PM reluctance motors High-performance design issues Motor applications and means of their control
3	Batteries and energies Characteristics of a battery Charging, discharging, and regenerative characteristics Battery energy-based design; design equations Temperature limitation as a design requirement Airflow cooling and calculations Battery cell device and its operation, thermochemistry/chemical energy, electrode processes, impedance model, battery types and technology, EV applications; performance, cost, abuse resistance, reliability, user issues, efficiency, resource availability, safety, environment, technology maturity, and technical barriers.
4 to 7	AC induction motor control using DSP controllers Fuzzy logic in motor control
8 to 11	Power electronics Three- phase AC to AC DC to DC converters Inverters, AC to DC converters Drive circuits
12 to 13	High power solid state devices with emphasis on IGBTs Smart devices used to develop safety features such as the detection of faulty currents and voltages and high temperatures.
14	Industrial applications for electric vehicles, including electric busses and trucks, and hybrid electric vehicles
15	Plant visitation Project presentations

- They assisted us with assessing the quality of the data taken in test runs before applying it to classroom.

Teaching the course

- They provided a research scientist who participated in teaching the course.
- The provided ideas for course projects.
- They participate in supervising the students on their design projects.

Plant visitations

- They allowed students to visit their plant.
- They give lectures to our students on the different kinds of work that goes on in different sectors of the EV industry
- They provided members of their engineering staff who could discuss a wide variety of issues related to vehicle design with our students.

DESIGN PROJECTS

Working in teams that integrate EE and EET students whenever possible, students complete a major design project, with each team selecting a topic from among the areas described in Table 3. The design projects require students to integrate the knowledge learned in different sections of the course. For instance, students need knowledge from power electronics where they learn how to generate PWM for the DSP part of the course where they program the DSP controller for a given speed. Solid-state characteristics of IGBTs are considered in selecting the proper switching device for a given operating frequency, current handling, and hold-off voltages. In addition, means of motor control learned in the motor section are used in the DSP programming. Knowledge from the section on batteries and energy is used to set limits on the currents and voltages for a particular application. For instance, running the motor at high speeds and high acceleration rates must take into consideration the power available from the battery and its discharge characteristics. Thus students must be able to link, or integrate, the knowledge that they obtain from the various sections of the course.

The student teams present the results of their projects to the class and interested faculty at the end of the semester. Presentations usually include a Power Point slide show, demonstrations of hardware and software, and their results and comments.

ASSESSMENT OF COURSE

The course has undergone considerable assessment. We assessed student satisfaction, student

Table 2. Experiments developed for the course

Lab1: Battery Charging System Students practice using the ABC150 battery charging system to learn how to use the manual mode to enter the required power to the propulsion system. They also learn how to write a script file to use the auto mode of the system. This file actually follows a charging curve as prescribed by the battery manual. Lead-acid batteries are used in this laboratory.
Lab 2: LabView Assignment #1 Students learn how to use the LabView software operating tools to manipulate front panel controls and indicators. Labeling tools, positioning tools in both functions and control palettes. Students learn how to create a virtual instrument and apply it to simple circuits with multiple functions.
Lab 3: LabView Assignment # 2 Students use LabView to emulate a block diagram given to them with comparators, sine and triangular generators in order to generate PWM signals.
Laboratory 4: DSP Assignment #1 Students learn to program a T.I. microcontroller, writing a simple C program to learn how to use the compiler, linker, and debugger. The program shifts a bit through an 8-bit port turning on one of eight LEDs at a time. The exercise is designed solely for the purpose of stepping through code since no timing is provided for the transitions between the LEDs.
Laboratory 5: DSP Assignment #2 Students write the code to set up a timer to interrupt program execution and execute a subroutine at a fixed interval. This sets up the time base required for processor-based speed control systems. An interrupt rate of 10,000 interrupts/second was selected, which is the motor control update rate used in the final exercise. When using this update rate, a motor turning at 2000 RPM will get new control inputs at every 1.2? of revolution.
Laboratory 6: DSP Assignment #3 Students use open-loop speed control. A sine table is used to generate the sine values. The sine table is 100 entries long and represents sine values for angles from 0 to 60 degrees. Variable *SinIndex* provides the proper index into the sine table. The lookup is accomplished by simply accessing an element in an array.
Lab 7: Pspice Assignment # 1 Students use PSpice to design one of the DC to DC converters such as buck, boost, buck-boost, or kuck converters. A report on the transient as well as steady state response of the circuit is required.
Lab 8: PSpice Assignment # 2 Students simulate three-phase sinusoidal voltage and current for three-phase induction motors including PWM circuitries with high voltage and current interface circuits.
Lab 9: PSpice Assignment # 3 Students use one of several switching algorithms for unipolar or bipolar PWM schemes for an inverter circuit.
Lab 10: Propulsion System Students develop the necessary voltages and currents to control the speed of a three-phase motor using LabView Students also run a complete simulation of the motor and inverter, including the pulse-width modulated signals using Pspice and write a report to discuss the comparison between the simulated and experimental results.

learning and critical thinking, the ability to work in teams, and carry out a design project. Student satisfaction was assessed through the conventional questionnaire, student learning was assessed by writing exam problems according to a problem-solving taxonomy, where problems were written to assess different levels of learning, such as:

- the application of basic procedures;
- the application of basic definitions;
- the selection of appropriate strategies;
- the application of basic principles;
- the application of design methods.

Table 3. Typical design projects

Computer simulation. Design and simulate a propulsion system from given specifications using a professional version of Pspice to simulate high-power devices.
Data acquisition. Using LabView, display the current and voltage waveforms in the propulsion system by accessing the sensors that have been placed inside the motor for monitoring.
Batteries and energies. Design a high voltage battery composed of parallel-series cells to meet prescribed charging, discharging, and cooling rate specifications.
DSP. Design software and hardware using a Texas Instruments DSP controller and control the three-phase motor to attain prescribed speed and acceleration profiles.
Others. Develop a plan for converting an EV propulsion system to an HEV system.

In addition, a self-reflection survey was used to assess student self-assessment of their satisfaction with their level of understanding of the course contents. Teamwork was assessed by the use of a questionnaire that asked them to report on their experiences in working in teams on laboratory projects and the design project and through the quality of their team projects, particularly the following:

- the ability to carry out a small design project;
- the ability to propose possible solutions for industrial problems.

Assessment of student satisfaction

Student satisfaction was assessed over two offerings of the course, and the results have been combined and are presented in Table 4 which presents data separated by major. EET students were enrolled only during the second offering of the course. The scale used was 5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, and 1 = strongly disagree.

Table 4. Assessment of student satisfaction

	Item	EE Students (n = 25)	EET Students (n = 4)
1	I enjoyed the team-taught aspects of the course	4.38	4.25
2	The grading system used to evaluate the students in the course was appropriate.	4.23	4.25
3	I enjoyed the presentation by the visiting industry scientists.	4.19	4.00
4	I enjoyed the motors section of the course.	3.88	3.75
5	I enjoyed the battery and energy section.	4.23	4.00
6	I enjoyed the power electronics section.	4.35	4.25
7	I enjoyed using Pspice to simulate power electronics components.	4.16	4.00
8	I enjoyed working in the propulsion laboratory.	4.25	4.25
9	I enjoyed working in groups on our project and in the oral presentation.	4.17	4.00
10	I enjoyed the DSP and fuzzy logic section.	4.07	4.25
11	I enjoyed the field trip to Allison Transmission that helped me see what engineers do in industry.	4.24 (n=24)	4.50 (n=2)
12	I feel that I developed an understanding of electric vehicle components, their operation and simulation.	4.23	4.00
13	The teaching assistants were suitable for the course.	4.02	4.00
14	I learned a lot from my project.	4.71	4.50
15	Including both engineering and technology students in one class is a positive feature of the course.	4.42	4.25
16	Overall, I felt the course has prepared me for a career related to electric and hybrid vehicles.	4.19	4.25
17	Compared with other elective courses in the curriculum, I found this course to be more applied and more industrial oriented.	4.18	4.00
18	I would like to see additional courses related to electric vehicles.	4.30	4.20
19	I would like to take a graduate course following this course if one is offered.	3.95	3.50
20	Compared to other senior level courses in my major, the hands-on nature of this course helped me master the materials to a higher level.	4.34	4.25
21	Compared to other senior level courses in my major, the theory aspects of the course was more difficult.	3.25	3.50
22	Compared to other senior level courses in my major, the homework assignments were more difficult	3.09	3.25
23	Compared to other senior level courses in my major, the laboratory experiments were more challenging.	4.36	4.25
24	Our team of EE and EET students functioned well.	4.20	4.25
25	Students from both majors contributed to the success of the team	4.00	4.00
26	Taking a course with majors from my counterpart's department was a good experience.	4.20	4.50

It is interesting to note the following from the results shown in Table 4:

- The responses of the EE and EET students track fairly well. Their responses were comparable on all of the items in the survey.
- The students agreed (4.0 or better) that they enjoyed ten of the eleven items (items 1–11) that asked how they enjoyed various aspects of the course. The single item that was rated slightly below the 'agree' level was item 4 on the section on motors. We will address this item in our planning for the next offering of the course.
- Students said that they understood the working of the basic components and their simulations (item 12) and that they learned a lot from their projects (item 14).
- They agreed that combining EE and EET students in one class is a positive feature (item 15) and that it was a good experience (item 26).
- Neither the EE or EET majors expressed an agreement with wanting to take a graduate course in the subject (item 19), with the EE majors reporting an understandably stronger interest (3.95) than the EET majors (3.50). This latter result is not surprising.
- Items 21 and 22 demonstrates that the EET students found the course a little more challenging than the EE students, but neither found the course more challenging that other senior level courses in their respective majors.
- Items 24 and 25 demonstrate that the teams functioned well that both majors contributed to team success.

During the development period of the course, four senior EE students participated in independent study projects that led to the development of several of the teaching modules for the course. Each student completed a satisfaction survey, whose results are shown below in Table 5. For each statement, 5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, and 1 = strongly disagree.

Negative comments from focus group discussions

One of the few negative points that arose in the assessment of the course is the use of a teaching assistant (TA) who was also a student in the class. The TA was selected on the basis of his practical experience with the laboratory setup. This problem was resolved second time we offered the course since the student was no longer in the course. Also, students reported that they need an introductory course in power electronics before taking this course to help them better understand EV power

Table 5. Assessment of student satisfaction of EE project students

	Item	Results (n = 4)
1	In my project course, I learned technical contents that were not covered in any other EE courses.	4.75
2	I enjoyed using computer simulation software to model electric Vehicle components.	4.62
3	I enjoyed using LabView to develop data acquisition system.	4.75
4	I enjoyed the hands-on aspects of my project	4.60
5	Courses like this motivate me to put more efforts into my studies.	4.60
6	I enjoyed learning about the operation of the different components of the vehicle.	4.75
7	If I were looking for more technical electives, I would like to continue taking more credits in this area.	4.60
8	I am interested in working on a senior design project in this area.	4.90
9	I enjoyed doing outside reading and research to learn more about the different component systems in the electric vehicle.	4.25
10	I enjoy learning on my own with guidance from the instructor.	4.88
11	This course required me to integrate knowledge from other courses that I have taken.	4.88
12	I would like to find a job in this area.	4.38
13	The materials covered in this course have given me a better view of how my engineering education is preparing me for work in industry.	4.50
14	Overall, taking this course was an enjoyable experience.	4.75

electronics. An additional one-credit, elective course in power electronics was developed to serve this purpose.

A feedback from the industrial partner is summarized below. Table 6 was based on a scale of 1 to 5.

Results of the assessment of student learning

Instructional objectives were written for the following types of learning outcomes:

- Type 1. Understanding of basic concepts.
- Type 2. Solving calculation problems that require an understanding of the basic principles, definitions, procedures, and strategies associated with the course materials.
- Type 3. Solving design problems that require an understanding in principles of design.
- Type 4. The ability to work in teams.
- Type 5. The ability to carry out a small design project.
- Type 6. The ability to propose possible solutions for large industrial problems.

Table 6. Industrial partners feedback

Item	Industry
1. Appropriateness and quality of the laboratory equipment in the Propulsion Laboratory of the School.	5.0
2. Appropriateness and quality of projects in the course.	5.0
3. Satisfaction with engagement with students of their field trip to Allison Transmission, Inc.	4.0
4. Satisfaction with student interaction during guest lectures on 'Hybrid Materials for Trucks and Buses'	4.0
5. Appropriateness and quality of course materials.	5.0
6. Ability of the course to prepare students for jobs in the electric vehicle sector.	4.0
7. Appropriateness of the design methods to prepare students for careers in design in the electric vehicle sector.	4.0
8. Value of integrating engineering and technology students in a senior elective course.	5.0

Table 7 gives sample questions on assessment.

The understanding of basic concepts was assessed by writing exam questions that asked students to write responses to questions concerning the following issues related to electric vehicles:

- power efficiency of EVs;
- basic principles of variable speed drives and keys to performance improvement;
- problems associated with high power BJTs as compared to IGBTs in their use of motor control in electric vehicle applications;
- drive requirement to produce competitive electric vehicles;
- block diagram of the basic units of the EV;
- block diagram to show the basic unit of a battery charging system;
- block diagram of hybrid electric vehicles showing main components;
- control events that start from pressing the paddle until we get the required speed of the vehicle;
- comparison between different types of motors and their applications to EVs;
- battery cell components and their impedance model;
- comparison between batteries in terms of their performance, reliability, technical barriers, technology maturity, and availability of resources;
- questions on charging, discharging, regenerative characteristics of a battery;
- manufacturing steps of IGBT and high power MOSFETs;
- understanding script files for auto mode of a battery charging system.

Over a sample population of 34 students and three exams, 84% of the questions were answered correctly.

The ability to solve problems involving calculations based on an understanding of the basic

Table 7. Assessment questions

Type #	Examples for assessment
Type 1	Discuss the considerations that speak against the commercial utilization of electric vehicles in its present form. Discuss the drive requirements for a competitive EV. Compare the internal combustion vehicle with the EV in terms of conservation of energy during deceleration.
Type 2	Compute the power dissipated in the windings of a three-phase motor under full load.
Type 3	Design a battery with electromagnetic and thermal considerations that include airflow for temperature stability.
Type 4	Write a program to process signals that represent an acceleration or deceleration using TI DSP board that you used in the laboratory. Demonstrate an understanding of effective teaming by writing an essay on the skills that lead to effective team work.
Type 5	Carry out an individual design project using CAD/CAM software such as PSpice to simulate a propulsion system.
Type 6	Demonstrate an ability to undertake large scale design projects by discussing how you would approach the task of converting an internal combustion engine to a hybrid electric vehicle.

principles, definitions, procedures, and strategies associated with course materials was assessed by writing questions that required students to demonstrate their understanding. Examples of the questions for this assessment include the following:

- calculations of three-phase systems;
- calculations of total harmonic distortion;
- current and voltage calculations and waveforms for PWM control circuits.

Over a sample population of 34 students and three exams, 80% of the questions were answered correctly.

The ability of students to solve design problems was assessed by writing questions that asked students to perform design calculations and write short paragraphs involving the following:

- The design of a high voltage battery to satisfy electromagnetic and thermal stability requirements.
- The design of a pulse width modulation for a prescribed level of total harmonic distortion.
- The design of an inverter for a prescribed current level, switching speed, and operating frequency.
- The design of an inverter to eliminate a particular harmonic.

Seventy-eight per cent of the 34 students solved problems of this type correctly.

The ability to work in teams

The ability to work in teams was demonstrated two ways. The assessment of student satisfaction with working in teams, described in Section VIII.A, items 24–25, demonstrate that students agreed that their team experiences were a positive experience. Evidence obtained from the assessment of their team reports on ten laboratory experiences and the design project demonstrated an overall evaluation of 90% success in accomplishing the goals of the experiments and projects. All but one of the seven laboratory teams received grade A.

LabView™ was used to monitor high voltage and high currents inside the vehicle. It serves two purposes in this particular application: data acquisition and providing student safety by accessing to the propulsion system via a PC. In addition, since LabView is such a powerful tool, students preferred to use it to emulate power electronics components as a part of their course project.

As we expected, the attachment of learning to a highly visible, hands-on, practical test bed such as the electric vehicle increases students' motivation to learn and participate. This is reflected in the faculty team's grading of the project reports near the 100% level. Students were seen putting in long hours in the propulsion laboratory and in the simulation laboratory. As we expected, the selection of a practical, highly visible test bed such as the electric vehicle motivated students.

Ability to propose possible solutions for large industrial problems

Two groups worked on an extra-credit project on developing plans to convert an electric vehicle into a hybrid electric vehicle. Starting with the block diagram of an electric vehicle, they proposed how additional components could be added to the EV to convert it into an HEV. Students searched the Web for different web sites and library resources for articles to achieve their goal. The extra-credit problem was driven by student motivation to learn more about hybrid electric vehicles. A research scientist from Allison Transmission, a local industry that works in the development of hybrid electric vehicles, assisted the student teams. Their final report was in the form of a proposal. Both groups received excellent ratings on their reports.

FUTURE PLAN

In order to prepare students in areas of skill development for their profession, to prepare them for careers in industry, particularly, the electric and hybrid electric vehicle industry, and to introduce them to a wide spectrum of technical topics, we are planning to design a curriculum where the electric vehicle and hybrid electric vehicle are the main emphasis of this curriculum. It will be designed to be a pioneering attempt to develop a team-taught curriculum where electrical engineering, mechanical engineering, mechanical engineering technology, and electrical engineering technology students learn as members of integrated teams. In this new curriculum, mechanical engineering and electrical engineering will be taking common courses such as mechatronics and electronic manufacturing as related to electric and hybrid electric vehicles, while electrical engineering and electrical engineering technology will be taking common courses in areas related to electronic fundamentals, battery systems, and microcontroller applications. The curriculum will continue to select course contents on a 'just-in-time' and 'only-as-needed' basis, and students will be asked to integrate knowledge. Students will also be integrated into teams in pairs, i.e. EE and ME student teams, EE and EET student teams, ME and MET student teams, and EET and MET student teams. Instruction in collaborative learning and team building will be included to promote active learning and teamwork.

CONCLUDING REMARKS

We are very pleased with the success of the first two offerings of the new course. Student satisfaction ratings are very high, student motivation is high, and the quality of their work on exams and projects is high. The merging of EE and EET students has also shown to be successful, as has been the teaming of faculty from EE and EET in developing and teaching the course. The use of the 'only-as-needed' criteria for selecting course contents and the 'just-in-time' method for delivery contributed to the success of the course. Students were able to see how knowledge must be integrated across design methods and technologies in order to carry out projects successfully. The success of the course has led the faculty to begin plans to develop an option in electric and hybrid electric vehicles which will integrate EET, MET, ME, and EE students in cross-disciplinary design teams.

The results of our assessment of the course can be used to understand student attitudes and interests for use in designing his or her new courses and to learn how to develop an assessment process for his or her new or existing courses. The former is particularly important today because of the growing interest in retention, persistence, and student satisfaction. The latter is especially important because of growing interest in accountability.

Acknowledgements—Our team of faculty involved in the development of the course would like to offer our appreciation to our vice-chancellor, Dr. Trudy Banta, for her assistance, guidance, and efforts in assessment throughout the development of the course. The development of the course was supported by a three-year grant from the Fund for Improvements in Post-Secondary Education (FIPSE) program supported by the Department of Education, grant #P116B60198.

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