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Breaking Down the Silos with an Integrated Laboratory Experience

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Breaking Down the Silos with an Integrated Laboratory Experience: Preparing Students for Capstone Design, Part II

Introduction:

In many electrical engineering programs, students are required to demonstrate the success of their senior capstone design project by building and testing a prototype of their design. Depending on the nature and complexity of the project, the final prototype may be a blend of analog and digital, hardware and software, discrete components and off-the-shelf parts. The students are challenged, not just by the design, but by the integration of these various types of technologies. Students are often ill-prepared to meet these challenges because of the nature of most course-based laboratory courses and students' inexperience in working with off-the-shelf parts.

To address these challenges, a three credit laboratory course was developed for first semester seniors in order to better prepare them for capstone design. The learning objectives for this course include:

1. Students will be able to successfully integrate hardware and software in design.
2. Students will be able to successfully interface (through hardware or software) with off-the-shelf parts.

The course includes seven or eight mini design projects. In addition to building and testing a prototype, most projects require the submission of a pre-lab design and a post-lab report. The projects overlap throughout the semester such that in any given week a student may be working on the report for the previous project, the build for the current project, and the design for the next project. For each build the students are given one to three weeks of lab time, at a rate of four hours per week.

To introduce the students to using off-the-shelf parts, one or more components or parts unfamiliar to the students are required for each project. The students must research the components, read datasheets and experiment with the component in order to understand how to use it in their design. Many projects also require the integration of hardware and software. PCs running Matlab and Freescale HC12 microcontroller development boards, subsequently referred to simply as microcontrollers, are available.

Several examples of design projects used in this course were presented at ASEE in 2013 [1]. This paper describes five exciting new projects that have been developed and used in the past three years.

Literature Review:

Over 20 years ago ABET began requiring a culminating design experience for all accredited engineering programs. According to this requirement, "Baccalaureate degree programs must provide a capstone or integrating experience that develops student competencies in applying both technical and non-technical skills in solving problems" [2]. In response to ABET, programs across the country have designed a capstone course to include in their curriculum. The variety of these courses is vast. In 1997, Dutson et al. offered a thorough literature review of capstone courses, covering a body of literature that has expanded exponentially since then [3]. Typically the learning outcomes and goals of these courses include exposure to real world design challenges, confidence building, and experience of team projects.

While these project-based courses help solidify knowledge of core engineering concepts, the courses are often designed to achieve additional pedagogical goals. Faculty have successfully used capstone courses to address issues of student success [4], expanding diversity [5], gaining experience with industry [6] and even to incorporate service learning into engineering curricula [7]. Mini projects have been implemented in the past for various ends, including ABET assessment [8]. Largely, these courses help to teach the many "soft skills" that students will need in their professional careers.

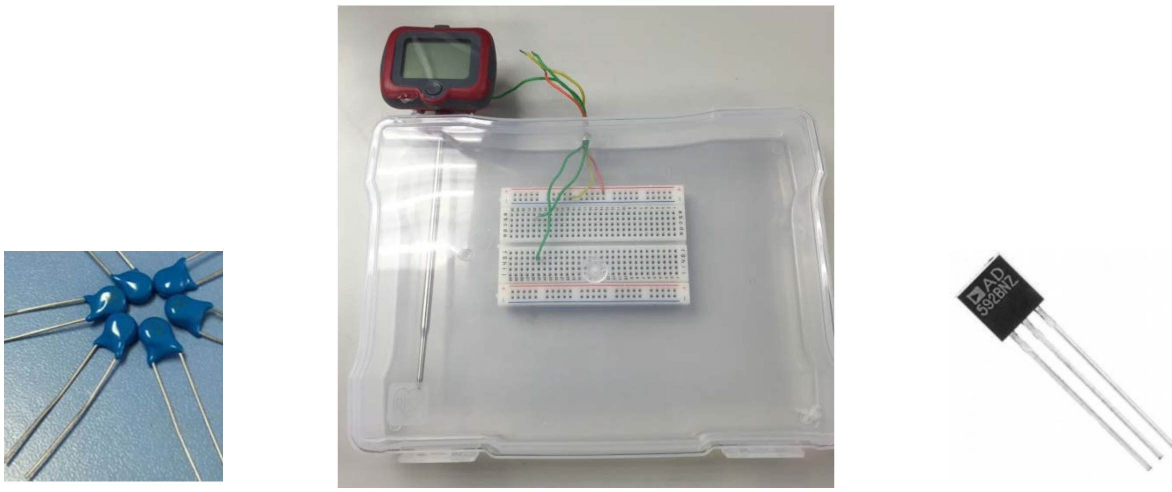
However, there is an additional set of soft skills that students need to succeed in these capstone courses. To that end, our electrical engineering department has added a senior-level course prior to the capstone course. While such a course shares the learning outcomes with the final senior design capstone, this course specifically aims to develop soft skills of working with off-the-shelf technology so that in the final senior project, they can focus more on problem solving and the complexities of that particular design challenge. To the typical list of soft skills developed in capstone course [9], we put forth that the integration of off-the-shelf technology is a challenge in itself, as is learning to interface hardware and software. Teaching these skills before the senior design capstone can help increase success in the more high stakes course that follows.

The Design of a Digital Thermometer:

The objective of this project was to design a digital thermometer using two different types of temperature sensors. The thermometer was required to accurately determine the ambient temperature in the range from 50°F to 150°F to within 5°F. Once calculated, the temperature determined from each temperature sensor was to be reported, with appropriate and informative text, on the computer monitor. The students, working in groups of two, had one week to build and test their prototype.

The students were required to use a microcontroller with an 8-bit ADC, a 10kΩ thermistor (Figure 1a), and an AD592 temperature transducer (Figure 1c). These two temperature sensors were selected because the parameter that changes with respect to temperature differs. For the thermistor, the resistance varies as a function of temperature. Alternatively, the output current of the AD592 is the parameter that varies as a function of temperature. The students were not familiar with either part so they had to research and test the parts prior to starting their design and writing their software program.

Once designed, the input interfaces were resistive and simple to assemble. The most challenging aspect of the project was the testing. Students were expected to test both sensors simultaneously so they could better compare the accuracy of each sensor. Aerosol coolant was provided as a cooling agent and hair dryers were provided as a heating agent. The students had to design and construct a test chamber in order to uniformly heat and cool the sensors. An example of such a test chamber is shown in Figure 1b.



a) 10kΩ Thermistors   b) Test Chamber   c) AD592 Temperature Transducer IC

Figure 1: Digital Thermometer Components and Test Chamber

There were other challenges that made for a wonderful learning experience. The two sensors responded to changes in temperature at different rates, so the temperature in the test chamber had to be changed very slowly in order to collect accurate measurements. Also, the relationship between voltage or current and temperature was not linear across the temperature range to be tested, so code had to be tweaked in the final stage of testing in order to achieve the required accuracy.

The Design of a Matchbox Seesaw:

The objective of this project was to design a seesaw for a matchbox car. Driven by a motor, the seesaw was to rock the car back and forth, changing directions based on the car's position to ensure that the car would never fall off the seesaw. Students working in groups of two had three weeks to build and test their prototype.

The students were required to use a microcontroller to drive the Hitec HS-422 servo motor pictured in Figure 2a with a 50Hz square wave signal. The pulse width of this signal indicates the position of the shaft with respect to the rest of the motor. The resting pulse width is 1.5ms. Pulse widths of 0.9ms and 2.1ms rotate the shaft 90° in either direction. Other shaft positions can be achieved by varying the pulse width between these two extremes.

Although the microcontroller can be used to generate the PWM waveform to drive the servo motor, it cannot provide the required current to the motor. This was discovered only from a careful read of the respective datasheets. A motor driver was needed to amplify the current delivered to the motor to meet the maximum input current of 800mA.

a) Hitec HS-422 Servo Motor b) Hall Effect Sensor

Figure 2: Matchbox Seesaw Components

Figure 3: Matchbox Seesaw Student Prototype

Once the code was written and the motor driver designed, each group was required to construct a 12” x 3” seesaw out of light balsa wood. Various metal brackets, X-ACTO knives and hot glue were provided for assembly. Small magnets and Hall effect sensors (Figure 2b) were also provided. Students positioned the magnets and sensors on the matchbox cars and on the wood of the seesaw such that the position of the car on the track could be determined. This information was used to change the direction and/or speed of the matchbox car. Two views of a student prototype are shown in Figure 3.

This project was particularly challenging because the movement of the motor shaft, which determined the angle of the plank of the seesaw, had to be tightly controlled. Any sudden movement or rapid change in its position could result in a dramatic increase in the speed of the car. The students quickly realized that if the car was moving too fast as it passed one of the Hall effect sensors, the system could not respond quick enough to prevent the car from flying off the end of the seesaw. The students also quickly realized the need to closely monitor the state of the Hall effect sensor to ensure that the software would always detect the presence of the car.

The Design of a Scoreboard Remote Control Unit:

The objective of this project was to design a remote control unit for a basketball scoreboard. The remote system was to be capable of adjusting the scoreboard for a penalty shot (1 point), regular basket (2 points), and a 3-pointer. There was also to be a reset button to clear the scoreboard. An example of the expected layout of the remote unit is shown in Figure 4. Students working in groups of two had two weeks to build and test their prototype.

Figure 4: Example Layout for Remote Control

The students were required to interface seven buttons like those shown in Figure 4 with a microcontroller. The key presses were to be captured and a corresponding signal transmitted via a ZigBee module using an asynchronous serial communication protocol. Another microcontroller, paired with a ZigBee module, was to receive the transmitted signals and update the score on a small display.

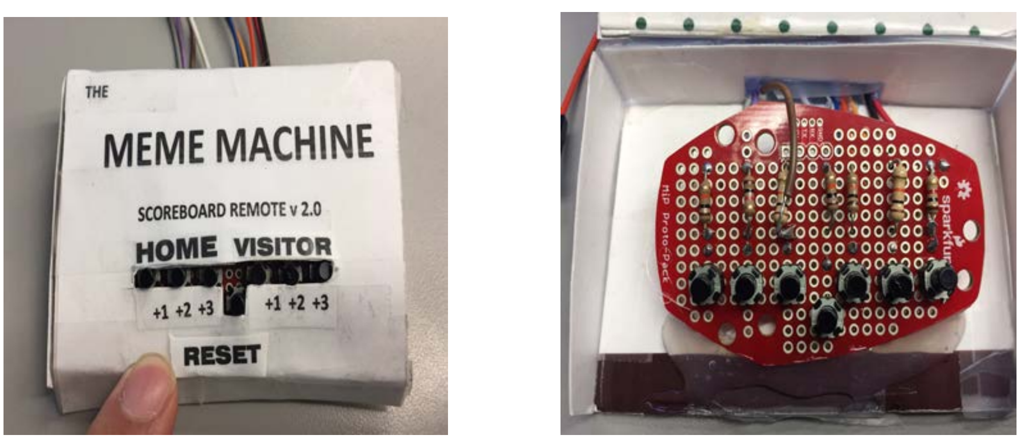


Figure 5: Scoreboard Remote Control Unit Student Prototype

In the course of this project students learned about hardware and software debouncing and using ZigBee modules for wireless communication. A bonus lesson was learned as the students began testing their prototypes. Depending on the code used to indicate individual button presses, multiple scoreboards were simultaneously updated when a button on any remote was pressed. A few teams solved this problem by created unique codes not used by any other group. The lab was abuzz with groups working together on coding schemes.

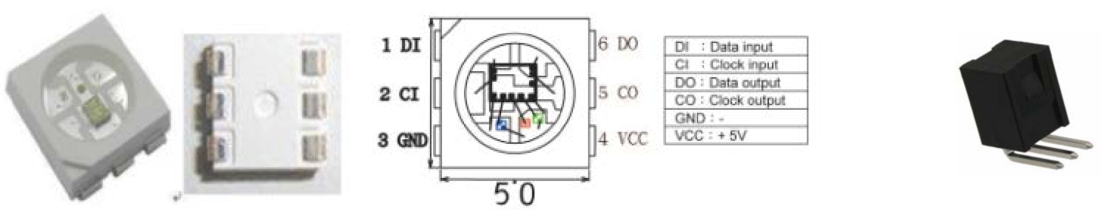
Another aspect of the project the students enjoyed was building the housing for their remote. They enjoyed the creativity of this requirement. This particular group of students were dabbing meme-loving Millenniums. This was humorously demonstrated with the prototype from one group of students shown in Figure 5.

The Design of a Bicycle Safety Vest:

The objective of this project was to design a piece of safety clothing for a bicyclist. The clothing was to be embedded with electronics to make the bicyclist visible from the front, back and sides. In addition, the electronics were required to illuminate (in some dynamic, not static, manner) an upcoming turn following the bicyclist indication of the turn direction. The students were encouraged to be creative. Students working in groups of two had three weeks to build and test their prototype.

The students were required to use up to ten APA 102C full color LEDs (Figure 6a). They were also allowed to use up to two TM1000Q tilt switches (Figure 6b) to indicate a turn direction and any other components available in the laboratory. Long lengths of ribbon cable and conductive thread were provided.

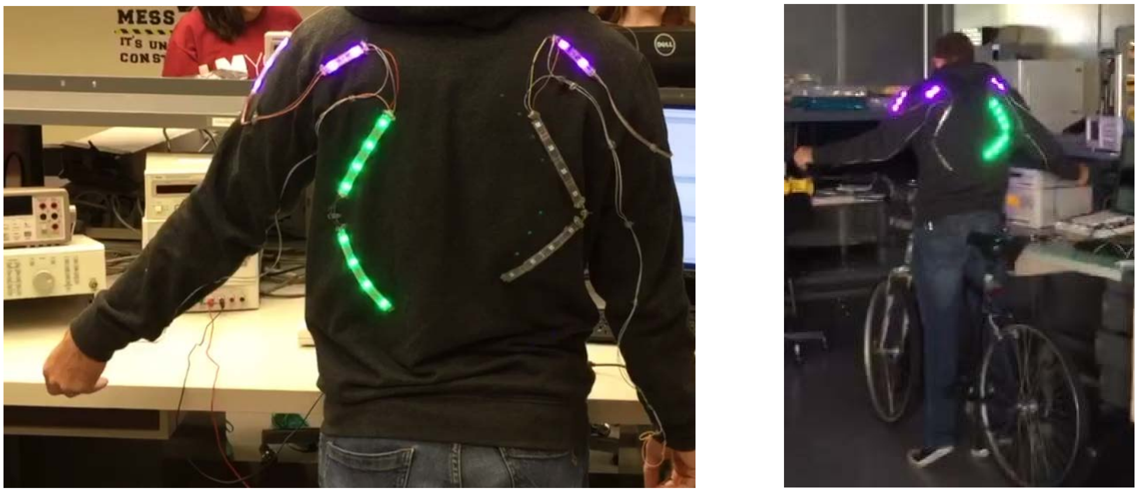
The most challenging aspect of the design was to learn how to illuminate various colors on the LED ICs. Each LED was programmed by 32 bit data frames indicating the brightness and color sent using a synchronous serial communications protocol. In addition, the LED ICs were daisy-chained together allowing data frames to be transmitted sequentially and received by consecutive ICs. Once this was mastered, the students moved on to the more creative aspect of the project.



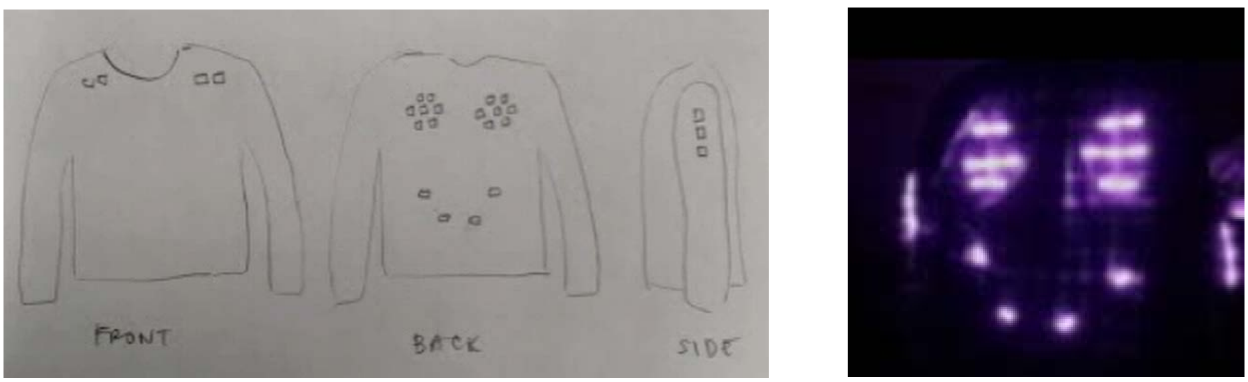
a) APA102C RGB Full Color LED Control IC b) TM1000Q Tilt Switch

Figure 6: Bicycle Safety Vest Components

The students had great fun designing the jacket and embedding the electronics in the fabric. Groups used hot glue, sewing thread and reflective tape to secure the electronics. On one prototype, the LEDs were arranged in the shape of two arrows that flashed to indicate the turn direction. This prototype can be seen in Figure 7a. On another prototype, the LEDs were creatively arranged in the shape of a face. The eyes alternatively blinked to indicate the turn direction. This prototype can be seen in Figure 7b. In both cases tilt switches were sewn into the sleeves to detect when the rider raised an arm to indicate a turn.



a) Illuminated Turn Arrows



b) Winking Smiley Face

Figure 7: Bicycle Safety Vest Student Prototypes

Commencement cap:

The objective of this project was to design adornment for a graduation cap that demonstrates creativity, technical skill and school pride. The design was to be mounted on a 9” by 9” form that could be attached to a standard graduation cap. The students were required to embed the mortarboard with electronics that provided lights, movement and sound. Each of these features was required to *play* a minimum of two patterns, which could be toggled between using an input tilt switch. Students were graded on functionality, polish and school pride.

Each group of two students was required to use the speaker, motor and tilt switch shown in Figure 8. In addition, each group was allowed to use a maximum of 15 LEDs, a maximum of three 7-segment displays and any other components available in the lab. The components required for this project are similar to those required for the bicycle safety vest project. To ensure that students are always introduced to new components with each project, the commencement cap and bicycle safety vest projects were used in different years, so with different students.

Students working in groups of two had two weeks to build and test their prototype.

The students enjoyed the creative aspect of this project a great deal. Figure 9a shows a replication of the commencement stage at Loyola Marymount University with LEDs representing various faculty members under the tent. The students programmed a microcontroller to play the graduation song, *Pomp and Circumstance*, through a connected speaker. Another group attached a tassel to the cap that switched sides as the tilt switch, attached to the student's wrist, was rotated. Three 7-segment displays were used to illuminate the initials of the university (Figure 9b). In a final example, shown in Figure 9c, a campus flag was raised as the university initials sparkled with flashing LEDs.

a) 8Ω Speakers b) Towerpro SG90S Servo c) TM1000Q Tilt Switch

Figure 8: Required Components for Commencement Cap Design

a) Commencement Stage b) Moving Tassel c) Victory Flag

Figure 9: Commencement Cap Student Prototypes

Assessment:

In addition to the general course evaluation form required by the university, an anonymous evaluation form specific to this course was administered at the end of each semester to assess the learning objectives. The evaluation form asked students to rate the effectiveness of the course in providing experience integrating hardware and software (learning objective 1) and in using off-the-shelf parts (learning objective 2) in preparation for the senior capstone course. These questions are shown on Figure 10. Below each possible response, in blue, is the frequency with which each response was selected. The denominator indicates the sample size or the enrollment in the course over the past two years. A chart of the frequency of each response for each question can be seen in Figure 11. Nearly all of the responses were positive (96.6%), with only one response of indifference and one response of ineffective. The ineffective outlier could be considered student error because there was no accompanying explanation. Regardless of how the outlier might be interpreted, however, the vast majority of the students felt better prepared for their senior capstone project at the completion of this course.

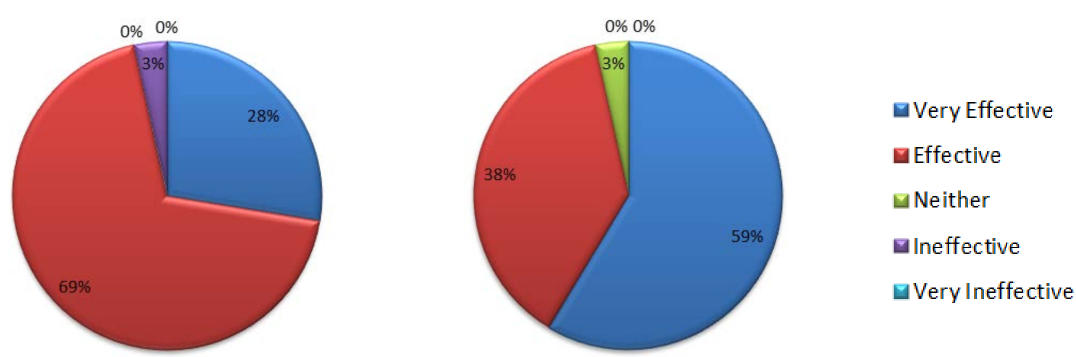
1. The prototype for your senior project will undoubtedly include hardware and software. Several of the experiments were designed to give you experience interfacing hardware and software. How effective do you think these experiments were in giving you this experience? Circle one of the following responses and explain your choice.

Very effective	Effective	Neither effective nor ineffective	Ineffective	Very ineffective
8/29	**20/29**		**1/29**	

2. Your prototype will also undoubtedly include one or more off-the-shelf components. Several of these experiments were designed to give you experience interfacing with off-the-shelf components (reading datasheets, tinkering with components in lab, interfacing components with additional hardware or software). How effective do you think these experiments were in giving you this experience? Circle one of the following responses and explain your choice.

Very effective	Effective	Neither effective nor ineffective	Ineffective	Very ineffective
17/29	**11/29**	**1/29**		

Figure 10: Course Evaluation Survey Questions



a) Question 1 Responses b) Question 2 Responses Legend

Figure 11: Course Evaluation Survey Responses

Students were also invited to comment on individual projects and the course in general. The comments were overwhelmingly positive. Some of the comments relevant to this paper are listed below:

- This course definitely exposed me to hardware components that I had not used before.
- I actually liked that Dr. Marino did not just tell us how to use all the components. It forced me to read the datasheets to find necessary information and apply a methodical approach to test the functionality of the components.
- Lab definitely gets you in the mindset for finding technical specifications.
- All the projects were so different from each other, so we were able to apply a broad range of our EE knowledge.
- The breadth of projects covered in this lab gave me a wide range of tools to use in my senior project. Each project was so unique that it forced me to continuously innovate and adapt.
- I found the different lab themes and creative solutions were the most beneficial aspect of the course.
- The most beneficial aspect of the course was the emphasis on a freedom of design.
- This course really allowed me to do my best work. I could focus on the design aspect and take the necessary time to come up with a good solution.
- The teacher actually knows how to make EE work fun. A+.
- My favorite lab course!!
- This lab was definitely the most enjoyable course I have ever taken.
- If you don't have fun in this class, you picked the wrong major!

Conclusions:

Five examples of design projects incorporating various technologies and off-the-shelf parts were created to better prepare students to meet the challenges of the capstone design. The results of assessment indicate that these projects are very effective at doing this. This combined with anecdotal student feedback show that the introduction of these new projects makes the course more fun, more relevant to an engineering career, and better prepares students to meet the expectations of their senior capstone project.

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