AC 2012-3040: FOR STUDENTS BY STUDENTS: LABWARE AND COURSEWARE DEVELOPMENT

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For Students By Students:
Labware and Courseware Development

Abstract

We have successfully implemented a program whereby students develop labware and courseware for other students. We have called this approach "For Students By Students or FSBS." In this program students as either for a senior design or graduate level project design, prototype and implement laboratory equipment and courseware for use by other students. This has proven to be a very effective approach to provide for up-to-date laboratory labware and courseware in rapidly changing disciplines such as electrical and computer engineering on a limited budget. More importantly, participating students gain valuable real world experience in designing, prototyping, and delivering a system with accompanying support documentation. In this paper we review 10 successful projects that have been completed over the past decade using the FSBS approach. We then provide a step-by-step methodology to implement this program. We also provide a case study for replacing the lab trainer and labware for a microcontroller course based on the Freescale S12 microprocessor.

Overview

In this paper we discuss a concept we have dubbed "For Students By Students (FSBS)." The basic concept is to illicit student help in developing labware and courseware that will be used by other students. We have found that students are highly motivated to work on meaningful projects that will be used by others. Students who participate in these labware and courseware development projects learn how to be project managers by managing all aspects of the project under faculty supervision.

Department programs also benefit via the FSBS concept. It is very time consuming and costly to develop new labware and courseware. Furthermore, faculty often do not have the time with all their diverse responsibilities to develop new and current materials in a timely manner. The FSBS concept allows them to be closely involved as a project mentor.

There is no shortage of students looking for meaningful, challenging projects. All accredited undergraduate programs of engineering and computer science require a capstone design experience. ABET criteria states: "Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints."[1] The criterion also provides a list of student outcomes commonly referred to as 3(a) to 3(k). Many of these student outcomes may be practiced by students participating in an FSBS project. Potential student outcomes include:

- "an ability to apply knowledge of mathematics, science, and engineering
- an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- an ability to function on multidisciplinary teams

- an ability to identify, formulate, and solve engineering problems
- an ability to communicate effectively
- an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice"[1]

In addition to undergraduate students, graduate students pursuing non-thesis masters degrees often must complete a substantial project. The FSBS approach allows them similar opportunities to those afforded undergraduate students.

The FSBS concept is not new. The authors have worked with multiple students on the development of labware and courseware over the last ten years with great success. A brief summary of these projects is provided in the next section. In all cases students have completed project requirements. Furthermore, they have served as co-authors on conference and journal papers.

We provided a brief overview of the FSBS concept in a recent Education Column for IEEE's *Computing in Science & Engineering* magazine.[2] In this paper we briefly review the projects completed via the FSBS concept. Our intent is to illustrate the depth and breadth of projects that are possible. We then provide a step-by-step description on how to develop an FSBS project. We illustrate the process using a recently completed FSBS project: a graduate student selected a replacement laboratory Freescale S12 evaluation board for our undergraduate microcontroller courses and then developed the accompanying labware.

Background

As previously mentioned, the FSBS concept is not new. Provided below is a brief review of projects successfully completed via this concept with references to the literature. Please note the student coauthors.

- An ongoing laboratory exercise in a graduate level Real Time Embedded Systems course requires students to program an autonomous robot to navigate through a maze. Student teams compete to see which team can navigate through the maze as quickly as possible without bumping into maze walls. The robots detect maze walls using an array of infrared sensors. Two freshman engineering students developed a reconfigurable 4' x 8' maze for the course. The maze walls can easily be moved to construct different configurations for use in the autonomous robot competition.[2,3]
- The robot for the maze completion was also developed using the FSBS concept. After several prototypes, a final design was accomplished using readily available, commercial off-the-shelf (COTS) components. The robot is a two platform design equipped with four infrared sensors and two servo motor powered wheels.[2,4] Both the maze and the robots have been used regularly in the laboratory portion of the course for six years.
- In support of our undergraduate microcontroller course, trainers based on the Motorola/Freescale HC12 and the S12 microcontroller were developed. The design team took a hybrid approach. They developed a trainer which couples a COTS microcontroller board with an additional student-designed daughter card to provide keypad access, a liquid crystal display, and easy access to input/output ports. The COTS and daughter cards are mounted to a common aluminum chassis which houses the power supply for both boards.[2,5]

- In addition to developing the trainer, the same student team developed laboratory exercises to support both the Motorola/Freescale HC12 microcontroller.[2,5]
- As a follow up to the development of the Motorola/Freescale HC12 trainer board, another student led a team of technicians to fabricate 15 of the trainers. The trainers have been used every semester for the microcontrollers course since 2002.[2,5]
- In an effort to update a senior-level bioinstrumentation course, a series of laboratory exercises were developed by a graduate student as his graduate program project. The laboratory exercises coupled instrumentation hardware with National Instruments LabView components via the NI ELVIS interface.[2,6]
- In addition to developing labware for the bioinstrumentation course, the graduate student also developed a series of laboratory exercises to support a senior-level bio-signal processing course.[2,6] Both the bioinstrumentation and bio-signal labware have been in use for five years.
- In support of a sophomore level, design intensive Verilog HDL-based digital design course, a series of progressively challenging design exercises were developed. The exercises culminate in a sequential state machine design.[2,7] The design exercises have been used for the past two years.
- In support of a senior-level, design intensive Verilog HDL course, a series of design exercises were developed based on an autonomous robot. The exercises, developed by a graduate student, progressed through increasingly challenging designs culminating in a student selected final design project.[2,8]
- In support of a senior-level, design intensive Verilog HDL course, a series of computer architecture design exercises were developed by a graduate student to allow students to design components for a functional and observable single cycle computer and also a pipeline-based processor. The exercises progressed through increasingly challenging designs culminating in a student selected final design project.[2,9] The exercises have now been used in two offerings of the course.
- In support of a newly developed, senior level course in Industrial Controls, a series of laboratory exercises were developed employing Programmable Logic Controllers (PLC). The exercises have now been used in two offerings of the course.[2,10]

In the next section we provide a step-by-step approach to develop an FSBS project.

Methods

Figure 1 illustrates the "For Students By Students" process. In the first step students are chosen for a specific project. Possible sources for student engineers include students interested in an independent study project, capstone design student engineers or graduate students needing a project. It is important to carefully match projects with students. Students must have the requisite expertise to successfully complete the project.

After a student or student team has been identified, it is important to meet with the students to jointly develop the project requirements. Requirements must be fully understood by all project participants. It may require several meetings to determine and document in writing specific project requirements.

Students are then allowed to pursue project development under faculty mentorship. Regular, frequent meetings are encouraged to review progress, answer questions, and provide guidance and encouragement. This process continues for the duration of the project. When complete, the project is delivered with documentation to the end user.

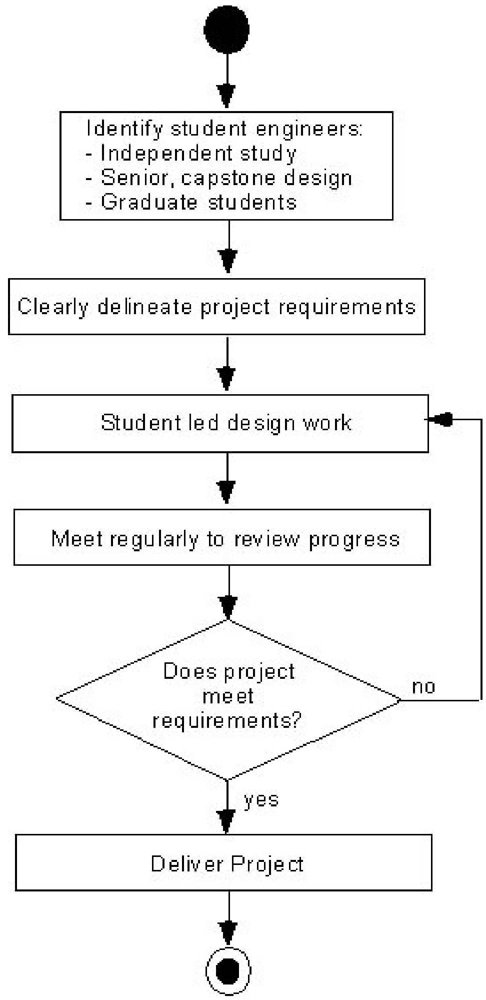

Figure 1. Completing a project via the “For Students By Students” process.

Case study. To illustrate the process we provide a case study. Funds were provided by a Hewlett Foundation curriculum improvement grant to update and improve the microcontroller trainer used in a senior-level microcontroller course. The course is required in both the Electrical and Computer Engineering degree programs. The course employs the Motorola/Freescale HC12/S12 processor as the target processor.

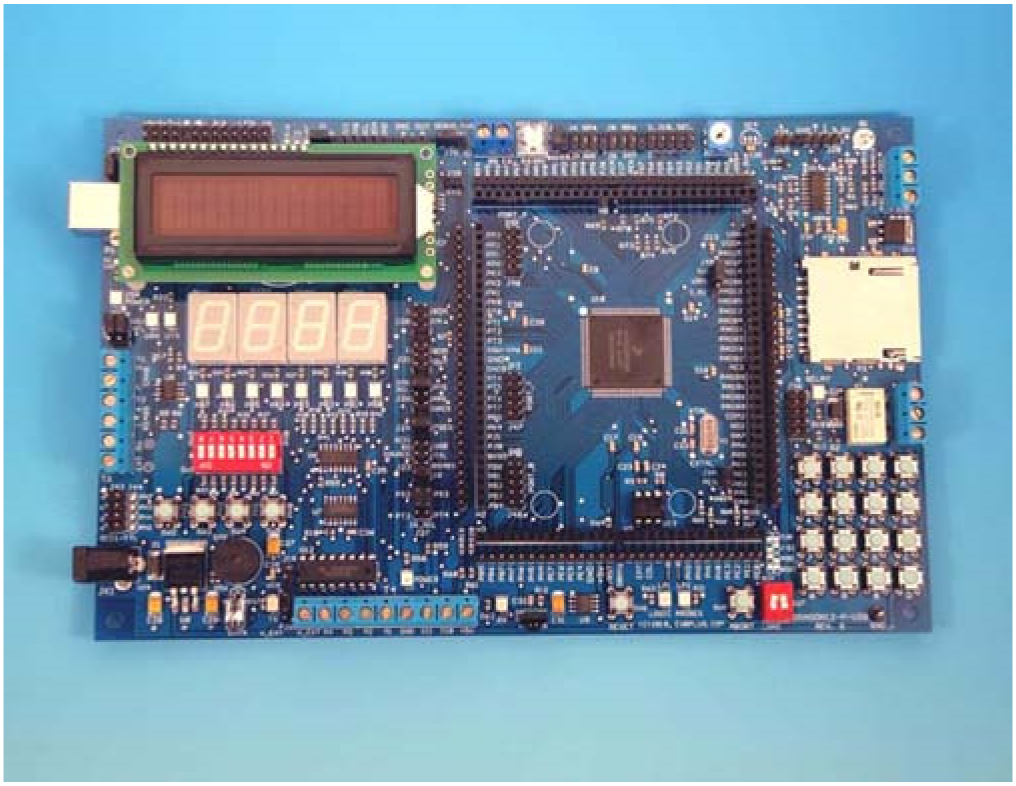

Figure 2. The Dragon12-Plus-USB evaluation board. Image used courtesy of Wytec.[11]

A masters candidate in the electrical engineering program was selected for the project due to a strong background in computer engineering. Several meetings were held to develop project requirements. The project requirements were determined to be:

- Select an inexpensive, commercially off-the-shelf evaluation board based on the Motorola/Freescale HC12/S12 microcontroller.
- Develop a series of laboratory exercises to support the microcontroller course.

The student selected the Dragon12-Plus-USB evaluation board. Reference Figure 2. The board is equipped with an MC9S12DG256 or MC9S12DP256 microprocessor. The microprocessor hosts D-Bug12, an on-board monitor/debugger program. Details on evaluation board features are available at reference 11.[11] Over a four month period the student developed a series of laboratory exercises to support the course. Regular project reviews were conducted via e-mail.

Results

A series of laboratory exercises were developed to support the microcontroller course. The ImageCraft Compiler ICC12 was used in program development. The ICC12 terminal window is used to communicate with the S12 microcontroller using the D-Bug 12 program. The ICC12 can also be used to write, edit, and compile programs in either assembly language or C programming language.[12] Both programming languages are used within the microcontroller's course.

Here is a brief summary of laboratory exercises developed:

1. Intro Laboratory – 1 week
   - This laboratory exercise introduces students to basic Debug12 commands to manipulate memory using the ICC12 terminal. Students will also write their first assembly program to perform basic arithmetic operations and communicate with the bank of LEDs on the trainer board.

2. Serial Communication Interface (SCI) Laboratory – 2 weeks
   - This laboratory exercise introduces the student to the SCI system, an asynchronous serial communication system. The student will send a character out through the SCI and verify the output using an oscilloscope. The student will then write a routine to receive a character through the SCI and display the received character on the bank of 8 light emitting diodes (LEDs). In order to demonstrate transmit and receive features, the laboratory groups will have to pair up so that one group will send and the other receive and then vice versa.
   - This laboratory has an optional component. If a student wants, have time, and/or up to instructor discretion, they can combine transmit and receive into one program so that it will continually transmit, the partnered group will receive, display the character on the LEDs, then echo the character back to the originally transmitting group who will do the same thing. This is a good example of full duplex (two way) communication but is very time consuming and challenging to accomplish.

3. Logic Analyzer and SCI Laboratory – 1 week
   - This laboratory exercise introduces students to the Logic Analyzer. The students will read introductory information about the use of the LA. The students will then write a program to transmit several characters through the SCI and verify the output on the LA. Students are encouraged to write in C in this lab but it is not necessary and it up to the discretion of the teaching assistant and/or instructor.
   - Software on the LAs can be used to capture the data from the LA so that students can print the data and include it in their laboratory notebooks.

4. Keypad and Liquid Crystal Display (LCD) Laboratory – 2 weeks
   - Code will be provided to students that does not work. The code was written to be asserted "active low" while the hardware configuration requires "active high" configuration. The students have to adjust two parts of the code:
     - Change the keypad code from active low to active high
     - Change LCD code to correspond to a 4 bit set-up as described in the additional material.

5. Analog-to-Digital (ATD) Laboratory – 2 weeks
   - Students will first develop a simple digital voltmeter that reads in a voltage through the ATD and displays it on the LCD (using working LCD code that should have been developed in lab 4). This voltmeter will be tested using a simple

voltage divider and then used to characterize the light sensor on the board. The light sensor is read through ATD channel 4 and is already connected to that pin through the correct circuitry.
- Students will then change their voltmeter into a digital thermometer. An LM35Precision Centigrade Temperature Sensor is on the board already and is connected to ATD channel 5. The LM35 reads in Celsius but the temperature should be displayed to the LCD in degrees Fahrenheit.

6. Output Compare, Input Capture, Pulse Width Modulation Laboratory – 2 weeks
   - Students will output a waveform using the Output Compare System and polling techniques in assembly language. The output should be verified using the oscilloscope but can be verified using the LA as well. Students should output the waveform through timer channel 5 to activate the speaker.
   - Students will then output a waveform using the PWM system in C. The output should be verified just as in the first task. In order to activate the speaker using PWM, the jumper will need to be moved to the correct position (see the Dragon12-plus manual for information).
   - Students will read in a signal from a function generator and measure the period and frequency using the Input Capture System. The values calculated should be printed to the screen.

7. 7 Segment Display and msCAN (Controller Area Network) Laboratory – 3 weeks
   - The main part of this laboratory exercise requires that students write code, in C, to display numbers 0 through 9 to each of the digits of the 7 segment display. The student can display whatever random numbers they desire but they must display 4 different numbers to demonstrate a complete working display.
   - The remaining portion of this laboratory deals with msCAN. The students will incorporate their 7 segment display code into the provided msCAN code. First, the student will display something on the 7 segment display when a message has been successfully sent and received (groups must partner up to test the transmit and receive msCAN features). Finally, the students will send 4 bytes via the msCAN and display those numbers via the 7 segment display.

8. Team Lab – 2 weeks
   - The students will develop a beginning prototype for a remote weather station. The design includes:
     - Wind Sensor
       - Display on LCD and LEDs
     - Temperature Sensor
       - Display on LCD and 7 segment display
     - Light Sensor
       - Display on LCD and RGB LED
     - Output everything via the SCI

Discussion and Conclusions

The For Students By Students Program provides benefits for all involved. Students have the opportunity to develop design and project management skills on real world projects. This skill set pays rich dividends when seeking a job. Faculty members have the opportunity to develop and enhance mentorship skills. Furthermore, faculty have the opportunity to observe undergraduate students working on a challenging project and gage their capability for graduate-level work. Educational programs obtain state-of-the-art labware and courseware material.

For some this approach may appear risky. Regular student and project mentor meetings minimize project risk and is very helpful in keeping the project on task and on schedule. We have employed this technique for ten years without any project failures. Often a project results in completion of a good first prototype rather than a finished product. The prototype along with lessons learned may be passed on to follow on teams in the development of refined prototypes.

We highly encourage faculty members to employ this approach in developing new labware and courseware. All material discussed in this paper is available from the corresponding author.

Acknowledgments

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