Student-Inspired Project-Based Learning in an Embedded Systems Course

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***Abstract* - This paper presents the experience of the author from a senior embedded systems course at an engineering college. The course is primarily made up of lecture and laboratory components. Besides those two components the course also includes a peer-teaching component and a final-project. In the peer-teaching component the students are expected to choose a topic related to the course material, perform thorough research, and then present the material to teach it to the whole class. The goal of the final project component is to challenge the students to come up with a problem of their own that can be solved using the material learned in the course. The students are encouraged to dig deep into their creative minds and come up with practical projects that address real problems. They spend time to brainstorm ideas for their projects and present their proposals to the whole class for comments and approval, before they actually start to implement their work. The main take away from the experiences of these projects is that the students felt ownership of their projects and spent every effort to bring their ideas to fruition. Most of the project teams involved two or three students from different disciplines so they bring their expertise from their respective fields to the project. Overall, based on the grade performance of the students in the course and feedbacks received at the end of the course, this student-inspired project-based-learning approach was found to be successful in enhancing the learning experiences of the students.**

Index Terms – Active-learning, Embedded systems, Entrepreneurial mindset, Peer-teaching, Project-based-learning

INTRODUCTION

Embedded systems courses form the core of the curriculum for most computer engineering degree programs. One of the primary learning objectives of this course in our institute is to enable students to use a microcontroller as part of a system to build intelligent embedded applications. This is a fast growing high demand area in the industry for students who have strong educational experience in this field. The job outlook for software developers, including embedded systems software, is expected to grow at a much faster than average rate of 21% over the ten years from 2018 to 2028 [1]. There is an increasing interest in developing smart products that people use daily to automate their everyday chores in households and service sectors [2-7]. Examples of such smart products that people are already getting exposed to include smart thermostat, smart locks, smart garage door openers, smart appliances, robotic vacuums, smart plant monitoring systems, smart cars with advanced driver assist features and future potential for automated driving.

In typical smart products or services the central element of the system that enables the intelligent operations by handling decision making tasks is a microprocessor or microcontroller. To be able to develop such systems students need a fundamental knowledge on the principle of operation and application development for embedded systems. This process involves the understanding of the microprocessor or microcontroller system architecture, hardware design, software development, testing, and debugging. It is also critical to develop skills that are important for the interfacing of the microprocessors or microcontrollers to external devices such as sensors, actuators, communication devices, and user interface elements. To support communication between the different hardware components of the system or between the system and the user, both hardwired and wireless communication options are available. For wired communication, synchronous or asynchronous serial protocols as well as parallel communication approaches could be used. Common wireless protocols for embedded applications include WiFi, Bluetooth (Bluetooth classic or Bluetooth Low Energy), and Zigbee.

Talking about the basic embedded systems principles and design techniques in a lecture class alone does not offer sufficiently engaging learning experience for the participating students. This paper focuses on the use active-learning approaches to motivate and raise the interests of the students so they can see the direct connection between the theoretical concepts and the practical applications of the course material on real world problems. The impact of this approach is further enhanced by challenging and allowing students to find their own problems they would like to work on as a final project for the course. Since the students choose projects that interest them they are more likely to be actively engaged and be committed to put every effort for the success of the project.

The rest of this paper is organized as follows. In the next section it presents an overview of the course topics that are the primary focus for the embedded systems course which is the subject of this paper. Following the course topics overview, the paper presents about the project-based learning experience, followed by a sample of the actual projects developed by the students. A survey was used to collect feedback about the students' experiences in the course, which the paper presents next, followed by discussions and conclusions, in the last section.

COURSE INFORMATION

The embedded systems course presented here focuses on contemporary 16 and 32 bit general purpose microcontroller (MCU) architectures. There is a large selection of MCUs in the market, some of which come with development kits that are well suited for educational use, while others may not be as easily accessible to use as a learning platform. In addition to the availability of low-cost and user-friendly hardware development platforms, it is also important to have good software development tools that support the chosen hardware. Since cost is always one of the key selection criteria for educational institutions, low-cost hardware kits with low-cost or free software development tools are often the preferred choices. For this reason, among the large selection of hardware and software options, and influenced by the author's previous experience, Microchip's PIC24 [8] and PIC32 [9] MCUs were chosen. However, it should be noted that the concepts covered in the course also easily apply to most other general purpose MCUs with appropriate modifications in the hardware specifics or low-level details of the system.

The course is presented in a combination of lectures and lab assignments. There are five contact hours per week which are made up of three 1-hour lectures and one 2-hour lab. The university follows a quarter or term system, with 10 weeks of classes followed by a few days for final exams.

The lectures component of the course presents the theoretical material about embedded system design; it goes over the details of the target microcontroller architecture, the interfacing modules, and the programming techniques. A list of the main course topics presented is given below:

a. Introduction to embedded systems
b. 16-bit and 32-bit MCU architecture
c. Assembly instructions and programming
d. Input/output interface modules
e. Interrupts
f. Timer modules
g. Timer functions – input capture and output compare
h. Real-time clock and calendar
i. Serial communication protocols: UART, SPI, I2C
j. Parallel master port (PMP)
k. Analog to digital converter
l. Introduction to Controller Area Network (CAN)
m. Embedded wireless connectivity

In addition to the lecture materials on the essential concepts of the MCU architecture, programming techniques, and various built-in peripheral interface modules, the course also offers several practical laboratory activities that help enhance the understanding of the concepts and demonstrate real-world applications. The lab exercises include activities on low-level programming to give insights on how the processor executes instructions, manipulates data between different types of storages, and see how the compiler generates code, etc. But for the most part the primary focus of the laboratory activities is on peripheral interfacing techniques so students explore the different ways the MCU communicates to common input/output devices using various forms of digital and analog interfacing as well as using serial and parallel communication protocols in embedded systems environments.

In this course students are required to take active roles in their learning experience. One of the active learning tools that was found useful and employed in this course is peer-teaching. The inspiration for peer-teaching came from research publication obtained in the literature [10], which describes the effectiveness of the method in actively engaging the participants and enhancing learning in both the peer-teachers and learners.

For the peer-teaching students are to choose a topic (from a list of topics provided by the instructor), conduct a thorough study of the topic and teach the material to their fellow students in class. The instructor provides guidance to the students as they work through the researching of their topic, identifying its important components, and preparation of their presentation. The students also prepare quizzes for the class which was found to be helpful so that the attendees will be paying attention to the peer-teachers and are actively engaged with the topic. Most of the topics for the peer-teaching component of the course are taken from the common MCU peripheral devices and interfacing modules (such as real-time clock & calendar, ADC, DAC) and various types embedded wired and wireless of communication protocols (such as UART, SPI, I2C, CAN, Bluetooth, WiFi).

STUDENT INSPIRED FINAL PROJECT

The lab assignments are typically small practical exercises that focus on one or a few specific course topics (processor architecture, hardware peripheral, programming, interfacing techniques, and/or embedded communication protocols, etc.) Lab assignments are not too difficult and they can be completed within one week each.

After the students have established a strong foundation in the theoretical principles and practical techniques for the development of embedded systems, in the second half of the term they start to work on the final project component of the course. One of the distinguishing features of the final project in this course is that students are expected to choose their own problem that they would like to work on.

To first lay out the expectations for the final project component of the course, the instructor introduces the students to the entrepreneurial mindset [11] so they can think outside the box and start exploring ideas for their projects. Brainstorming [12] and painstorming [13] approaches are discussed to inspire the students to examine their life (at home, school, workplace, etc.) and the things or people they interact with on a daily basis to identify some potential project ideas.

Once the students identify their project idea they are required to present their project proposal to the whole class. The instructor and students may provide comments and feedback on the proposal before it is approved. The projects are typically done in groups of two or three students. Since the course is taken by students from multiple disciplines, mainly computer engineering (CE), computer science (CS), and electrical engineering (EE), interdisciplinary groups are strongly encouraged. Upon successful completion of the final project the students are expected to present their work via oral presentation, demonstration of the systems operation, and a final report documenting their work.

The main reason for allowing the students to self-select their project ideas is so that they feel ownership of their project, i.e. they don't feel like they are being forced to work on someone else's ideas. Thus, they get excited about the project, they put a great deal of effort to see the project succeed, they know what to expect as the final outcome by the completion of the project, and they want to prove that they are capable of achieving what they set their minds on. This approach has been successful as has been demonstrated with results presented in this paper. Due to the space limitation, below we are presenting only a sampling of some of the projects that were created by the students over one time offering of the course during the fall of 2019 term.

a) Drunk driver test system

Two students worked on this project. They were motivated by the fact that a large percentage of car accidents in the US and globally are caused by drunk drivers. So they came up with this idea of an automated system to test whether a person is drunk before allowing them to start or drive the car. The system incorporates an alcohol sensor to measure the amount of alcohol content in a person's breath. Before activating the measurement of the alcohol sensor the microprocessor waits for a blow of air from the person's mouth, which is detected by using the sound sensor. The person must be sitting on the driver's seat before they can initiate the test. A pressure sensor is used for detecting if the person is actually sitting on the driver's seat. The students also created an Android app to control their system. The app communicates with the microcontroller system using Bluetooth and it is used to start the test and monitor the results, which indicates whether the person passed the alcohol test or not. In future work this system could be implemented as a vehicle electronic engine control unit (ECU) that can interface to the vehicle controller area network (CAN) bus and control the vehicle.

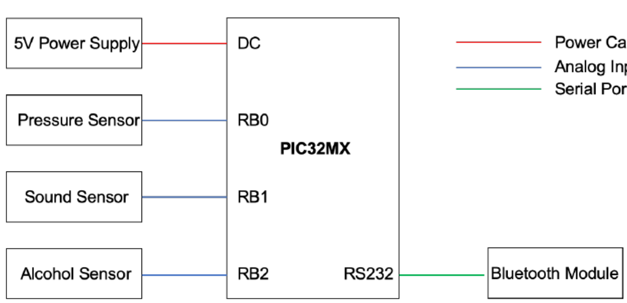

FIGURE I
BLOCK DIAGRAM OF DRUNK-DRIVER TEST SYSTEM
(By: Yizhi Fan and Mingdi Bian)

b) Real-time room occupancy tracker

Two different student teams, each containing two students worked on this project in the fall term of 2019. The main motivation for the students to work on this project is to address a real challenge they were facing on campus. Our campus has a number of popular study rooms, called d-spaces. These rooms are distributed around campus in different buildings. At the moment there is no reservation system to use the rooms, they are used on first-come-first-serve basis. The only way students can find out if a room is available is to walk all around campus to each room where they are located and see if they are busy or empty. Time being a scarce resource for busy students, especially around exam times, these groups of students sought to find a better solution to help them remotely monitor if a given room is available. The approach followed by one of the teams (Benjamin Kocik and Jonathan Dang) was to place WiFi scanners in a room with intelligent monitoring application. If the room is currently occupied there will be WiFi signals from the students' devices who are occupying the room. The students had to refine their algorithm so it does not generate false negatives by picking WiFi signals from passerby's or people in adjacent rooms.

On the other hand, the second team of students resorted with the use of motion, sound, and light sensors to detect if the rooms are empty or occupied by people. They also incorporated a timer feature that would allow the users to write the amount of time they expect to use the room for. This allows other students to monitor over a web interface approximately at what time the room might become available. Both teams created a web interface for their applications with real-time rooms' status update that users can monitor remotely.

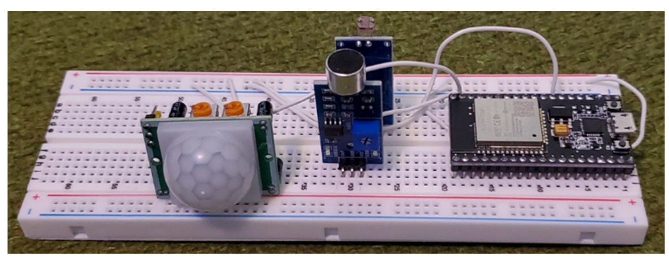

FIGURE II
SENSOR BASED REAL-TIME ROOM OCCUPANCY TRACKER
(By: Donovan Porter and Hunter Ylitalo)

c) Smart alarm system

This is one of the most popular projects among the students that seemed to have attracted interest among them due to the fact that many students struggle to wake up to early morning classes or other appointments. Three multi-disciplinary students, from computer engineering (CE), computer science (CS), and electrical engineering (EE) majors got together to work on this project in the fall term of 2019. They proposed this project due to the lack of satisfaction with existing alarm systems out in the market, including smartphone apps. They wanted to address the issue of being late to class, work, or other appointments.

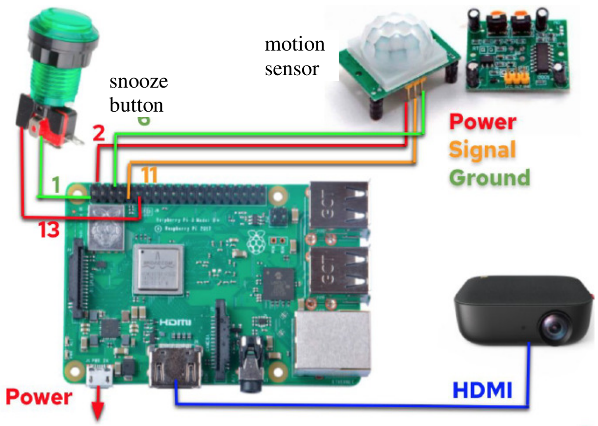

FIGURE III
SMART ALARM SYSTEM
(By: Erica Townsend, Allison Hurley, and Shayna Sande)

Their implementation uses a Raspberry Pi embedded computer system with a monitor or projector, a motion sensor, and a button. The user uses a web interface from their phone or computer to access the server running on the Raspberry Pi and configure the information for the smart alarm. This information includes the time they usually snooze the alarm for past it initially goes off and the time the user takes to get ready before getting out of the house. The smart alarm system calculates automatically the drive time to their destination based on google maps (so dynamic delay information is incorporated) and the time it takes for parking. All these factors are used by the smart alarm system to determine the wake-up-time for the user.

d) Low-cost 360 degree LIDAR scanner

Even though the cost of LIDAR (light detection and ranging) sensors are gradually going down, they still remain outside the price range for most low-budget projects. A team of three students got together to work on this project for building a 360º LIDAR scanner using a low-cost 1D single-point LIDAR. The project was performed in the fall term of 2019. To achieve proper operation of their scanning LIDAR the students mounted 1D LIDAR sensor on a servo motor using 3D printed parts for gears and housing of their system. They needed to develop feedback control techniques for accurate positioning of their servo motor as the LIDAR scan operation is carried out at each angle. The students successfully

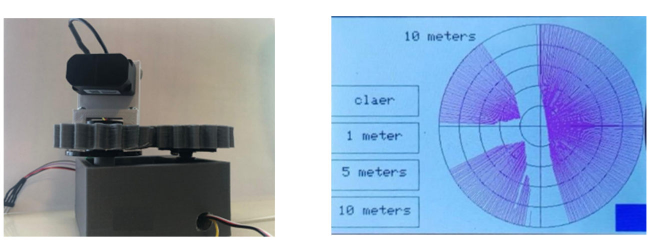

FIGURE IV
LOW-COST 360 DEGREE LIDAR SCANNER
(By: Adem Beyaz, Marc Osswald, and Fabian Heine)

demonstrated their project by creating a 2D map of an environment.

In addition to the student projects presented above, there were several other interesting projects that were proposed and implemented by students in the embedded systems course over the last several years. Among those remaining projects that were implemented in the fall of 2019 term include: WiFi enabled cooking temperature monitoring system, real-time monitoring of power consumption of devices in a home, RFID based door access control with keypad backup option, RFID based cashless and contactless payment system for a vending machine, heartbeat monitoring and alert system, a persistence of vision (POV) fan with wireless charging for clock display. Due to space limitations, this paper could not present these projects in more detail.

OVERALL EXPERIENCE

At the completion of the term students submitted a survey about their overall educational learning experience in the course. Some of the student comments from these surveys are given below:

- "*The peer teaching during the last 4 weeks are excellent and I have found it way easier to learn about the material and have found the class to be a lot more interesting.*"
- "*The strengths of this class are that I got a lot of hands-on experience with coding and learning on how to communicate with the MCU. This class also taught me how to speak publicly and how to prepare for meetings and to clearly convey my thoughts to others.*"
- "*I like the flexibility of the course. Allowing lab and lecture to actually work together was good and if we were overloaded with one section, adjustments were made.*"
- "*Students will learn about the microcontroller from the hardware to the software. I can confidently say that I can apply the things I learned to many different situations.*"
- "*In Labs, you have the chance to make some very cool pieces of technology like an ultrasonic sensor, keypad, and the final project which combines what you've learned/done to apply to a complex microcomputer system.*"
- "*Be prepared to put forth an effort in this class, but don't be afraid because you will reap the rewards of knowledge tenfold.*"

DISCUSSION AND CONCLUSION

As can be observed from the comments by the students at the end of the term, this course has been highly successful in integrating the theoretical concepts of embedded systems with the practical laboratory and real-world projects. The student-inspired project-based learning approach has been well received among the students as they are able to apply their creativity in identifying real-world problems that have practical value and develop effective solutions that work. It is also important to note that the students had great fun while working on these projects, even though they were not easy.

The instructor had prior exposure to the ideas of instilling entrepreneurial mindset in students by using KEEN's framework [14]. According to this framework educational success of our students should not be limited to mastering the technical skills. It should also include the 3C's (curiosity, connections, and creating values) as parts of the educational outcomes to help cultivate the entrepreneurial mindset in the students. The students are inspired to demonstrate constant *curiosity* about the changing world and encouraged to challenge existing norms or accepted solutions. With the *connections* piece of the 3C's students are expected to integrate information from multiple sources as they think about their project proposals and work on building their solutions. The last piece of the 3C's is about *creating values*, which means as students think about project ideas they need to focus on identifying opportunities that would add value to the customers or target users of the product or service.

The peer-teaching component of the course was also found to be an effective active-learning tool by making students take responsibility in their own learning, by identifying and gathering relevant information, and effectively sharing it with their peers in class. Students appreciate the value of peer-teaching as it motivates them to get out of their comfort zone and have courage to take the role of a professor for a day in teaching a specific topic for the whole class.

As a conclusion, the instructor would like to comment a key observation on how much the students devote themselves to see successful results when they are allowed to feel a sense of ownership of their project problems which are inspired from their own experiences in their daily life, wherever it might be from. And at the end of all this, the students really appreciate the practical value of their education and they get rewarded with great satisfaction of their accomplishments.

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