Integrating Internet of Things (IoT) into STEM Undergraduate Education: Case Study of a Modern Technology Infused Courseware for Embedded System Course

Jing (Selena) He[†], Dan Chia-Tien Lo[†], Ying Xie[†], Jonathan Lartigue[‡]
[†]Department of Computer Science, Kennesaw State University, Marietta, Georgia 30060, USA
[‡]Department of Software Engineering, Kennesaw State University, Marietta, Georgia 30060, USA
Email: {jhe4, dlo2, yxie2, jlartigu}@kennesaw.edu

***Abstract*—Internet of Things (IoT) is rapidly emerging as the next generation of communication infrastructure, where myriad of multi-scale sensors and devices are seamlessly blended for ubiquitous computing and communication. The rapid growth of IoT applications has increased the demand for experienced professionals in the area. Since few, if any, dedicated IoT courses are currently offered, most Science, Technology, Engineering, and Mathematics (STEM) students will have limited or no exposure to IoT development until after graduation and entrance into the workforce. Moreover, there is a little room for adding additional courses into existing STEM curriculum. Therefore, we propose to transform STEM core courses by integrating IoT-based learning framework into their corresponding lab projects.**

The design challenges of the new learning framework is summarized in the paper. Subsequently, we propose the effective learning approaches to address those challenges. Moreover, in this paper, we present a case study by incorporating IoT-based learning framework into a Software Engineering (SWE) embedded system analysis & design course. Specifically, we introduce a lab development kit composed of Raspberry Pi/Arduino boards and a set of sensors with Zigbee supporting to provide wireless communication in the class lab section. We adopt module design method to design the course labware. Well-developed modules are presented and one sample module is illustrated in the paper. The labware is evaluated through survey questions. The majority of the students provided positive feedback and enjoyed the IoT-based lab development kit.

I. Introduction

Internet-of-Things (IoT) has emerged as a new network paradigm, which allows physical entities (such as chairs, lamps, and briefcases, *etc.*) and/or physical phenomenon (such as temperature, heart rate, and moving action, *etc.*) to communicate with each other. Eventually, the collected data and fused information are connected to the Internet, to provide opportunities to build smart/intelligent systems and applications. Additionally, many modern technologies and devices such as Radio-Frequency Identification (RFID), Near Field Communication (NFC) (*i.e.*, Zigbee and Bluetooth), Wireless Sensor Network (WSN), cloud computing, social networks, universal mobile accessibility advanced technologies (*i.e.*, Wi-Fi hotspots, and cellular network), and big data analytics support IoT to compose a next generation network infrastructure [1].

The ubiquity of IoT has expanded greatly in the last two years, and a June 2015 McKinsey Global Institute report estimates it will have a $3.9-11.1$ trillion dollar potential impact across just nine sectors of industry by 2025 [2]. These industries correlate closely with current rapidly growing sectors for software developers, such as health care, manufacturing, retail, and urban planning. The McKinsey report also notes that IoT development will lead to "a rising demand for vertical expertise to help companies in specific industries incorporate IoT technology". Higher demand in these areas infers an increased need for qualified software developers, but current STEM undergraduate curricula offer little exposure to IoT concepts and practices.

IoT has not yet become part of Compute Science (CS) or SWE curricula, and certainly not in the broader STEM fields. Due to the lack of STEM curricula in IoT and because there is a little room for adding additional courses into existing STEM curricula, we propose to transform STEM curricula by integrating IoT-based learning framework into the various courses with lab projects - using the new learning framework as a campus-wide shared resource. The goal is that students can understand IoT fundamentals and gain hands-on programming experience in a variety of technology-driven courses. To facilitate the learning framework to be easily integrated by different related courses in STEM curricula, we adopt a modular-based design to develop the labware for each course. Each module has multiple learning levels, which includes lecture notes on foundational and emerging topics, tutorials, review questions, hands-on laboratory practices with real-world application, and semi-constructed projects utilizing inexpensive, portable, and energy-efficient equipment.

This paper presents our initial effort on dealing with the challenges about the learning approach and designing method of the IoT-based learning framework. In this paper, we also describe the experience to integrate the pilot modules of the designed labware into Embedded System Analysis & Design course. The teaching material are evaluated through survey questions and interviewing students. The majority of students surveyed/interviewed provided positive feedback and enjoyed the IoT-based lab development kit.

The rest of this paper is organized as follows: in Section II, we mentioned the challenges to design the learning framework and the learning approach for IoT education. In Section III, we introduce the technologies involved in implementing the IoT-based learning framework. In Section IV, we describe the pilot modules which applied in Embedded System Analysis & Design course. The evaluation of the labware is discussed in Section V. In Section VI, we review some related works on IoT education. Finally, the paper is concluded in Section VII.

II. IoT-based Learning Framework

In this section, we first summarize the challenges to design the IoT-based learning framework and then propose effective learning approaches to overcome the aforementioned challenges.

A. Design Challenges

A new paradigm of learning in Science, Technology, Engineering, and Mathematics (STEM) is *learning by doing*. Responding to President Obama's call for a nationwide Computer Science for All Initiative [3], we propose to establish a laboratory-based learning framework to educate the next generation of students who are equipped with technology skills. The long-term goal of this project is to provide a cross-campus technology infrastructure or framework that supports teaching STEM-related course, and transform the way we teach these course using emerging computing technologies to the 21st Century undergraduate. The framework is an environment for teaching computing concepts and theories using hands-on, problem solving, and pedagogy which prepare and enhance student learning experience. The challenges to design such a framework is summarized as follows:

1) How to accommodating emerging computing technologies into this framework?

The purpose of this framework is to prepare students for the 21st Century industry. Hence, seamlessly integrate emerging computing technologies into this framework is important.

2) How to supplementing teaching materials in applied STEM fields through applying this framework?

The authors are from Computer Science and Software Engineering departments. As we know, there is a little room for adding additional courses into existing CS/SWE curriculum. Hence, how to supplement teaching materials without adding new courses in another challenge?

3) How to improving students' hand-on experience and increase the opportunities to collaborate among STEM related fields?

The goal of this project to prepare our undergraduates with technological skill. Moreover, all kind of industries in different fields are closely interweaved with each other. Hence, a good framework should consider to solve this challenge.

4) How to promote undergraduate students in research through applying this framework?

Kennesaw State University (KSU) changed its status to *comprehensive university* in August 2013 [4] and was classified as an "R3" institution — a doctoral research institution with moderate research activity, in February, 2016 [5]. Research is an important component to educate next generation.

5) How to cultivating students interesting in learning and keep student retention in STEM related field?

Lots of under-representative groups chose STEM related fields in early stage, but finally quit the program [7]. How to improve student' self-efficacy and retention is a critical challenge needed to be address.

6) How to broadening participation in STEM related fields?

Ethnic and gender inequities and under-representation in STEM related fields, and, more so in computing field, in the national workforce is profound [6], [7]. We definitely need to address this challenge.

B. Proposed Framework and Learning Approaches

To address these challenges, we propose to set up an instrumentation laboratory which supporting the new learning framework. The features of this novel learning framework are summarized as follows:

1) Integrating Internet-of-Things (IoT) to establish the learning framework:

The IoT-based learning framework is a collection of communicative, integrated computing devices and instruments for mapping abstract concepts and theories taught in classrooms, or while teaching, into practical, hands-on experiential knowledge.

The internet, as a massive telecommunication infrastructure, currently supports a plethora of computing and sensory device capable of signaling or communicating with each other. When properly programmed, these devices can be used to test and validate theories and abstract concepts. The logical behaviors and data which such devices communicate with, or share, could be used to validate correctness of the underlying course concepts, models, or theories. Because of this capability, we adopt IoT to accommodate emerging computing technologies into the learning framework. In sum, the integration of latest hardware and software allows students to learn the emerging technology, and to be well-trained for the urgent industry needs.

2) Integrate the learning framework into different STEM-related courses by adopting a modular-based design approach:

Each module will have multiple learning levels. The modular design gives instructors the flexibility to adopt the full course or to integrate selected modules, *e.g.*, course related projects, based on their specific needs. Each module will include lecture notes, tutorials, review questions, hands-on laboratory practices, and assignments. All learning materials will be available online.

3) Developing a series of interdisciplinary hands-on projects associated with each module:

The importance of Experience-based/hands-on learning has long been recognized in the learning theory literature [8]. In each module, we develop hands-on materials specifically for the module learning objectives. Since the targets of this learning framework is related STEM courses, interdisciplinary projects should be designed by working with STEM-faculty across campus. In addition, to make the learning more effective, all hands-on practices are implemented in a IoT-based lab development kit, which is composed of low-powered electronic devices Raspberry Pi/Arduino boards and integrate with a set of sensor nodes with Zigbee supporting to provide wireless communication capability. The low cost and high portable properties make the lab development kit possible to offer lab intensive course in resource limited institutions either lacking of faculty expertise or lab maintenance/initiation budgets. Moreover, the lab development kit provides Graph User Interface (GUI)-based Integrated Development Environment (IDE), and huge of online tutorials/forums, which shorten students learning curve and facilitate projects development, debugging and testing.

4) The framework is scalable and capability of problem-solving activities in STEM research:

Through the well-designed problem-solving activities in each module, the students can get familiar with the process of conducting research, which includes developing a research project; conducting a literature review; investigating appropriate methods and tools to implement the research project; making oral presentation of the application of the research project; and writing technique manuscript of the research findings.

5) Various modules are augmented with project-oriented technology-driven contents from STEM related fields:

For each module, we propose to develop a series of semi-conducted programming projects associated with the technology introduced in this module. This learning-by-doing pedagogy will promote students life-time long learning skills. It will allow students not only practice pre-designed hands-on labs, but also have opportunities to design and invent their own applications.

6) The framework adopt team-based approach. Various modules are augmented with real life application from STEM related fields:

The studies found that students want to understand more real-life applicability within CS. Varma [9] also found that students desire relevance from their studies. Moreover, students, especially women, look for creativity in their studies [10] of which CS is not perceived to have much [11]. Other factors dissuading more women from studying CS consist of the negative image of CS. Females want to work with people, are opposed to sitting behind a computer all day, and think they dislike programming despite never trying it [6].

Hence, we propose team-based approach which let students work with people. Moreover, the real-world projects provide students with the opportunity to apply the knowledge and skills acquired in their courses to a specific practical problem; extend their academic experience into working with new ideas and learning new advanced technologies; demonstrate their proficiency in written and oral communication skills; extend and refine their knowledge and skill in the realization of their personal and professional goals.

III. IoT-based Learning Framework Overview

In this section, the technologies used to develop the new learning framework are summarized first. Subsequently, we describe the proposed framework architecture.

A. Technologies Overview

1) Internet of Things

Internet of Things (IoT) has emerged as a new network paradigm, which allows various physical entities in the world to connect with each other. The observed or generated information of these entities have a great potential to provide useful knowledge across different service domains, such as building management, energy-saving systems, surveillance services, smart homes, smart cities, etc. [1]. One foundational technology of IoT is the Radio-Frequency IDentification (RFID) technology, which allows microchips transmit the identification number of the objects to a reader through wireless communication. Through RFID technology, the physical objects can be identified, tracked, and monitored automatically. Nowadays, RFID technology has been widely adopted in logistics, pharmaceutical production, retailing, and supply chain management [12], [13]. Another foundational technology of IoT is Wireless Sensor Networks (WSNs), which adopt interconnected intelligent sensors to periodically sense the monitored environment and send the information to the sink (or base station), at which the gathered/collected information can be further processed for end-user queries [14]. The applications include disaster control, environment and habitat monitoring, battlefield surveillance, traffic control, and health care applications [15]. Additionally, many other technologies and devices such as Near Field Communication (NFC) [16], short-range wireless communication (*i.e.*, ZigBee [17] and Bluetooth [18]), universal mobile accessibility (*i.e.*, Wi-Fi hotspots [19], and cellular networks [20]), social networking [21] and cloud computing [22] support internet of things to compose a extensive network infrastructure.

2) Raspberry Pi/Arduino Boards

Arduino is an incredibly flexible open micro-controller and development environment which is easy to use. Arduino was first launched in 2005, which is based on a board with a single micro-controller, and input/output pins for communications and control of physical objects and the environment. The functionality to connect and control physical objects directly relates to internet of things. Hence Arduino gained popularity in short time because of the simplicity to use and cheap price in basic model. Different boards with various capabilities have been developed since 2005, such as UNO, Mega, Leonardo, Minim Due, Yun, *etc* [23].

Raspberry Pi is a series of credit-card-sized single board computers developed in the United Kingdom by the Raspberry

Pi Foundation with the intent to promote the teaching of basic computer science in schools and developing countries. All models feature a Broadcom system on a chip (SOC) which include an ARM compatible CPU and an on chip graphics processing unit GPU [24].

Raspberry Pi/Arduino boards have been chosen to implement the lab development kit, because they are low-powered, low cost electronic devices and provides GUI-based IDE, and huge of online tutorials/forums. In addition, Raspberry Pi/Arduino boards offers enough capacity and functionalities with its availability of myriad of third party components.

3) Web 2.0

Web 2.0 is a term to describe the second generation of World Wide Web (WWW), which emphasizes the ability for people to collaborate and share information online [25]. Web 2.0 services include video hosting services, wikis, blogs, social networking, and resource sharing environments (such as Flickr).

Every system uses resources. These resources can be pictures, video files, Web pages, business information, or anything that can be represented in a computer-based system. A resource can consist of other resources. While designing a system, the first thing to do is identify the resources and determine how they are related to each other. Once we have identified our resources, the next thing we need is to find a way to represent these resources in our system. In Web 2.0, there are two formats to represent the resources, eXtensible Markup Language (XML) and JavaScript Object Notation (JSON). XML is a meta-language that can be used to define our communication language, while JSON is a lightweight alternative to XML format. JSON is a collection of key/value pairs, which belong to a subset of the object literal notation of JavaScript. Since these key/value pair structures can be adopted in any programming language, JSON is independent of the programming language used when exchanging data.

4) Google Cloud Web Services

Private cloud web service is needed to handle back-end requests from Raspberry Pi/Arduino boards and mobile application. Google App Engine will be used to implement the framework backend, which will accept POST requests from the Raspberry Pi/Arduino boards and store the data in the cloud. The web service will also provide GET requests which will return the sensing data in JSON format, which will be used to display the retrieved data in the mobile application. In addition, for energy efficient design, we adopt *master-slave* communication architecture, in which the slave nodes only responsible for collecting data and send data to master nodes, while mater nodes take the responsibilities of calculation and storing data to the cloud server. The architecture and the flow of data of the cloud web service is illustrated in Fig. 1.

5) REST and RESTFul APIs

Representational State Transfer (REST) is an architectural style that specifies constraints, such as the uniform interface, for networked hyper-media applications. It is primarily used to build Web services that are lightweight, maintainable, and scalable. When Web services use REST architecture, they are called RESTful APIs (Application Programming Interfaces). REST is not dependent on any protocol, but almost every RESTful service uses Hypertext Transfer Protocol (HTTP) as its underlying protocol. In sum, RESTful systems typically, but not always, communicate over the HTTP with the same HTTP verbs (GET, POST, PUT, DELETE, etc.) used by web browsers to retrieve web pages and send data to remote servers.

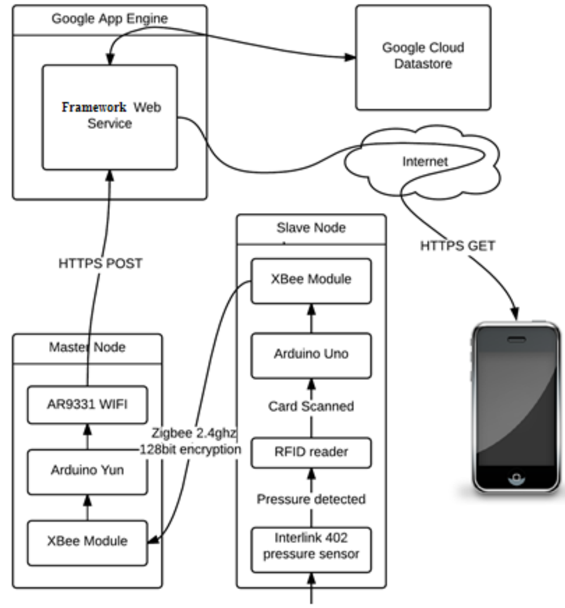

Fig. 1. Google Cloud Web Service Architecture.

Every system has resources. The purpose of a service is to provide a window to its clients so that they can access these resources. REST does not put a restriction on the format of a representation of resource. Moreover, RESTFul API does not require the client to know anything about the structure of the API. Rather, the server needs to provide whatever information the client needs to interact with the service. For example, the server specifies the location of the resource, and the required fields. The browser doesn't know in advance where to submit the information, and it doesn't know in advance what information to submit. Both forms of information are entirely supplied by the server. Hence, RESTFul APIs is now popular in implementing web services and mobile Apps.

6) Other Technologies

Some other technologies, such as location-based services, big data analysis and visualization, social networking, robotics management, security and protection are important components to implement the learning framework. Moreover, different STEM fields may have different technologies need to be integrated into the learning framework implementation.

B. Framework Architecture

To illustrate, we discuss a practical example, IoT-based laboratory development kit for designing an activity, the students could participate in to gain hands-on experiential knowledge, maintain their interest levels, and are aimed towards the

STEM-workforce. As shown in Fig. 2, an RFID reader can automatically read each devices identification and passes the ID data to the Arduino ATmega32u4 microcontroller. The integrated sensors can continuously collect physical data. The students can write a program to periodically cause the data to be sent to a Cloud server using, for example, an open-source ThingSpeak data platform. The program then passes the sensory data along with the timestamp to the Atheros R9331 microcontroller through a bridge (API) library [26]. Finally the bridge library issues an HTTP POST request to the ThingSpeak API [27] along with the device-ID. ThingSpeak uses a concept of “channels”, where each channel can be configured with different labels to hold different kinds of data. In Fig. 2 two channels are shown. The USER channel can hold user information, while the SCAN channel holds sensing data.

For advanced IoT applications, an Android application can be developed to allow administrators or other interested users to monitor the collected data and view the results on a mobile device. The overview of the Android architecture is also illustrated in Fig. 2. Fig. 3 depicts a typical Arduino Yun lab development kit with RFID sensor and pressure sensor. These devices are inexpensive, yet they can offer incredible platforms for developing STEM-related projects as students are prepared for the workforce.

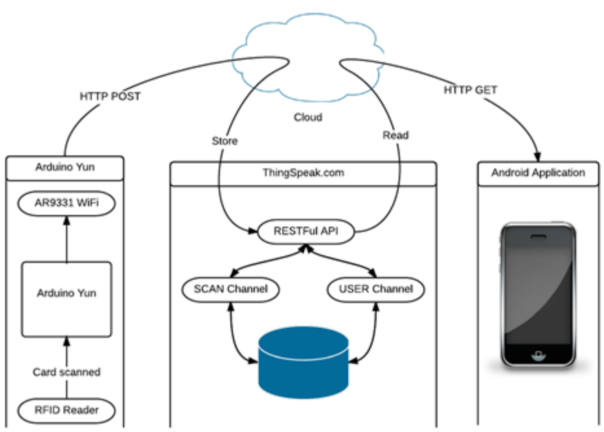

Fig. 2. IoT-based Learning Framework Architecture.

IV. The Embedded System Course Labware

To applying the proposed learning framework, we developed the labware for Embedded System Analysis & Design Course, which is a collection of self-contained modules that provide necessary concept introduction and hands-on laboratory exercises on embedded system. These modules emphasize the balance between theoretical foundations and technical practices of embedded system design and development. The labware contains eleven modules which can be divided to two categories: eight fundamental modules and three advanced modules. The fundamental modules cover the basic concepts of embedded system, while the advanced modules focus on important trends of modern embedded system. Each module

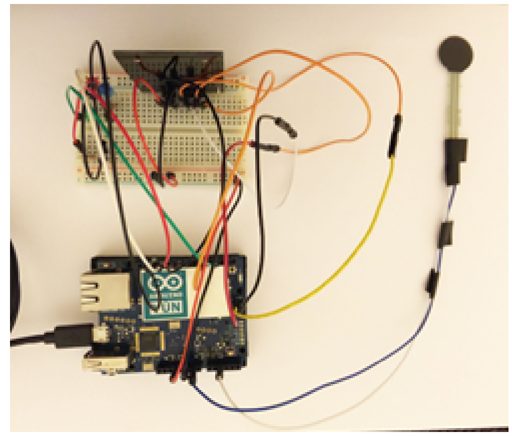

Fig. 3. Arduino Yun Lab Development Kit.

includes pre-lab activities (concept introduction and lab preparation), hands-on lab activities, and post-lab activities (review questions, assignments, and case studies).

In this section, we briefly present each module and then show an example module to illustrate the design.

A. Lab Modules

The modules are designed based on the ACM Computer Science Curricula 2013 [28] and the authors’ teaching experience on embedded system courses. All module will follow the same pattern of design. Fig. 4 summarized the eleven modules designed for embedded system course and how the modules contents mapping to ACM Computer Science Curricula 2013 topics. The detailed description of each module are presented as follows:

Category	Lab Modules	ACM CS Curricula 2013 Topics
Fundamental Modules	Module 1: Introduction to Embedded System	• Overview of Operating Systems • Operating System Principles • Assembly Level Machine Organization
	Module 2: Embedded Software Development Life Cycle	• Development Methods • Software Project Management • Static Analysis
	Module 3: Micro-controller Interrupts	• Software Processes
	Module 4: Real Time Operating System	• Real Time Systems
	Module 4: Embedded System Programming	• System Performance Evaluation • System memory organization and Architecture • File Systems
	Module 6: Peripherals of Embedded System	• Device Management • Resource Allocation and Scheduling
	Module 7: Serial Communication of Embedded System	• Communication and Coordination
	Module 8: Embedded Software Testing	• Software Verification and Validation • Code Generation
Advanced Modules	Module 9: Embedded Web Technology	• Networked Applications
	Module 10: Wireless Embedded System	• Cross layer communication
	Module 11: Embedded System Security and Protection	• Foundational Concepts in Security • Principles of Secure Design • Platform Security

Fig. 4. Lab Modules of Embedded System Course.

Fundamental Modules of Embedded System:

Module 1: Introduction to Embedded System

This module introduces embedded systems categories and application, embedded system constraints and features, embedded systems hardware and software co-design, software cross-compiling, debugging, testing, and integrating. Students will get started with embedded software development tools and IoT-based lab development kit for developing real embedded systems.

Module 2: Embedded Software Development Life Cycle

The software engineering analysis and design methodologies for embedded systems are emphasized in this module. The time constraint static and dynamic analysis with Root-Mean-Square (RMS) and Earliest-Deadline-First (EDF), the behavior analysis and modeling tools (Context Diagram, Data Flow Diagram (DFD), Finite State Machine (FSM), State Chart), and the embedded software design patterns are discussed in depth. An analysis and design lab on a traffic light control embedded system will be provided.

Module 3: Micro-controller Interrupts

This module is designed for Computer Science and Software Engineering students since it is hardware oriented. It focuses on CPU, registers, memory, and I/O port components of micro-controllers. I/O interrupt requests and their Interrupt Service Routine (ISR) such as timers are discussed. The hands-on labs for regular I/O port processing and timer interrupts will be provided.

Module 4: Real Time Operating System (RTOS)

This module introduces the concepts of multitasking and inter-task communication, multitasking scheduling including round-robin scheduling and priority based scheduling. The RTOS labs including counter, traffic control system, temperature control system. Students will learn hands-on experience on the real time operating system and build their RTOS based embedded applications.

Module 5: Embedded System Programming

Embedded system programming is covered in this module including embedded modular programming, programming with CPU Register, memory access, I/O read/write, reentrant and Interrupt Service Routines(ISR). This module is designed for all computing majors. Interrupt programming labs for external edging based and level based triggers, and counter based events will be provided.

Module 6: Peripherals of Embedded System

Embedded systems have their specific interfaces such as keypad, buttons, switches, sensors, smart touch screen, Analog-to-Digital and Digital-to-Analog converters for input interfaces and LCDs, LEDs, stepper motors, and many other actuators for outputs. This module will discuss these I/O devices and their device drivers.

Module 7: Serial Communication of Embedded Systems

This module introduces the main elements in serial communication such as Data Communications Equipment (DCE), and Data Terminal Equipment (DTE), synchronous and asynchronous data communication, software and hardware handshaking in serial communication, and RS-232 communication protocol. It will also discuss serial I/O ports, Universal Asynchronous Receiver/Trasnmitter (UART), and many other issues in serial communication. Labs of Serial communication with PC and modems will be provided.

Module 8: Embedded Software Testing

Embedded software testing is an important phase in embedded Software Development Life Cycle (SDLC). Time constraint requirement testing, multitasking testing, integration and acceptance testing, requirement verification and system validation will be covered. Testing tools will also be introduced.

Advanced Modules of Embedded System:

Module 9: Embedded Web Technology

This module introduces embedded systems for web applications including Embedded TCP/IP stack, Web enable embedded systems, embedded mini-web server. The web enable embedded system development without commercial operating system support is covered. Labs of a mini web server and web enabled alarm clock will be provided.

Module 10: Wireless Embedded System

This module introduces the technologies of Radio Frequency (RF), infrared, and Bluetooth, in wireless communication and IEEE standards such as long range 802.11b (also known as Wi-Fi), short range 802.11a for higher bandwidth and high volume multiple users connection (multimedia content), long range and high volume 802.11g, and the short range, temporary networking connection oriented inexpensive Bluetooth wireless options. Wireless embedded application labs with Raspberry Pi/Arduino boards will be provided.

Module 11: Embedded System Security and Protection

This module introduces key security properties (Confidentiality, Integrity, and Availability), concepts of risk, threats, vulnerabilities, attack vectors, authentication and authorization, access control, and trust and trustworthiness. Explain the features and limitation of embedded operating system used to provide protection. The labs are provided to carry out system administration tasks according to a security policy.

Module 1 to Module 8 have been well developed and evaluated in KSU Embedded System Analysis & Design course in Spring 2016. Module 9 to Module 11 are under intensive development and will be integrated into courses for evaluation soon. More modules will be designed in the future to address different aspects of IoT for all STEM related fields.

B. Example Module

In this section, we show an example module to illustrate the learning approach and the designed labware. Fig. 5 shows our design of the Module 1: Introduction to Embedded Systems. Module 1 aims at providing students fundamental concepts of embedded systems. The module first provides the pre-lab activities that include introduction slides, C/C++ language review, and the basic steps to set up IoT-based lab development kit. The lab activities provide a couple of hands-on projects, which try to let students familiar with Raspberry Pi IDE, and run codes on Raspberry Pi devices. The post-lab activities include case studies, review questions, and semi-conducted real-world application projects.

C. Integrate the IoT-based Learning Framework into other CS/SWE Courses

Since we adopt a modular design for the learning framework, the learning materials can be easily integrated by different core courses in CS/SWE curriculum. Some sample modules developed recently are shown as follows:

Module 1: Introduction to Embedded Systems

Description: this module introduces embedded systems categories and application, embedded system constraints and features, embedded systems hardware and software co-design, software cross-compiling, debugging, testing, and integrating. Students will get started with embedded software development tools and Raspberry Pi based lab development kit for developing real embedded systems.

Learning Objectives:
• Students understand embedded systems categorization
• Students understand how to identify the time and resource constraints for embedded systems
• Students understand the embedded systems hardware and software co-design
• Students understand how to distinguish embedded software development from other software development
• Student familiar with Raspberry Pi lab development kit

Activities:
- Pre-lab Activities:
  1. Introduction (slides)
  2. C/C++ review (slides)
  3. Set up Raspberry Pi lab development kit (slides)
- Lab Activities:
  4. Embedded Programming Labs with Raspberry Pi lab development kit
     Lab1: Hello World (instructions)
     Lab2: Multimedia Flash demo (instructions)
- Post-lab Activities:
  5. Case study: 7-segment LED counter (instructions)
  6. Review questions
  7. Assignments
     Semi-conducted Project: LED indicator with different range of sensing data (instructions)

Fig. 5. The Design of Introduction to Embedded Systems Module.

1) Computer Architecture and Robotics (CS3510): CPU and memory of microcontroller, interrupt, peripherals of embedded systems, serial communication, and robotics control programming;
2) Computer Network (CS4622): flow control, congestion avoidance, wireless communication through WiFi or bluetooth, and client-server communication;
3) Cloud Computing (CS4524): scheduling, multi-tasking, real-time system, and store data in clouds;
4) Data Mining (CS4412): mining real-time collected data by applying different algorithms, such as decision trees, k-means algorithms, support vector machines, the Expectation-Maximization (EM) algorithms, k-nearest neighbor (KNN) algorithms, regression trees, bayesian networks, Neuron Networks, *etc*.
5) Software Engineering (SWE4724): semi-constructed projects;
6) Capstone Project (CS4850): semi-constructed projects.

The hardware resource needed to teach these modules is minimized due to the portable lab platforms associated with the online lab materials. The real hands-on labs are guided by step-by-step document/videos. Supported by these multimedia lab guidelines, students can conduct the labs anywhere anytime using the low-power portable tiny microcontroller platforms. They can run labs, do assignments, complete projects without restriction from the class and lab schedule and lab space requirement. This learning-by-doing pedagogy will promote students life-time long learning skills.

V. Course Experience and Student Evaluation

As part of this study, we analyzed learning outcomes and student opinions for applying the Raspberry Pi-based lab development kit into a 3000-level undergraduate embedded systems analysis & design course at Kennesaw State University in Spring 2016. The course utilized Raspberry Pi Model B+ devices in early assignments and projects for approximately one-half of a semester to introduce basic embedded systems concepts, practices, programming, and testing. Later, the course transitioned to a more traditional, primitive embedded micro controller. In this case, the course used the Toolstick Uni micro controller, which based on an Intel MCS-51 (commonly known as the 8051) architecture and produced as a classroom kit by Silicon Laboratories.

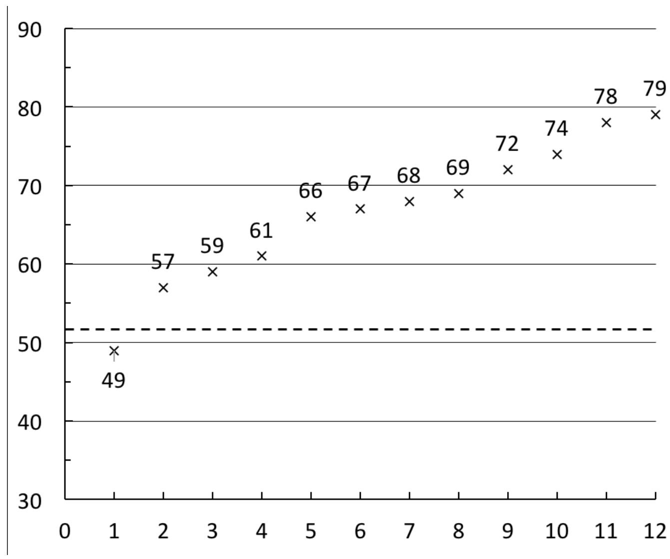

Fig. 6. Student affinity for Raspberry Pi-based lab development kit in an embedded systems course, based upon a 7-point Likert-Scale summation over 18 questions. The dashed line represents a neutral score of 52.

Retrospective student surveys [29] were administered in the final week of the course to assess student opinions about the use of Raspberry Pi-based lab development kit to introduce embedded systems concepts. The assessment was comprised both of free-form questions and eighteen Likert-type and Likert-scale assessment questions [30]. A seven-point Likert scale [31], [32] was employed and student agreement was measured on a range of statements related to use of Raspberry Pi-based lab development kit in the course, interfacing the Raspberry Pi devices with various sensors, and the difficulty of assignments with the Raspberry Pi devices compared to more the traditional micro controllers utilized later in the course. Of the 18 questions, six pairs of reversal questions measured essentially identical opinions from both positive and negative agreement. One additional pair of companion questions assessed a similar statement from differing viewpoints, but cannot accurately be categorized as reversal-scale questions.

Results of the retrospective assessment indicate a strong sentiment among students that use of Raspberry Pi-based lab development kit in an embedded systems course *(See Figure 6)*. Specifically, student overwhelmingly responded (average 6.17 on maximum scale of 7) that assignments and projects using the Raspberry Pi-based lab development kit prepared them for more later assignments using pure embedded micro controllers *(See Table I)*. Similarly, with an average response of 6.0 out of 7, students agree that working first with analog and digital sensors, motors, and similar devices using the Raspberry Pi devices prepared them for connecting similar sensors to an embedded micro controller. Finally, students on

Statement	Average Response *(Scale of 1 to 7)*
The use of Raspberry Pi-based lab development kit helped prepare me for complex embedded systems topics later in the course.	**6.17**
Designing, writing, and testing software to run on the Raspberry Pi-based lab development kit is easier than designing, writing, and testing software to run on the Toolstick Uni.	**5.67**
Learning to wire digital and analog sensors to the Raspberry Pi prepared me for connecting sensors to the Toolstick Uni.	**6.0**
The Raspberry Pi is a sufficiently robust and capable device for use in an embedded systems course.	**5.08**
Programming the Raspberry Pi in C / C++ is more appropriate than Python in an embedded systems course.	**5.5**

TABLE I
SELECTED STUDENT RETROSPECTIVE RESPONSES ON UTILIZATION OF RASPBERRY PI-BASED LAB DEVELOPMENT KIT IN EMBEDDED SYSTEM COURSE

average (5.67 out of 7) agreed that developing and testing software on the Raspberry Pi-based lab development kit is easier than developing and testing directly on an embedded micro controller, supporting the idea that Raspberry Pi-based lab development kit can reduce student anxiety in the early stages of an embedded computing course.

As you seen, the students feedback was overwhelmingly positive. Many students said in the class survey that they had great opportunities 1) to practice the theory and abstraction through a practical application; 2) to integrate their knowledge learn to solve real-world problems; and 3) to co-design and develop software with Raspberry Pi devices to produce real-world embedded systems on their own. Some students commented that the lab was very challenging. This lab has really raised my level of interest in IoT application development. To sum up, our labware received positive feedback from students and progress was made towards the objectives of promoting students interests and improving their experience in embedded system and IoT application design and development.

VI. RELATED WORK

Many colleges and universities are developing or offering courses on IoT, however, their capacity is still in infant stages because it is a relatively new field. The authors investigated IoT curriculum in U.S. universities. Only a few universities offer online courses related to IoT education, such as MIT offered an online course titled Internet of Things: Roadmap to the connected World [33] beginning on April 12, 2016. Moreover, lots of learning materials of IoT are posted as a MOOC (Massive Open Online Course) [34]. Because of the increasing demand, even industry offers IoT certificate program, such as CISCO [35].

However, IoT is gaining global significance. China for example has initiated a strategic program to push the development of core technologies and applications in IoT area with a special focus on agriculture, logistics, transport, electricity, public health, and so on. Moreover, academics are investigating the potential of IoT for reforming vocational education [36], digital campus [37], and teaching management system [38]. In Europe, Queen Mary (London) offers a four-year BSc(Eng) in IoT Engineering [39]. Waterford Institute of Technology (Ireland) offers a four-year BSc(Hons) in IoT [40]. University College Dublin (Ireland) offers BE in IoE engineering [41].

All the aforementioned works only apply IoT education into one specific discipline, such as computing or engineering, which is completely different from our project goals. We propose to design a across-campus technology infrastructure/framework, that support teaching of Science, Technology, Engineering and Mathematics (STEM) relate courses or project by integrating IoT technologies.

VII. CONCLUSION

The authors propose to establish a learning framework, which integrates Internet-of-Things and hardware/software technologies, to create a new paradigm of learning. We believe that students learn better and knowledge is retained better using a hands-on and team-oriented learning approach. The authors propose to develop intercapillary projects, which are purposefully designed to solve problems that are draw from concepts in STEM areas. In this paper, we shows the efforts about the design phase and illustrate a case study to apply the learning framework into a Embedded System Analysis & Design course. The students were asked to designed and implemented solutions to the projects in the Internet-of-Things-based lab development kit, which composed of internet-enabled sensors, micro-controllers, networking devices, and programming environments. Twelve students participate in the initial evaluation of the learning framework and learning materials. The majority of students surveyed provided positive feedback and enjoyed the IoT-based lab development kit. In the future, we will design more modules for different STEM related courses. We will continuously improve the lab environment setup, lab instructions, and slides quality based on students' comments and suggestions.

Incorporating IoT into existing STEM curriculum offers the opportunity to position undergraduates more competitively with respect to this growing skillset and market, to ensure existing coursework and projects keep pace with emerging trends in industry, and to increase student interest and success in targeted courses.

ACKNOWLEDGMENT

This material is based in part upon work supported by the National Science Foundation under Grant Numbers 1438858 and 1623724. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. This work is also funded in part by the Kennesaw State University's Office of the Vice President of Research (OVPR) Pilot/Seed Grant, by the College of Science and Mathematics Interdisciplinary Research Opportunities (IDROP) Program.

REFERENCES

[1] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, *Internet of Things (IoT): A vision, architectural elements, and future directions*, Future Generation Computing System, 29, pp. 1645-1660, 2013.

[2] J. Manyika, M. Chui, J. Woetzel, R. Dobbs, *Unlocking the potential of the Internet of Things*, McKinsey Global Institute, June, 2015.

[3] Computer Science For All initiative, https://www.whitehouse.gov/blog/2016/01/30/computer-science-all, accessed in April, 2016.

[4] KSU Comprehensive University, https://web.kennesaw.edu/news/category/tags/comprehensive-university, accessed in April, 2016.

[5] KSU R3 Institution, https://web.kennesaw.edu/news/stories/kennesaw-state-elevated-doctoral-research-institution-carnegie-classification, accessed in April, 2016.

[6] Carter, L. (2006). *Why students with an apparent aptitude for computer science dont choose to major in computer science*. ACM Technical Symposium on Computer Science Education (SIGCSE) (March 2006), Houston, TX, 27-31.

[7] Buzzetto-More, N., Ukoha, O., and Rustagi, N. (2010). *Unlocking the barriers to women and minorities in computer science and information systems studies: Results from a multi-methodolical study conducted at two minority serving institutions*. Journal of Information Technology Education, vol. 9, 115-131.

[8] A. Janiak, and R. Rudek, *Experience-Based Approach to Scheduling Problems With the Learning Effect*, IEEE Transactions on Systems, Man, and Cybernetics Society, 39(2):344-357, March, 2009.

[9] Varma, R. *Making computer science minority-friendly*. Communications of the ACM (February 2006), vol. 49 (2), 129134.

[10] Yardi, S. and Bruckman, A. *What is computing? Bridging the gap between teenagers perceptions and graduate students experiences*. ICER (September 2007), Atlanta, GA, 39-49.

[11] Rich, L., Perry, H., and Guzdial, M. *A CS1 course designed to address interests of women. ACM Technical Symposium on Computer Science Education*. (SIGCSE) (March 2004), Norfolk, VA, 190-194.

[12] X. Jia, O. Feng, T. Fan, and Q. Lei, *RFID technology and its applications in internet of things (IoT)*, 2nd IEEE conference on Consumer Electronics, Communications and Networks (CECNet'12), pp. 1282 - 1285, 2012.

[13] C. Sun, *Application of RFID technology for logistics on internet of things*, AASRI Conference on Computational Intelligence and Bioinformatics, pp. 106 - 111, 2012.

[14] J. He, S. Ji, Y. Pan, and Y. Li, *Constructing Load-Balanced Data Aggregation Trees in Probabilistic Wireless Sensor Networks*, IEEE Transactions on Parallel and Distributed Systems (TPDS), Vol. 25, No. 7, pp. 1681 - 1690, July, 2014.

[15] J. He , S. Ji, R. Beyah, Y. Xie, and Y. Li, *Constructing Load-Balanced Virtual Backbones in Probabilistic Wireless Sensor Networks via Multi-Objective Genetic Algorithm*, Transactions on Emerging Telecommunications Technologies (ETT), Vol. 26, No. 2, pp. 147 - 163, February, 2015.

[16] T.G. Zimmerman, *Personal area networks: Near-field intrabody communication*, IBM System Journal, Vol. 35, pp. 609 617, 1996.

[17] P. Baronti, P. Pillai, V.W. Chook, S. Chessa, A. Gotta, and Y.F. Hu, *Wireless sensor networks: A survey on the state of the art and the 802.15. 4 and ZigBee standards*, Computer Communication, Vol. 30, pp, 1655 1695, 2007.

[18] Bluetooth, *S.I.G. Specification of the Bluetooth System*, version 1.1. Available online: http://www.bluetooth.com (accessed in March 2015).

[19] G. Anstasi, M. Conti, E. Gregori, and A. Passarella, *802.11 power-saving mode for mobile computing in Wi-Fi hotspots: limitations, enhancements and open issues*, Wireless Networking, Vol. 14, pp. 745 768, 2008.

[20] M.K. Karakayali, G.J. Foschini, and R.A. Valenzuela, *Network coordination for spectrally efficient communications in cellular systems*, Wireless Communication, Vol. 13, pp. 56 61, 2006.

[21] J. He, S. Ji, R. Beyah, and Z. Cai, *Minimum-sized Influential Node Set Selection for Social Networks under the Independent Cascade Model*, ACM MOBIHOC 2014, pp. 93 - 102, 2014.

[22] J. A. Gonzalez-Martnez, M. L. Bote-Lorenzo, E. Gomez-Sanchez, and R. Cano-Parra, *Cloud computing and education: A state-of-the-art survey*, Computers & Education, Vol. 80, pp. 132 - 151, 2015.

[23] Ardunio Products, Available online: http://arduino.cc/en/Main/Products, accessed in April, 2016.

[24] Raspberry Pi, https://www.raspberrypi.org/, accessed in April, 2016.

[25] T. O'Reilly, *What is Web 2.0: Design patterns and business models for the next generation of software*, International Journal of Digital Economics, Vol. 65, pp. 17 - 37, 2007.

[26] Arduino Bridge Library. http://arduino.cc/en/Reference/YunBridgeLibrary, accessed in April, 2016.

[27] ThingSpeak API. https://thingspeak.com/, accessed in April, 2016.

[28] ACM/IEEE the Joint Task Force on Computing Curricula, Computer Science Curricula 2013, December 20, 2013.

[29] Ellen Taylor-Powell, *Questionnaire Design: Asking questions with a purpose*. University of Wisconsin-Extension. May, 1998.

[30] Likert, R. *A Technique for the Measurement of Attitudes, Archives of Psychology*, 22(140):5-55, June, 1982.

[31] Losby and Wetmore, *Program Evaluation Tip Sheet: Constructing Survey Questions*, 2011. http://www.cdc.gov/dhdsp/programs/spha/docs/constructing_survey_questions_tip_sheet.pdf, accessed in April, 2016.

[32] Changing Works, Likert Scale, http://changingminds.org/explanations/research/measurement/likert_scale.htm, accessed in April, 2016.

[33] MIT online IoT Course, https://mitprofessionalx.mit.edu/courses/course-v1:MITProfessionalX+IOTx+2016_T1/about, accessed in April, 2016.

[34] IoT MOOC recourses, https://www.class-central.com/report/iot-free-online-courses/, accessed in April, 2016.

[35] Cisco IoT Certificate Program, https://learningnetwork.cisco.com/community/internet_of_things, accessed in April, 2016.

[36] H. Bai, and S. Jia, *The internet of things and higher vocational education reforms*, Journal of Shijiazhuang Vocational Technology Institute, 2012.

[37] D. Yan, and M. Chen, *The application of the internet of things in digital campus*, Modern Educational Technology, 2012.

[38] A. Qi, and Y. Shen, *The application of Internet of Things in Teaching Management System*, IEEE computer special issue on the Internet of Things, 2012.

[39] Queen Mary BSc(Eng) in IoT Engineering, http://jp.eecs.qmul.ac.uk/jp_teach.html#bite, accessed in April, 2016.

[40] Waterford Institute of Technology BSc(Hons) in IoT, https://www.wit.ie/courses/type/science/department_of_computing_maths_physics/bsc-hons-in-the-internet-of-things, accessed in April, 2016.

[41] University College Dublin BE in IoE engineering, http://www.ucd.ie/bdic/prospectivestudents/degreescourses/undergraduatecourses/betheinternetofthingsiotengineering/, accessed in April, 2016.