Experience on Teaching Multiple CS Courses with Portable Embedded System Labware in a Box

Kai Qian, Xiaolin Hu, and Liang Hong

Abstract—**The rapid growth of embedded systems results in a shortage of professionals for embedded software development. However, embedded system education is not well represented in current Computer Science (CS) academic programs. Due to budget cuts and resource limit, it becomes harder for higher education institutions to maintain traditional laboratory than ever before. In this paper we present our implementation of portable embedded system labware in a box (a very affordable 8051 microcontroller development kit) for multiple CS courses. Its portability allows students to work on the labs anywhere and anytime. The evaluation has shown that the hands-on lab oriented curricula well engage students in learning of CS disciplines and better prepare our graduates directly into the nation's embedded system design workforce.**

Index Terms—**Embedded labware, Keeping budget, Hands-on lab, Take-home development kit**

I. Introduction

DUE to limited resources including budget, equipment, lab space, or faculty expertise, many schools teach computer science (CS) or computer engineering (CE) core courses without any hands-on lab practices or with antiquated equipment which drastically hinders student learning.[1-2] To overcome these difficulties, we have developed an online embedded software labware which consists of an inexpensive portable MCU development kit with, development software and embedded operating system, and modular teaching materials including learning modules, labs, slides, quizzes, assignments, and projects.

All designed hands-on labs are implemented with this portable MCU development kit in a box. The portable and modular design of this labware provides a "ready-to-adopt" model for broadening embedded system education and enhancing labs for other CS courses. This labware is especially suitable for the universities/colleges that have the need of embedded system education but are constrained by limited financial budget, scarce dedicated staff and faculty and lab facilities.

The high expertise for instructors, and high time demanding for running labs make many schools difficult to provide students with hands-on labs.[3] To overcome these obstacles, we carefully design the supplemental curricular lab modules to be easily adopted in other institutions, and provide background knowledge for instructors. Each of the curricular modules will be high cohesion and low coupling so that instructors will have some leverage in selecting suitable modules in an add-on approach without abandoning their existing curriculum design. The modular designed labware can not only be used for embedded system education but also for teaching other CS/CE core courses such as Computer Architecture, Operating systems, and Capstone projects. Its portability allows students to work on the labs at anywhere anytime.[4] Studies have shown that hands-on lab oriented lab modules well promoted students engagement in their learning. , and prepare our graduates directly into the nation's workforce.

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II. Portable Hands-on Labs in a Box

A. Review Stage

In the developed labware, all hands-on labs are developed and implemented using a portable, supercharged 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 average price of a textbook. The kit is shown in Figure 1 and a sample lab is shown in Figure 2

Fig. 1. Palm Sized Portable C8051F005DK MCU development kit

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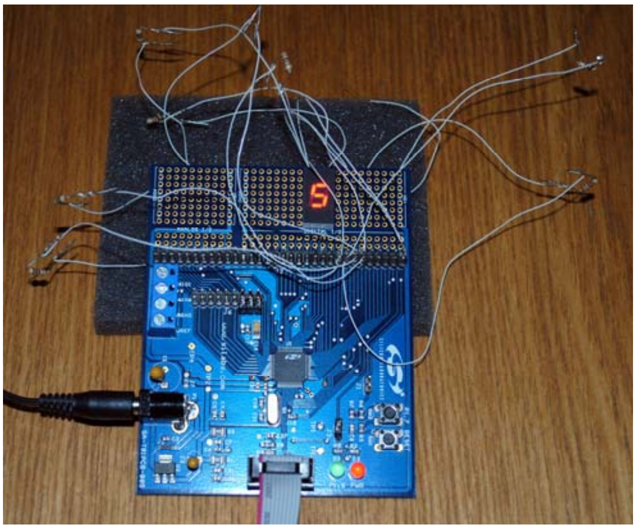

Fig.2. A sample lab of 7-segment LED counter with the development kit

The kit comes with an Integrated Keil C51 µVision IDE software with which students can do cross-compilation, debugging, and testing on their own PC/Laptop before deployment to a target embedded system and work with real-world embedded system projects instead of simulation only. Figure 3 is a screen shot of a RTOS debugging and testing.

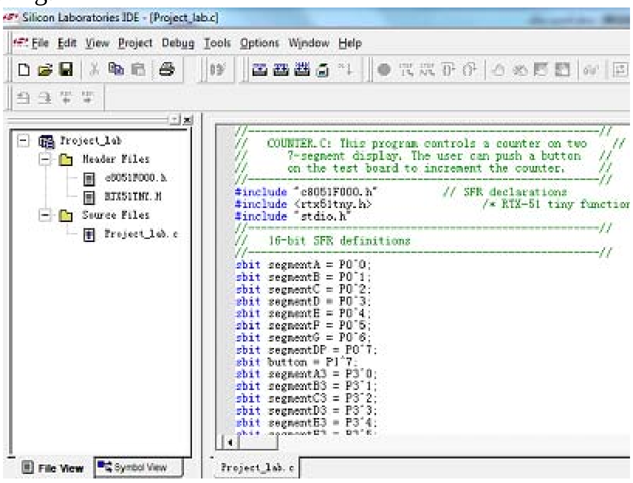

Fig.3. Sample of RTX51 RTOS with Keil µVision IDE

III. MODULAR AND PORTABLE LABWARE

The developed labware adopts a modular structure that organizes all learning materials into a sequence of lab modules. Each module includes lecture notes, PPTs, review questions, hands-on laboratory practices, and assignments. It also provides portable real world labs with this popular MCU development kit. All learning materials and lab manual videos are posted online. Because of the modular design, the labware is easy to be integrated in other undergraduate computing courses. Meanwhile, the hardware needed to teach these modules is minimized due to the portable labs. We have used these modules in an online embedded software development course, an undergraduate computer architecture course, a software engineering course, and a CS capstone course. We plan to integrate the course in more other courses such as operating systems.

This labware is designed with a particular focus on the software design and development of embedded system rather than the hardware design although students will be exposed to hardware design especially in the I/O peripheral layouts and interaction controls.

All the lab modules above have been used in a CS embedded system design course for several semesters. Among these modules the Microcontrollers 8051 and Embedded programming modules have been used in computer architecture course to support these topic study:

TABLE I
COURSE CONTENTS

Module	Contents
Introduction to embedded system	Overviews of embedded system concepts, Fundamentals, Components, Constraints
Embedded system software engineering	Time Constraint Analysis with RMS and EDF Modeling and architecture (Context Diagram, DFD, FSM, State Chart) Design criteria
Microcontroller 8051	Microcontroller, I/O Ports, memory, SFR, Interrupts
Embedded programming	C51, Assembly for 8051
Concurrency	RTOS based multi-tasking scheduling, Round-robin Preemptive priority, Sync and Async tasking
Serial communications	Communication modes, UART, serial Port I/O, Handshaking, Baud Rate
Case study and Projects	Software engineering SDLC

- CPU and Memory of Microcontrollers
- Interrupt
- Peripherals of embedded systems
- Embedded assembly and C programming

The concurrency scheduling module with tiny and full edition of RTX51 RTOS is planed to be used in Operating Systems course to cover the following topics:

- Round Robin CPU Scheduling
- Priority-Driven Preemptive CPU scheduling
- Collaborative CPU scheduling

The semi-constructed projects in Case study and Projects module are used for Capstone project Software engineering courses. Students have hands-on experience in SDLC to model, analyze, hardware software co-design, develop, and test embedded software with real microcontroller rather than just simulations.

The hardware resource needed to implement these modules is minimized with this inexpensive portable development kit and associated lab guide materials.

All labs are designed in such a way that students get hands-on practice along with the theory which boosts the students' confidence by working on the real hardware and software platforms to take on the challenges of the real world.

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The hands-on labs focus mainly on applying all the embedded system concepts such as RTOS to real world application with the C8051F005DK development kit.

Samples of hands-on labs with kits include 3 digit 7-segment LED counter, Digital clock, Temperature control system with sensor, keypad, LCD display, RS232 with PC, traffic control system with RTOS and home automation system project.

IV. Evaluation

This labware has been used in embedded systems, computer architecture, capstone project classes so far. We have conducted anonymous student survey evaluation in these three classes. Many students said in the evaluation survey that they had great opportunities to practice the theory and abstraction to practical applications; to integrate their knowledge learned in the CS and SE programs to solve real-world problems; to co-design and develop software with microcontrollers to produce a real world embedded systems on their own. Students enjoyed in working with the development of embedded software in cross-platform environment. One of the contributions of the designed labware and equipments is its low cost, reusability, and feasibility for any schools with limited financial recourses. It also provides a model for any instructors to start up an embedded software course with supported labs. The following chart shows the feedbacks from 37 students from three classes.

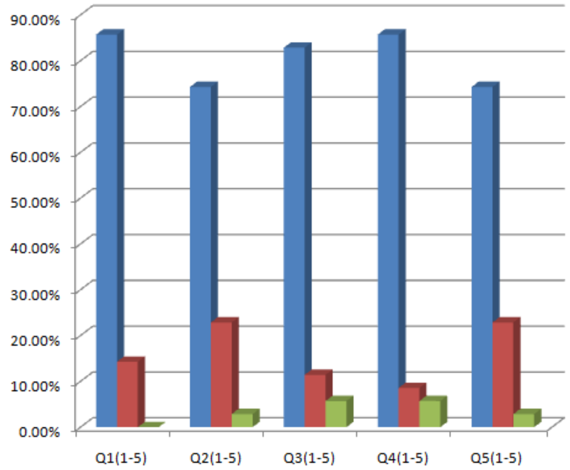

Fig.4. Course Evaluation Result

Q1. I like being able to work with this portable kit.
Q2. The accompanying labs help me learn more on hardware and software co-design.
Q3. The hands-on labs help me understand better on computer architecture
Q4. The hands-on labs help my learning experience on embedded systems
Q5. The project helps me apply learned knowledge to real application

There are five score survey choices for each evaluation question:

Strongly agree(5), Agree(4), Neutral(3), Disagree(2), Strongly Disagree(1);

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”. The student survey chart shows a very positive learning assessment.

The statistic data on the bar chart shows overwhelming promising supportive feedbacks from students.

V. Conclusion

This paper presents a new pedagogical teaching and learning model for improving students' learning in embedded system and preparing students for tomorrow’s embedded system workforce. Most students enjoyed what they learned in this portable and easy to use labware. In particular, students favor the hands-on portable labs. Students were excited with their creativity opportunity of working on the embedded projects with the kit.

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