Modular Design and Adoption of Embedded System Courseware with Portable Labs in a Box

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Abstract—**Teaching embedded system in universities and colleges that have limited resources faces difficulties due to the lack of dedicated embedded system labs and specialized embedded system instructors. To overcome these difficulties, we developed a new embedded system courseware with real labs that is portable, modular, and easy-to-adopt. An important feature of the developed courseware is that the courseware is structured into multiple self-contained modules. This modular design allows instructors to adopt the full course or integrate only selected modules into their existing courses. This paper presents our experience of partially adopting the courseware by implementing selected modules in a Software Engineering class. Evaluation results show that students perceived the selected modules and hands-on labs as useful in their learning and provided positive feedback about the courseware.**

Index Terms— **embedded system courseware, hands-on lab, modular design, software engineering**

I. INTRODUCTION

IN recent years, embedded systems are becoming increasingly important due to their wide applications in every aspect of our society [1]. They represent a key technology in modern industry, such as consumer electronics, industrial automation, military/aerospace, automotive industry, and telecommunications [2, 3, 4]. Embedded systems are specialized because these systems naturally involve hardware and software components that interface to various electrical, mechanical and chemical processes with real time requirement [5]. This makes embedded system education an excellent example of an area of study that provides depth, breadth, and rigorousness for meeting the emerging workforce and education needs in science, technology, and engineering [6, 7]. More and more higher education institutions realize the importance for computer science and software engineering students to be exposed to the engineering disciplines in design and development of real-time embedded systems [8, 9]. Unfortunately, despite existing efforts in embedded system education, embedded system remains to be a highly difficult and specialized subject. In particular, existing instruction models rely on two prerequisites, i.e., significant investment in resources (e.g., embedded system labs) and high requirement for instructors (e.g., faculty whose expertise is in this area). These prerequisites make the dissemination of existing instruction models highly dependent on the resources that an institution can afford, and thus are impractical for universities and colleges that lack the resources and build-ups in this field. The challenges in offering embedded system courses in these institutions include the prohibitive cost of setting up hands-on real labs; scarce dedicated staff and faculty in this field; and the excessive time needed for developing course materials and projects [10].

To overcome the above difficulties for broader embedded system education, we have developed a new embedded software courseware with real labs that is portable, modular, and easy-to-adopt [11, 12]. The developed courseware targets on universities/colleges that have limited resources for teaching junior or senior undergraduate courses on embedded systems. The new courseware includes teaching modules on foundational and emerging topics, companion labs with inexpensive portable real lab equipments, and well-designed projects that provide students with hands-on experience in learning embedded software. The developed courseware has two key features. The first feature is portability and feasibility with real hands-on labs and projects. Hands-on laboratory and projects are essential for students to understand the concepts and to gain real-world insights in embedded software development. The developed courseware supports real labs that are based on a low cost and portable embedded micro computer unit (MCU) kit. The portability of these labs allows students to work on projects without constrained by the time and location of a traditional embedded system lab. Due to the low cost of the MCU kit colleges and universities with budget constraints can also implement such labs. The second feature is modularity for flexible course adoption. The developed courseware is carefully structured into multiple modules, each of which has self-contained materials including lecture notes and real hands-on laboratories guided by step-by-step flash tutorials. This modular design allows instructors to adopt the full course or integrate only selected modules into their existing courses.

The developed courseware has been implemented and evaluated in two universities: Southern Polytechnic State University (SPSU) and Georgia State University (GSU). The two universities focus on different aspects of the implementation and evaluation. Specially, SPSU focuses on implementing the full course as a single semester undergraduate course in the Computer Science and Engineering (CSE) department. GSU focuses on partially implementing the courseware by integrating selected modules into an existing course, the undergraduate Software

Engineering course, in the Computer Science (CS) department. We have reported the results of implementing and evaluating the full course at SPSU in previous work [13, 14]. In this paper we present the results of partially adopting the courseware by implementing selected modules into the Software Engineering class at GSU.

II. MODULAR COURSEWARE WITH PORTABLE LABS IN A BOX

A main goal of the developed courseware is to make it easy for instructors to adopt the full courseware as a new course or flexibly integrate selected modules into existing courses based on the instructors' needs. To achieve this goal, we follow on a modular design to develop and organize the courseware into different teaching modules. Each module covers a specific topic of embedded system design and is "self-contained" in the sense that it includes all the necessary information and materials related to this topic. The materials included in each modular include lecture notes, review questions, assignments, and real hands-on labs based on the portable palm-size MCU development kit guided by step-by-step Flash tutorials. These materials are available online for students to download. The labs with online multimedia guidelines and assignments can be conducted anywhere and at anytime without additional facility requirements; they can be used for in-classroom learning or online learning.

The developed courseware includes 10 teaching modules that cover different aspects of embedded software development. These modules emphasize the balance between theoretical foundations and technical practices of embedded software development. Each module can be taught in one or two lectures, depending on the content of the module and students' background. The 10 teaching modules are listed below:

- Module 1: Introduction to embedded system
- Module 2: Embedded software life cycle and time analysis
- Module 3: Microcontrollers
- Module 4: Real Time Operating System (RTOS)
- Module 5: Embedded software development
- Module 6: Peripherals of embedded systems
- Module 7: Serial communication
- Module 8: Embedded software testing
- Module 9: Embedded Web Technology
- Module 10: Wireless Embedded Systems

Accompanying the teaching modules, hands-on laboratory and projects on embedded software development are emphasized. The real labs and projects are based on a low cost and portable embedded micro computer unit (MCU) kit: the 8051 MCU based C8051F005DK development kit from Silicon Laboratories Inc. The development kit comes with necessary I/O, serial ports, and a basic RTOS, and can be reused many times without using a solder. It costs less than the average price of a textbook. The C8051F005DK board has an on-board temperature sensor, a button that can pressed by users to generate interruptions to the embedded program running on the chip,

and one LED light that can be controlled by the embedded program. On top of these components, we added a Bluetooth transceiver to the C8051F005DK board to enable Bluetooth communications between the board and a desktop or laptop computer. These hardware components make it possible for students to develop interesting projects using the board. Figure 1 shows the C8051F005DK board with the added Bluetooth transceiver.
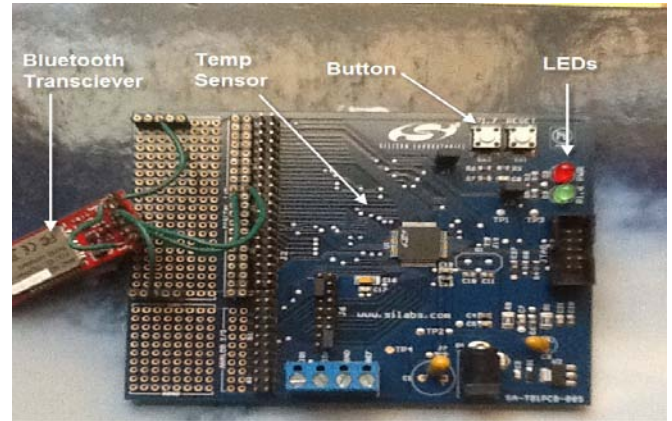

Figure 1: The C8051F005DK board with Bluetooth transceiver

III. IMPLEMENTING THE COURSEWARE IN THE SOFTWARE ENGINEERING CLASS

In order to evaluate the effectiveness of the modular design in a course that integrating only selected modules (instead of adopting the full course) of the developed courseware, we implement the courseware in the Software Engineering (SE) class in the Department of Computer Science at Georgia State University (GSU). The SE class covers techniques used in large scale scientific or technical software development, including requirements analysis, specification, systems design, implementation, testing, validation, verification, and maintenance. The original SE class did not include topics of embedded software development. In order to integrate the developed embedded system courseware, we decided to introduce the embedded software development topic into the SE class, and selected several teaching modules that are most relevant to the embedded software development topic to be integrated into the SE class. The goal was to allow students in the software engineering class to gain design knowledge and implementation skills in embedded software engineering.

Specially, we integrated three course modules into the software engineering classes in the Fall 2010 semester and in the Fall 2011 semester (these two classes are referred to as the Fall 2010 class and the Fall 2011 class in the remainder of this paper). The three selected modules were "Introduction to embedded system", "Embedded software life cycle and time analysis", and "Embedded software development". These three modules were taught in two lectures, each of which lasted 105 minutes. The first two modules were covered in one lecture, taught in the beginning of the semester. The last module was covered in one lecture, taught in the middle of the semester. Besides lectures, the software engineering class required students to form groups and work on group projects. For this purpose, students in the classes could choose to develop their group projects using the embedded board (shown in Figure 1). If

students choose to work with the embedded board, they need to use at least one embedded board to fulfill some functionality of their system, and develop software running on a desktop computer to communicate with and control the embedded board. In both classes, there were two student groups choosing to work with the embedded board for their group projects (other groups worked on projects not related to the embedded board). These groups and their project topics are listed below. Note that due to the nature of the SE class, even if students worked with the embedded board, their main software development efforts were still on the desktop end. For example, in the "Inventory Shelf Life Manger" project, the embedded board was used to collect real time temperature data (using the on board temperature sensor) of an inventory shelf. The data were fed into a program running on a desktop computer to determine the remaining shelf life based on current and prior conditions. If a product's shelf life is affected by temperature exposure, management is notified with the updated shelf life estimate via email. The major functions of the inventory shelf life manager system are fulfilled by the software running on the desktop.

Fall 2010 Class
- *Group 1 project topic*: Inventory Shelf Life Manager using an Embedded System
- *Group 2 project topic*: An information management system interacting with the embedded system

Fall 2011 Class
- *Group 1 project topic*: Temperature-based fire suppression system using the embedded board
- *Group 2 project topic*: A drink kiosk control/management system based on the embedded board

IV. EVALUATION

To evaluate the results of integrating selected modules of the courseware in the Software Engineering class, we used pre-evaluation and post-evaluation questionnaire to collect data from students who took the class. The pre-evaluation questionnaire was mainly about students' background and their perception about embedded systems. The post-evaluation questionnaire was mainly about their evaluations of the implemented courseware. In both questionnaire, there were five score choices for each evaluation question: Strongly agree(5), Agree(4), Neutral(3), Disagree(2), Strongly Disagree(1). The pre-evaluation data were collected in the first week of the semester and the post-evaluation data were collected in the last week of the semester. Below we analyze the data for the 2010 class and the 2011 class respectively and draw some conclusions.

For the 2010 class, there were 29 students took the class, among them two groups of students worked on the embedded board for their group projects (one group had 5 students; another group had 4 students). According to the pre-evaluation questionnaire data, students in this class were familiar with and had positive experience with computers. The data also showed that 75% of students strongly agreed that "I learn better by hands-on lab work", and 25% chose "agree". This compares to only 5% of students agreed "I learn better by listening to lectures". When students were asked if they agree "I learn better by personally doing or working through examples", 70% of them chose "strongly

agree", and 25% chose "agree", and only 1 person chose "disagree". Therefore, in general students thought hands-on lab and a computer-learning/ tutorial system were useful to help their learning.

The post-evaluation questionnaire was mainly about students' evaluation about the implemented courseware. In particular, it asked for students' feedback for the following five questions:

Q1. I like being able to work with this portable kit.

Q2. The two teaching modules on embedded software help me learn more.

Q3. The teaching modules and the embedded board help me understand better on computer architecture.

Q4. The teaching modules and the embedded board help my learning experience on embedded systems.

Q5. The embedded system project helps me apply learned knowledge.

Similarly, there are five score choices for each evaluation question: Strongly agree(5), Agree(4), Neutral(3), Disagree(2), Strongly Disagree(1). Besides them, we added another choice "Does not apply to me" because not all students in the software engineering class worked with the embedded board (only those students who chose to develop their class project based on the embedded board worked with the embedded board). The post-evaluation questionnaire data show that each question had about half of the students choose "Does not apply to me". This was mainly due to the fact that it was a software engineering class and there were only two lectures on the embedded system topic and two groups of students worked on projects based on the embedded board. Thus not all students were familiar with the topic or experienced with the embedded board. Among the students who did not choose "Does not apply to me", approximate 85% of students chose "agree" or "strongly agree" about their preference of the portable kit; about 64% of students felt the benefits of the teaching modules and the accompanying labs; 79% of students felt the teaching modules and the hands-on labs were helpful for their learning of embedded system, and 67% felt the teaching modules and embedded project helped them apply learned knowledge. Figure 2 shows these percentage data for students who did not choose "Does not apply to me". In the figure, the left side bar represents the combination of the choices of "Strongly agree" and "Agree"; the bar in the middle of three represents the combination of choices of "Neutral"; the right side bar represents the choices of "Strongly Disagree" and "Disagree". As can be seen, the student survey chart shows a positive learning assessment.
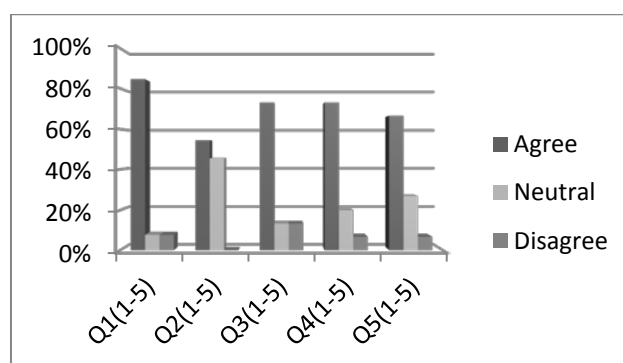

Figure 2: Evaluation results for the 2010 class

For the 2011 class, there were 28 students took the class, among them two groups of groups students worked on the embedded board for their group projects (both groups had 4 students). Similarly, the pre-evaluation questionnaire data show that students in this class were familiar with and had positive experience with computers, and they generally thought hands-on lab and a computer-learning/ tutorial system were useful to help their learning. The post-evaluation questionnaire data show similar results as those in the 2010 class, as displayed in Figure 3.
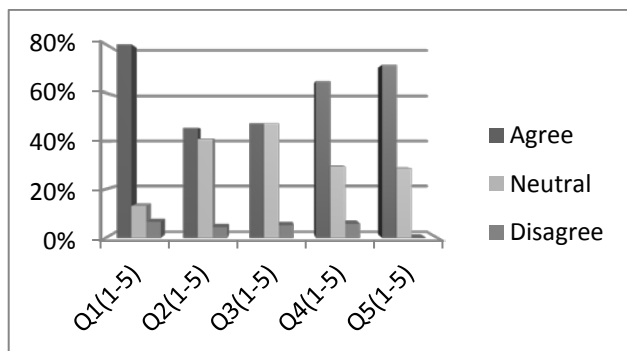

Figure 3: Evaluation results for the 2011 class

Based on the pre-evaluations of the two classes, we can see that the majority students perceived the hands-on labs and tutorial systems are useful in their learning. The post-evaluation data indicate that more than 80% students who were exposed to the selected teaching modules and/or the embedded board liked to work with the portable embedded kit, and most students felt the selected modules on embedded systems helped them to learn. From students' comments at the end of the questionnaire survey, we notice that students who worked on the embedded board for their group projects were more involved in the topic and had more positive feedback about the courseware.

V. CONCLUSIONS

Although this is a limited implementation of the developed courseware (in each class there were only two lectures on the embedded system topic and two groups of students worked on projects using the embedded board), collected data show that the selected teaching modules and embedded board generated positive outcomes for the SE classes. The modular design of the courseware made it easier to implement the selected modules into the SE class. Future work includes how to disseminate the developed courseware to support broader adoption and evaluate its results.

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