Cherian Mathews, University of the Pacific

Cherian P. Mathews is Professor and Chair of the Department of Electrical and Computer Engineering at the University of the Pacific. He received a B.E degree in Electrical and Electronics Engineering from Anna University, Chennai, India, and M.S. and Ph.D. degrees in Electrical Engineering from Purdue University. Prior to joining the University of the Pacific in 2005, he held a faculty position at the University of Florida / University of West Florida Joint Program in Electrical and Computer Engineering. He has also held visiting faculty positions at Purdue University and Rose-Hulman Institute of Technology.
Using a Design Course to Augment Program Curriculum and
Foster Development of Professional Skills

Abstract

This paper describes the structure of a recently reorganized senior design project course sequence in the Department of Electrical and Computer Engineering at University of the Pacific. The paper focuses on the first course in a two course senior project sequence, a course that was recently reorganized with a view to improve student design and professional skills. Previously, students did not do much design in the first project course; the emphasis was on project selection and preparation of a design proposal. Having had no prior comprehensive design experience, students were observed to struggle in the course of project implementation in the second senior project course. The re-organization sought to remedy this problem by introducing design projects in the first course that would ensure that students had a comprehensive design experience prior to their second project course. The paper also outlines how the course is structured to help develop student professional skills such as oral and written communication, project management, leadership, and ability to function on a multidisciplinary team.

The paper also describes how a power electronics project was used recently in the first senior project course to help augment the program curriculum. The department has not offered many power-related electives in recent history, but is seeking to provide additional offerings in response to local and regional needs. A student survey shows that the power electronics project has served to stimulate student interest in this subject, prior to the planned offering of a power electronics elective next year. Student feedback also shows that the project course has been effective in developing student design and professional skills.

Introduction

The major design experience of students in the department of Electrical and Computer Engineering at University of the Pacific occurs in a two-course Senior Project sequence. A few years ago, the first project course focused on an introduction to design processes, with students concurrently working to define a project and prepare a design proposal. Students did not begin seriously working on the design project until they were in the second project course, at the end of which a functional deliverable was expected. Not having prior experience with a major design project, students were slow in making progress on their projects in the second course. Similar experiences were reported by Tranquillo and Cavanagh of Bucknell University. The solution at Bucknell was to create a rapid design challenge in which students embarked on a rapid comprehensive design experience prior to beginning their senior design course. To remedy this problem at University of the Pacific, the first senior project course was reorganized such that it exposed students to a comprehensive design experience in a structured environment. This paper describes the organization of the first senior project course using the Fall 2009 semester projects to illustrate its constitution.

Several authors have discussed the development of student professional skills and how to do this in the context of design. The senior project course re-organization at University of the Pacific
also sought also to help develop student professional skills (such as communication, project management, leadership and teamwork) during the course. This paper describes the avenues used to develop student professional skills and also discusses assessment methods.

The paper also describes how the first senior project course was used to help augment the existing program curriculum during its Fall 2009 offering. There is a consensus that projected workforce shortages are looming in the energy and power sector. The U.S. power and energy engineering workforce collaborative\(^5\) has prepared a report on this workforce shortage problem and outlined strategies to address the problem. To help jumpstart university development of power and energy curricula in response to the need for qualified workers, the Office of Naval Research, the National Science Foundation, and others have funded the University of Minnesota’s curriculum development and dissemination efforts\(^6\). The US Department of Energy is also funding proposals related to workforce training for the electric power sector\(^7\). In response to local industry needs, to satisfy demand from students, and to respond to the projected workforce shortages, the department of Electrical and Computer Engineering has begun developing and offering courses in the energy and power area. Having benefited from participation in one of University of Minnesota’s summer workshops, the department plans to offer a power electronics course next year, for the first time since the loss of faculty expertise in the power area many years ago. It was decided to center the senior project course around power electronics to expose current students to power electronics, and to motivate student interest in power electronics prior to a future course offering. The project course could thus serve as a vehicle to augment the program curriculum by exposing students (some of whom would have graduated prior to the offering of the power electronics course) to the important area of power electronics.

The purpose of this paper is three-fold: (1) To describe the re-organization of the first senior project course to ensure that students were exposed to a comprehensive design experience prior to embarking on a more complex design project in the second senior project course. (2) To describe the mechanisms and opportunities used to foster the development of student professional skills during the project course. (3) To report on how a power electronics-based project was used to augment the program curriculum in Fall 2009. The paper also presents assessment results related to the above three items.

**Organization of the Senior Project Course**

The Electrical and Computer Engineering department at University of the Pacific offers three degree programs: Electrical Engineering (EE), Computer Engineering (CpE), and Engineering Physics (EPhys). Students in the senior project course thus come from three different disciplines and can bring different strengths to a project team. Each team in the first senior project course typically consists of 3 students, and contains at least one CpE student. The remaining two students in the team include at least one EE or EPhys student. Student teams are therefore multidisciplinary: computer engineers on the team are proficient in software and embedded system design and contribute more towards these aspects of projects; electrical engineers have strengths in analog electronics, circuit design, and prototyping, and make contributions in these areas; EPhys students have circuits and electronics knowledge coupled with a greater background in science and engineering science that they can bring to bear on their projects.
The senior project course is very structured; students tackle three related projects of about 5 weeks duration each over the course of the semester. All student teams work on the same projects, which are defined by the instructor. The first project is always a “paper design”, where students design circuits and algorithms to meet the design objective. Students also use simulations to verify their designs. In the second project, students use the project 1 design as the basis for implementing a working prototype. The third project is an extension of the first two, often involving a computer interface to the project, and implementation of a more robust prototype.

A team leader is assigned for each project, and leadership roles are rotated from one project to the next. Teams are required to use project management principles and develop a work breakdown schedule and Gantt chart for each project. Oral presentations and written reports are required for each project. Intermediate reviews and final demonstrations are also required for each project. Breaking down the course into 3 projects makes project execution easier for students; it allows them to focus their energies on a piece of the larger project at a time. Due to the short duration (about 5 weeks) of each project, students get early feedback from the instructor and this helps them stay on track with their projects.

The project course is a 2 unit class that meets for 1 hour each week and uses a textbook by Ford and Coulston\textsuperscript{7}. Topics such as project management and teamwork are covered early in the semester, as teams will need to use these ideas almost immediately. Class time is also used to introduce topics related to the design process such as needs identification, specification of requirements, and functional decomposition. Student teams work together outside of the scheduled class period to work on their projects.

The following section outlines the projects used during the Fall 2009 semester. The sample projects help shed more light on the way the course is structured.

**Sample projects from the Fall 2009 offering**

As mentioned in the introduction, the Fall 2009 projects were centered around the area of power electronics. This was done to help expose students to topics not currently in the curriculum, and to stimulate interest in power electronics prior to the planned offering of a power electronics course. Figure 1 gives the specifications for the first project. It involves the design of a “boost converter” that can boost a 5V DC input voltage to a 9V DC output voltage level. The first project happens to contain mostly analog design elements; however, all students in the course (EE, CpE, and Ephys) have had the first electronics course and have sufficient background to be able to understand the working of the boost converter.

DC voltage step-up was a novel concept to students; they were familiar with transformers that change AC voltage levels, but not with boost converter circuits. Their interest was further piqued when they realized that such converters were used to boost battery voltages in cell phones and hybrid electric vehicles.
Obtain a 5V DC input from a USB port. Design a switch mode converter that uses this input source to generate a 9V DC output that is capable of supplying 50mA. The ripple on the output voltage should be no greater than 0.1V. The suggested switching frequency for the converter is 100kHz.

Choose component values (show all design details). Also choose desired components (switching device, diode) that will meet the design specifications. Simulate your design and demonstrate that the design specifications are met.

Devise interface circuitry that will accept a logic output from a control device (such as a microcontroller or programmable logic device) and convert it to levels that can control your switch.

Project 2 requires hardware implementation of the design of project 1, with some additional requirements related to user input and status displays. In project 1, the duty cycle of a switching transistor determines the boost ratio of the circuit. By adjusting the duty cycle, different output voltages can be obtained. Figure 2 gives the specifications for project 2. Part 1 involves construction of the circuit designed in project 1, while part 2 is an extension of the project that allows user input to dictate the boost ratio and thus the output voltage of the converter. Project 2 also requires measurement and display of the actual output voltage generated by the converter.

Part 1:
Implement your project 1 design and demonstrate its functionality (boost conversion from 5V to 9V for a 50mA load). Your implementation should include a programmable duty cycle generator to switch the transistor on and off.

Part 2:
Continue to use a 5V DC input for your converter and keep the load the same as for Part 1. Modify your design to accomplish the following:

1. Your system must accept user input that specifies the desired output voltage, which can be 6, 7, 8, 9, 10, 11, or 12V. The input device cannot be just a set of switches. Use a keypad or other input device that requires just one touch from the user.
2. In response to the user input, the system must automatically adjust the output voltage to that which is specified.
3. The system must measure and display the output voltage that is generated on a display device. The display should display volts and tenths of volts (for example, it should be able to display 12.1V).
4. Accuracy of generated voltages should be ±2%.

Extra credit: 7% extra credit if you wind your own inductor and use in your project. A ferrite core and specifications are available.
Project 2 involves significant computer hardware and software; teams used a microcontroller to read the user input specifying the desired output voltage, to generate a square wave of appropriate duty cycle (which determines boost ratio) to drive the switching transistor, and to measure and display the output voltage produced by the converter. While executing project 2, teams could break down responsibilities based on the skills of team members; CpE students could tackle the software aspects, while the EE and Ephys students could work on the analog elements. One team containing an EPhys student took on the extra credit task of designing and winding their own inductor.

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<th>Build on Project 2 and accomplish the following:</th>
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<td>1. Use Eagle PCB software (<a href="http://www.cadsoftusa.com">www.cadsoftusa.com</a>) to layout your design in preparation for creating a printed circuit board. The software is already installed on our program computers. Deliverables include: Schematic diagram, output of electrical rule check, output of design rule check, printout of final board layout, electronic submission of a zipped folder containing all project files.</td>
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<td>2. Put your circuits on a circuit board – all components must be soldered or wire-wrapped. Projects that use a PCB will receive 7% extra credit.</td>
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<td>3. Interface your circuit board to a PC. Software running on the PC must receive signals from your board and display the output voltage of the converter on the PC.</td>
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Figure 3: Description of project 3

Figure 3 gives the description of project 3. It involves using a CAD tool to layout the circuit designed in project 2 in preparation for creating a printed circuit board, converting the breadboarded circuits of project 2 into more permanent circuits (using wire-wrap or soldering), and interfacing the circuit to a personal computer (PC) to allow the converter output voltage to be viewed on a PC. As was the case with project 2, project 3 also contains a mix of analog (circuit board layout and construction) and digital (PC interface) elements.

Assessing the efficacy of the project course

The project course is crafted to improve student design skills and professional skills (ability to function on multidisciplinary teams, teamwork, leadership, communication, ability to engage in lifelong learning, project management). There was a secondary objective in the Fall 09 offering of the course: to introduce students to power electronics, a subject not in the present curriculum, with a view to motivating student interest in a future power electronics course offering. The following subsections discuss the ways the course seeks to achieve these objectives, and how they are assessed.

Ability to function on multidisciplinary teams

The projects described in the previous section require a wide range of skills. Student teams, which typically consist of 3 members, are guaranteed to have one CpE major and one non CpE
major (EE or Ephys). The third team member could be from either of these groups. All teams are required to provide work breakdown schedules for their projects. These schedules list the subtasks in each project, and the team members assigned to each task. Instructor assessment based on these work breakdown schedules shows that students divide tasks based on their background and skills. For example, EE or Ephys majors worked on the derivation of boost converter equations, component selection, and simulations of project 1, the circuit assembly of project 2, and the printed circuit board layout of project 3. CpE majors on the teams worked on microcontroller programming (to accept user input from a keypad, to generate a square wave of appropriate duty cycle to drive the switching transistor, to measure boost converter output voltage using an analog-to-digital converter, and to display the output voltage on an LCD panel). CpE majors also worked on software to interface the boost converter to a PC in project 3. The work breakdown schedules and final project demonstrations made it clear to the instructor that different team members brought their unique backgrounds and skills to bear on the project. The course thus provides students an opportunity to work on a multidisciplinary team. Attendance at a recent ABET workshop confirmed that such experiences are valid for assessing student ability to function on multidisciplinary teams.

**Project management skills**

Students are exposed to project management concepts (work breakdown schedules, network diagrams, Gantt charts etc.) in the lecture component of the project course. Teams are required to prepare and submit schedules for each project. They are also assigned homework on work breakdown schedules, network diagrams, and Gantt charts. All of this data was used to assess student proficiency in project management. A student survey (results presented in the following section) shows that students feel strongly that they have gained project management skills in the course. Instructor evaluation of the assessment data also shows that students have gained project management skills.

**Teamwork and leadership skills**

Students are exposed to team concepts and leadership principles through in-class discussions, and from material in the course textbook. Assessment of teamwork is based on instructor evaluation (by asking questions at progress reviews and final demonstrations), and by peer evaluation (students assess contributions of all their team members at the end of each project). Both the instructor evaluation and peer evaluations showed that students gained teamwork skills. One group reported having problems with a team member; comments from the peer evaluation showed that despite some difficulties with team dynamics, students feel that they gained valuable experience in dealing with a difficult team member.

The structure of the course (which is broken down into 3 projects) also helps with the development of teamwork and leadership skills. With a 3 person team, each team member gets to serve as a group leader for a project, since leadership roles are rotated from one project to the next. Team dynamics solidify as teams go from one project to the next; teams gain experience and are able to work more effectively as they go on to subsequent projects.
Communication Skills

Students are required to write a project report for each of the three projects. They also prepare intermediate progress reports. For one of the projects, students were required to submit a draft report. The instructor reviewed these draft reports and provided feedback for improvement that teams had to take into account when preparing the final report. Students thus have a number of opportunities to practice and improve their writing skills in the project course. Students also make 3 to 5 oral presentations during the project course. This includes oral presentations on their projects as well as in-class presentations on topics related to the design process. The instructor provides feedback to teams on their oral presentations. The multiple required presentations give students opportunities to improve their oral presentation skills.

Ability to engage in lifelong learning

The project course forces students to research topics unfamiliar to them; they thus improve their ability to learn independently, and gain an appreciation of the need for lifelong learning. During the Fall 2009 offering, the following were some areas where students had to seek out information and learn independently: (1) The area of power electronics and boost converters was unfamiliar to students; they had to learn about boost converter operation and design principles. (2) Students had no prior exposure to high frequency inductors. They learned about ferrite cores, and one team designed and wound their own inductor. (3) The project pushed students to expand their knowledge of microcontroller programming and interfacing; they had to use subsystems that they were unfamiliar with, and also had to integrate and debug numerous program modules. (4) Students were unfamiliar with CAD tools for printed circuit board layout and had to learn how to use them. (5) Students learned independently about graphical user interfaces and learned to transfer data from their device to a PC. Assessment was based on the quality of the final product for each of the three projects (knowing that significant independent learning was required to successfully complete each project). A survey used to capture student perceptions also shows that students believe they gained lifelong learning skills.

Design skills

As mentioned in the introduction, one of the motivations for organizing the first senior project course in the manner outlined here was to give students a comprehensive design experience (in a structured environment) prior to the second senior project course. The first project course exposes students to project management principles, gives them experience in researching components, creating prototypes, and helps improve their programming and debugging skills. All of this has helped students perform better in the second senior project course, in which students tackle more complex projects. It has been observed that students approach the second senior project course with more confidence. The quality of the projects in the second senior project course has also improved.

Results of a Student Survey

Assessment by the instructor as outlined above has shown that the first senior project course helps develop student professional skills and design skills. A student survey administered at the
end of the project course sought to capture student perceptions regarding skills gained. The survey also asked questions regarding the project focus on power electronics and whether it served its intended purpose of motivating student interest in power electronics. The survey contained the following questions:

1. Has this project helped to stimulate your interest in the field of power electronics?
2. Would you be interested in taking a power electronics course if it was offered?
3. Has the course helped improve your design skills?
4. Has the course helped improve your project management skills?
5. Has the course helped to improve your communication skills?
6. Has the course helped to improve your ability to function on a team?
7. Has the course helped develop your leadership skills?
8. Has the course helped you recognize the need for lifelong learning and helped improve your ability to engage in lifelong learning?

Students were asked to respond to the questions using a 5 point Likert scale. A rating of 5 represented strong agreement with the question; a rating of 1 represented strong disagreement with the question, and 3 was a neutral rating. The senior project class during the Fall 2009 semester consisted of ten students with 6 CpE, 2 EE, and 2 Ephys students. Table 1 lists the student responses to the eight questions listed above and also gives the average rating for each question.

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Table 1: Summary of student responses to the survey instrument

Questions 1 and 2 relate to whether the course stimulated interest in power electronics, and whether students would be interested in taking a power electronics course if it was offered. Responses to question 1 (in the first data column of Table 1) show that five students gave a rating of 4 and thus indicated that the course stimulated their interest in power electronics. The responses to question 2 show that the same five students also indicated that they would be interested in taking a power electronics course if it was offered (four of them gave the highest
Questions 3 to 8 of the survey relate to improvement in the design and professional skills of students. The results in Table 1 show quite clearly that students believe that the course helped improve their design and professional skills. Not a single student gave a rating below 3 for any of these questions. Further, the average rating for all these questions is well above 3 (and above 4 for a majority of the questions). Question 4, which relates to improvement in project management skills, had the highest average rating (4.4) of all questions. Students clearly appreciated the introduction to work breakdown schedules, Gantt charts, and other project management ideas seen in the class.

**Lessons Learned**

The reorganization of the first senior project course has given students experience working on a comprehensive design project in a structured environment. This has helped improve student performance in the second project course. For example, several teams in the second project course implemented their designs on printed circuit boards after their experience in the first project course. This rarely happened during a design project that was concentrated in one semester.

The lowest student ratings in the student survey results of Table 1 relate to questions 5 and 7 that relate to communication skills (average rating of 3.8) and leadership (average rating of 3.6). It would be good to incorporate workshops on making effective oral presentations, utilize university resources such as the university tutoring center to assist with writing skills, and employ student reviewers from the English department to provide feedback on written reports as outlined by Catalano et al.

**Conclusions**

The structure of a recently reorganized senior project course at University of the Pacific has been described. Student teams in the project course are multidisciplinary, with two to three different majors represented on each team. The project course is structured to help develop the design and professional skills of students; faculty observation and results of a student survey show that the course indeed does perform this function. Students completing the first senior project course are thus well positioned to successfully undertake a major design experience in the second senior design project course. The paper also describes how the vehicle of a design project was used to expose students to topics outside current course offerings, and thus augment the program.
curriculum. The course was very successful in enhancing student interest in the field of power electronics, so much so that 50% of the class including at least one Computer Engineering student expressed interest in taking a power electronics class.

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