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COLLABORATIVE MULTIDISCIPLINARY ENGINEERING DESIGN EXPERIENCES IN IOT (INTERNET OF THINGS) FOR TEACHERS THROUGH SUMMER RESEARCH SITE PROGRAM

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ABSTRACT

The objective of the NSF RET (Research Experiences for Teachers) site program hosted by the University of Central Florida is to provide K-12 teachers with a hands-on engineering design experience covering all aspects of the Internet of Things, from the manufacturing of a sensor, to the hardware and software that allows it to connect to the Internet. This program gives teachers learning opportunities to explore the practical use of science for engineering applications, and provide a context in which students in their classroom can test their own scientific knowledge as they recognize the interplay among science, engineering and technology. The uniqueness of this site program lies in the engagement of teachers in various facets of scientific, engineering, and educational methods based on Train-the-Trainer model with rotation in multiple research labs. In order to support the STEM educational services for teachers and students in middle and high schools, our site program aims at creating competent teacher trainers who ensure quality pre-service and in-service teacher education, by providing multidisciplinary experiences that are relevant to the current technical development. Teachers in the adjacent public school districts are primary participants in this site program. Significant efforts have been made to recruit teachers serving underrepresented student populations, and female and minority teachers who can reach out to them.

In our RET site program, the participants rotated to four different laboratories with a 1.5-3 week residency in each, where they learned about the practice of engineering in various disciplines at the research laboratories on the university campus under the guidance of faculty and graduate mentors. The teachers presented their learning outcomes in the final week and were invited back to share their educational implementation experiences in their classes. This site program provided teachers with interdisciplinary engineering design experiences relevant to innovative technical development, and helped them develop teacher-driven teaching modules that can be deployed in the classroom.

1. INTRODUCTION

The traditional view of the Internet is a collection of interconnected *computers*, desktops or notebooks where the users utilize programs (typically a browser) to access remote websites, social media, or other services. The emergence of tablets and smartphones made access mobile and more user-friendly, but otherwise the mode of operation remained the same. The recent emergence of the Internet of Things (IoT) radically changes this mode of operation. The connected devices are not computers running a browser anymore – they can range from home appliances such as washers and dryers, to wearable health monitors, and a very large number of small sensors, which are connected to the internet even without their own user interface. The efficient manufacturing of these miniature-sensing devices was enabled by the progress of low-cost/low-power consumption computing devices and the advances in micro-electro-mechanical systems (MEMS) technology. Some analysts predict that the number of connected devices in the Internet of Things will reach into the trillions [1].

We can see the Internet of Things as the fulfillment of Mark Weiser's vision of ubiquitous computing [2, 3]: "the physical world that is richly and invisibly interwoven with sensors, actuators, displays, and computational elements, embedded seamlessly in the everyday objects of our lives, and connected through a continuous network".

Our K-12 education system has extensively adopted the traditional internet model wherein students regularly use internet-connected tablets and computers from an early age. However, the Internet of Things represents a significant disruption since the usual concept of "web browsing" does not apply. The objective of this RET is to provide K-12 teachers with hands-on experiences with the complete lifecycle of a component of the Internet of Things, from the manufacturing of a sensor, to the hardware and software that allows it to connect to the Internet.

An additional dimension of K-12 science education was brought up by the recent National Research Council report on the framework for K-12 Science Education[4]. In the K-12 context, science is generally taken to mean the traditional natural sciences: physics, chemistry, biology, earth, space and environmental sciences. However, the committee recommended the inclusion of engineering and technology for several reasons: (a) it is important for students to explore the practical use of science, given that a singular focus on the core ideas of the disciplines would tend to shortchange the importance of applications; (b) these topics typically do not appear and thus are neglected if not included in science instruction; and (c) engineering and technology provide a context in which students can test their own developing scientific knowledge, and for many, their interest in science, as they recognize the interplay among science, engineering, and technology [4].

In our RET site program, the participants rotate to four different laboratories with a 1.5 to 3 weeks of residency in each, where they learn about the practice of engineering at the research laboratories on the University of Central Florida (UCF) campus under the guidance of faculty mentors. The uniqueness of our program lies in the engagement of teachers in various facets of scientific and engineering methods based on Train-the-Trainer model with job rotation in collaborative team environment.

In order to support the STEM educational services for teachers and students in K-12 by providing quality interdisciplinary experiences that are relevant to technical development, our site program aims at creating a critical mass of highly qualified teacher trainers who ensure quality of pre-service and in-service teacher education.

2. PROGRAM DESCRIPTION

RET Site in Collaborative Multidisciplinary Engineering Design Experiences for Teachers (CoMET), is a National Science Foundation (NSF) funded project (awarded in 2016) at UCF. This project supports active long-term collaborative partnership between K-12 STEM teachers and college faculties and students to bring knowledge of engineering and computer science as well as technological innovation to pre-college and community college classrooms. The goal of these partnerships is to enable K-12 STEM teachers and college faculties to translate their research experiences and new knowledge gained in university settings into their classroom activities. This RET Site has aims to provide K-12 STEM teachers with a hands-on engineering design experience covering all aspects of the Internet of Things (IoT), from the manufacturing of a sensor, to the hardware and software that allows it to connect to the internet. This and other information about the RET program along with a link to the program solicitation, is available at the program website (https://www.nsf.gov/eng/eec/ret/search.jsp).

The practical goal of this project is to engage thirty STEM teachers from local Central Florida counties and actively engage in an eight-week RET summer experience, and one-week Train-the-Trainer Workshop the following summer, over the course of three years. The purpose of the second summer workshop is to service teachers through a train-the-trainer model. There would be 10 new teachers enrolled each year, who would train others and involve about 120 more teachers. Recruitment efforts are focused on three local school districts, Orange County Public Schools (OCPS), Seminole County Public Schools (SCPS), and Brevard County Public Schools (BCPS). Collectively, these districts have over 20,000 teachers and 310,000 students. According to the proposal, special emphasis in recruitment is targeted for those teaching at schools located in underprivileged areas, as well as on traditionally underrepresented groups such as women and minorities. In order to facilitate the dissemination process and augment its impact, pairs of STEM teachers are recruited from the same school when possible.

For this RET site, there are five measurable objectives identified for what the project aims to accomplish.

1. To recruit a diverse, talented high school teacher population from counties in the vicinity of UCF,
2. To provide the recruited teachers with interdisciplinary engineering design experience relevant to innovative technical development.
3. To develop and disseminate to a large-audience teacher-driven teaching modules that can be deployed in the classroom.
4. To create a critical mass of highly qualified teacher trainers who ensure quality of pre-service and in-service teacher education.
5. To disseminate the results of this RET effort to other interested stakeholders in the region and around the nation.

For the first year of the program, the project enrolled ten participants from a large applicant pool of 107 teachers. Seven identified themselves as White or Caucasian, three identified as Black or African American, while three categorized themselves as Latino or Hispanic. Five were male and five were female. One indicated that they had completed another RET program prior to this one.

2.1. Nature of Teacher Activities

According to the proposal, each year ten teachers are selected to develop RET-inspired lesson plans, which they implement (teach in their classroom) the following school year.

Participants receive a stipend of $8,000 for the summertime component, plus additional funding for participation in the winter conference and spring meeting activities. Over the eight-week RET summer experience, faculties provide lectures to introduce their research. The teachers then work with the mentors to participate in learning modules in sequence, where they gain the knowledge and skills needed for constructing connected sensor devices by the end of the summer. The project operates with a principal investigator, a coinvestigator, two senior personnel, six faculty mentors, and graduate student mentors. The team is assembled of faculties from Electrical Engineering, Environmental Engineering, Mechanical Engineering, and Computer Science, with demonstrated success in research and education, who work together to engage the teachers in streamlined research activities – device design, fabrication, testing, programming and validation. The site program started on June 5, 2017 with the duration of eight weeks. The first day experience was comprised of welcome, schedule, pre-assessment, module pretest, networking, UCF campus tour, library workshop, and lab tour. A program syllabus as well as an eight-week schedule booklet was given to the teachers. The teachers were enrolled in UCF Webcourses, an online teaching and learning platform, so they could access handouts, assignments, and notes online. The ten teachers participated in the preplanned RET Site activities based on the proposed research modules in sequence. For the first two weeks, each three to four teachers teamed up and worked with one of three faculty mentors of their choice depending on their interest and teaching subjects in their schools. They could choose one from three different topics in the Sensor Device Module; Environmental Sensors, Resonant Sensors, and Strain Sensors. Then, they proceeded to participate in the Interface and Testing Module for three weeks, in which they learned about working principles of analog and digital circuits as well as data analysis and validation. Remaining three weeks was dedicated to Software/Network Module and Mobile Programming Module. A speaker selected from faculty mentors presented his/her research during a weekly lunch meeting and workshop. In this meeting, weekly updates were communicated, and important subjects were discussed. Throughout the RET Site - CoMET program, the organizing team implemented pre- and post-test for each module and an entire program. The data is being collected and analyzed. The yearly RET project components are summarized in timely manner in figure 1. Also, Table 1 in the annex shows the daily schedule of the program during the eight weeks of summer.

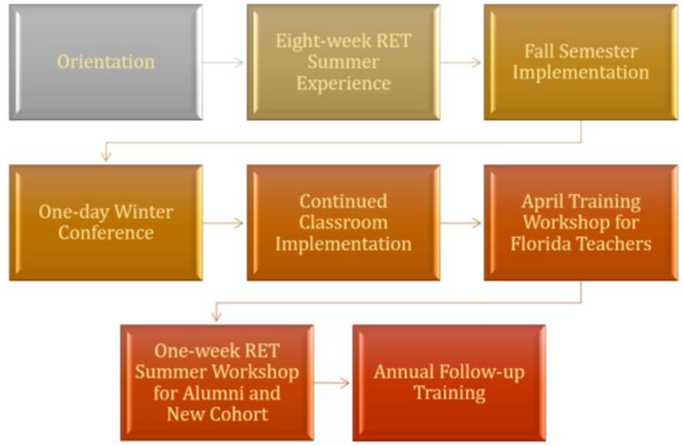

Figure 1: RET Program Components

At the end of the summer, teachers presented their own learning outcomes in the final week, as well as their plans for developing lesson plans to implement in their classrooms. Following the RET Summer Experience, teachers further developed and scheduled their lesson plans. During this Fall Semester, implementation phase for the project team has been focused on helping the teachers to generate enthusiasm amongst the high school students, assess their progress, and achieve successful transfer. Teachers returned for a one-day conference during the winter break in December to discuss and assess their implementation efforts, and receive a refresher in project research. One year after the workshop, project alumni participated in Florida Engineering Education Conference, a hands-on, interactive training workshop for the State of Florida teachers, held annually each April at UCF. Approximately 200 K-12 teachers attend the conference each year. Project alumni each hosted a 45-minute concurrent session sharing lesson plans developed during the RET program, and best practices and lessons learned throughout the implementation with other K-12 teachers. Upon completion of the program, the teachers are given one course credit certification. Beginning in Year 2, the RET alumni will participate in a one-week RET Summer Workshop with incoming RET teachers as part of the RET Train-the-Trainer model being developed. The purpose of the workshop is to provide support for new teachers and to receive updated coaching for how to further disseminate RET content. The overview of the program is illustrated in figure 2.

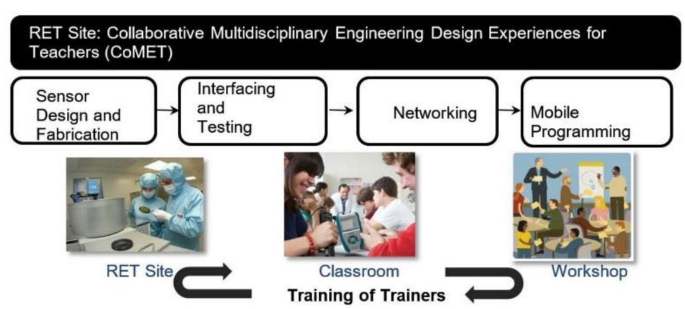

Figure 2: Overview of RET Site: CoMET Program

2.2. Train-the-Trainer Methodology and Universal Design for Learning

A critical component of this RET program is the Train-the-Trainer model where teachers who have been through our RET program can use the materials and exercises in the curriculum to disseminate training and content knowledge to future teachers at their home schools and planned teacher workshops (see figure 3). During the second year and on, teachers from the previous cohort return to provide support for new participating teachers and receive updated coaching on how to effectively disseminate content. Once trained, these expert teachers receive follow-up training annually and assist with new teachers each consecutive year planning and presenting. This process provides a way to help trainers stay aware of new material and sharpen their training skills while at the same time helping with the iterative design of workshops. In addition, project personnel model appropriate instructional methods for clear and consistent delivery of content knowledge. Once teachers have been successfully trained, they are able to deliver professional development workshops to instructors in their home district thereby enhancing the dissemination and broader impact of the project goals and objectives.

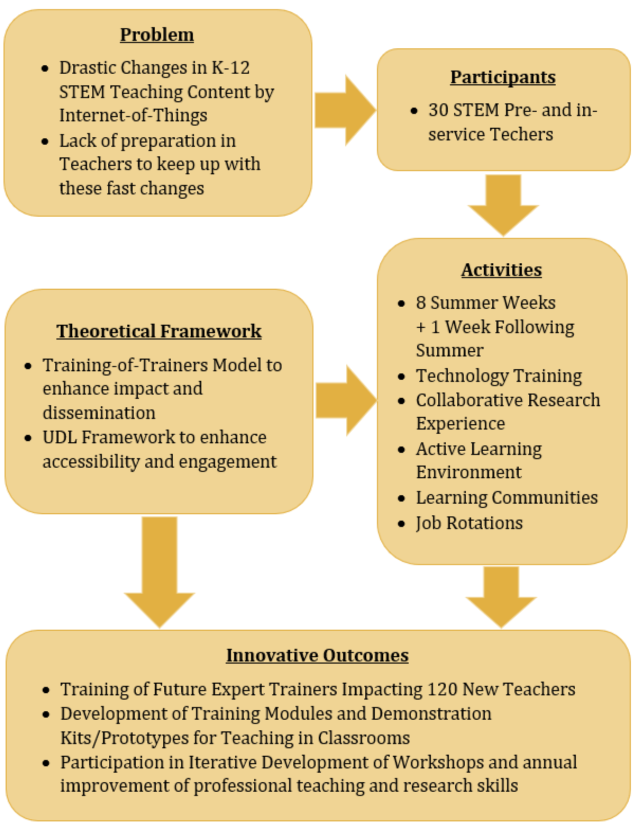

Figure 3: Logic Model for the RET Site Program Based on Train-the-Trainer Methodology and Universal Design for Learning

To bolster the Train-the-Trainer model we also utilized Universal Design for Learning (UDL)[5], a framework for the design and implementation of instructional materials meeting the needs of individuals by proactively circumventing curriculum barriers. This is accomplished through careful consideration of the broad range of needs, motivations, and strengths across all learners, including traditionally marginalized populations such as English language learners, those with disabilities, and participants with diverse cultural backgrounds. The CoMET team is developing the ToT model in their program using UDL starting from the second year of the program in summer 2018.

3. RESEARCH PROJECT MODULES

Each team, constituting of three to four teachers, chose one among three different sensor projects depending on their background and interest. They spent 1.5 to 3 weeks in each module in sequence to complete their projects.

Sensor Device Module – 2 weeks

- Design and Fabrication of Environmental Sensors (*Chemistry, Physics and Environmental Sciences*)
  Working principles: Material synthesis, Photomask Design, Cleanroom Microfabrication, Device packaging
- Design and Fabrication of Resonant Sensors (*Physics*)
  Working principles: Photomask Design, Cleanroom Microfabrication, Device packaging
- Digital manufacturing for Strain Sensors (*Chemistry and Physics*)
  Working principles: Composite material fabrication, 3-D printing

Interface and Testing Module – 3 weeks

- Interface Hardware Design for Sensors and Device Testing (*Physics, Computer Literacy*)
  Working principles: Analog and digital circuit basics, Data analysis and validation

Software and Networking Module – 1.5 weeks

- System Software (*Computer Literacy*)
  Working principles: The basics of the Linux operating system. Processes and files. Accessing input/output devices. Linux on the Raspberry Pi. Introduction to the Java programming language.
- Networking (*Computer Literacy*)
  Working principles: The basics of computer networking, the layered model, principles of TCP/IP, addresses and sockets, programming a simple web server in Java on the Raspberry Pi.

Mobile Programming Module – 1.5 weeks

- Mobile Programming (Computer Science)
  Working Principles: Mobile operating systems, Introduction to Android, Writing a simple Android program accessing the web.

The detailed project descriptions are listed below.

3.1. Sensor Device Module – 2 weeks

3.1.1. Sensor Module 1: Phosphate Sensors for Environmental Monitoring

Phosphate is widely used as an ingredient in fertilizers to maximize crop yield, which may unintentionally lead to serious environmental problems. Thus, regular monitoring of phosphate in natural/engineered water systems is desirable and a simple, robust, and compact in-situ phosphate sensor is in great demand.

One of known detection methods is to measure phosphate electrochemically based on the formation of $Co_3(PO_4)_2$ precipitate on a cobalt (Co) layer. When the sensor is immersed in the solution containing phosphate, cobalt phosphate is formed on the electrode surface during the following electrochemical reactions [6].

$$3CoO + 2H_2PO_4^- + 2H^+ \leftrightarrow Co_3(PO_4)_2 + 3H_2O \text{ (at pH 4.0)}$$
$$3CoO + 2H_2PO_4^{2-} + H_2O \leftrightarrow Co_3(PO_4)_2 + 4OH^- \text{ (at pH 8.0)}$$
$$3CoO + 2PO_4^{3-} + 3H_2O \leftrightarrow Co_3(PO_4)_2 + 6OH^- \text{ (at pH 11)}$$

These electrochemical reactions lead to a change in output voltage (mV) depending on the phosphate concentration[7] according to the Nernst equation[8]. In this research, inspired by the nanostructure of alloys, we propose to electroplate a layer of Co-Cu alloy and then obtain a nanofibrous Co electrode through selectively etching copper (Cu). This nanofibrous Co electrode when converted to CoO is expected to improve the detection limit due to the increased surface area. The phosphate concentration in water samples is then measured electrochemically with the proposed sensor. The sensor is fabricated on an oxidized silicon wafer, which consists of an electrode, a connection line, and a contact pad (see figure 4). The sensor is encapsulated and packaged on to a PCB board for testing.

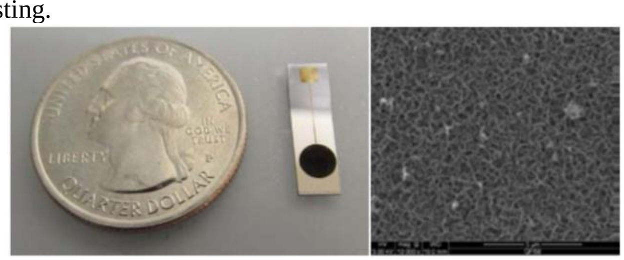

Figure 4: Fabricated Sensor (on the left), and Nanofibrous Sensor Surface (on the right)

This module is beneficial for K-12 teachers in chemistry, environmental sciences, and physics. Through this module teachers are given prototype devices and instructional material and they

(a) Learn about the electrochemical reactions that can be used to monitor environmental pollutants,
(b) Gain knowledge and hands-on skills in the area of cleanroom microfabrication, additive and subtractive processes including photolithography and etching, and
(c) Establish methodology to characterize and validate sensor performance characteristics.

3.1.2. Sensor Module 2: MEMS Passive Wireless Temperature Sensors

Wireless temperature sensors are growing in popularity in industrial, commercial, healthcare, and even residential settings [9]. Conventionally, piezoelectric crystals such as LiNbO3 or quartz were exploited to fabricate resonant temperature sensors [10]. Piezoelectrically-transduced MEMS resonators such as thin-film piezoelectric-on-silicon (TPoS) resonators also offer characteristics desirable for passive operation as temperature sensors [11]. In figure 5, the principle of wireless sensing with a TPoS resonator is depicted. The RF signal generator transmits a pulse-modulated sine wave through an antenna. The resonator, directly connected to an antenna, is forced into oscillation upon receiving the interrogation signal. If the frequency of the sine wave matches the natural resonance frequency of the resonator, the amplitude of oscillations will be maximized. An oscilloscope is used to collect the decaying signal returned from the resonator and the registered resonance frequency is used to extract the temperature since resonance frequency changes with temperature.

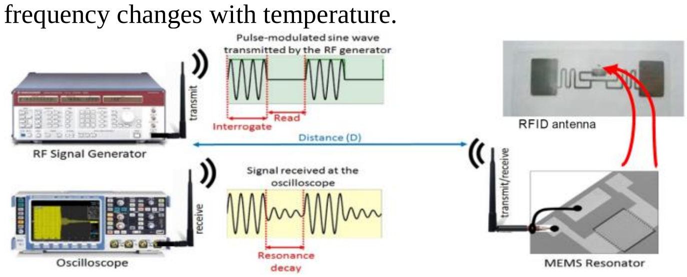

Figure 5: The Principle of Operation for Wireless Temperature Sensor. (The MEMS resonator on the right is a high-order multi-tether design and is directly connected to an antenna.)

In this research module we propose to study the sensing range of TPoS wireless resonant sensors after assembling the resonator on a commercially available RFID antenna. Such antennas can be purchased in rolls and the resonator is wire-bonded to the antenna for testing. This reduces the form factor of the sensor and result in a practical device that could be used for everyday applications.

This module is beneficial for K-12 teachers in chemistry, and physics. Through this module teachers are given prototype devices and instructional material and they

(a) Learn about piezoelectric MEMS resonators and their application,
(b) Acquire hands-on skills in RF device testing and characterization, dicing, and wire-bonding, and
(c) Understand complexities associated with wireless sensing and methodologies to characterize wireless sensing performance.

3.1.3. Sensor Module 3: Digital Manufacturing of Carbon Nanotube Film-Based Strain Sensors

The carbon nanotube film-based strain sensor has a change in electrical resistance that is proportional to strain of the material to which it is adhered [12]. The film can be coated on the surface or embedded in composite structures as a mechanical strain sensor for structural health monitoring and vibration control applications. Traditional strain gages can only measure the strains on the structure surface and are limited to a single function (strain sensing). However, carbon nanotube film-based strain sensors not only can be embedded in the structure but also can function as strengthening and damping materials/components.

The carbon nanotube film-based strain sensor is manufactured with a digitally controlled nozzle to spray carbon nanotube/refrigerant solution on a substrate. Carbon nanotubes are deposited on the substrate while the refrigerant is evaporated. A polymer solution is sprayed onto the substrate through a digitally controlled nozzle to make a film. A schematic of this digital manufacturing process is shown in figure 6. This manufacturing process allows for fast and accurate manufacturing of nanomaterials-based strain sensors. With this digital manufacturing process, the exact composition and thickness of carbon nanotube film is achievable. A Wheatstone bridge circuit is be used for converting the resistance change into the voltage change to test the strain sensor.

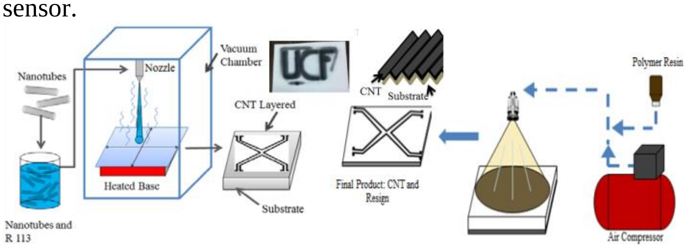

Figure 6: Digital Manufacturing of Carbon Nanotube Film-Based Strain Sensor

This module is beneficial for K-12 teachers in chemistry, physics, and mechanical engineering. Through this module teachers are given prototype devices and instructional material and they

(a) Learn about relationship between the electrical resistance of carbon nanotube film and the mechanical strain of composite structures for strain sensor design,
(b) Gain knowledge and hands-on skills in the area of digital design and manufacturing of strain sensors,
(c) Establish the methodology to characterize and validate the strain sensor performance characteristics

3.2. Interface and Testing Module – 3 weeks Hardware Platform Development and Internet-of-Things Integration

Networked devices pervade our lives, from commonplace devices such as telephones, watches, security systems, thermostats, smoke detectors, door locks, appliances, lamps, and smart vehicles to critical systems such as utilities, GPS, banking and medical units [13]. To fully understand the design process of IoT devices, designers need to study different design techniques as well as the manufacturing process. Consider a group who wishes to introduce a new device for which the specifications have been decided into the market. It then becomes an engineering problem to design a unit that meets these specifications whilst budgeting for time to market and available amount of research and development capital. Engineers are thus forced to look into pre-completed work, in terms of reference designs provided by component vendors and any accompanying software libraries or interfaces. The main goal in this lab module is to inform K-12 teachers about concepts involving IoT device development so that they can teach this material to high school students.

Specifically, these teachers have to learn how to integrate pre-made solutions into a working product. That is, off-the-shelf parts are often used during the design and production stages of the device. Teachers look for pre-made solutions by vendors until a design that closely resembles the specified needs is found. Obtaining design kits and development boards is usually a standard practice at this stage of design with vendors also sending application engineers to aid in the design of the device. A Google Nest Thermostat which is served as the reference design in this lab module can be taken as an example.

Also, because IoT devices often target the mass market, they must be relatively easy to use otherwise they may not take off. It is very hard to make an IoT device popular if large learning curves or difficult setups to potential customers are imposed. As a result, teachers should also learn on how to evaluate the IoT device through a user's perspective.

Another important consideration during the design of IoT devices is the possibility of deploying updates. In order to install an update, an Internet-connected device downloads an image from a server and installs it onto itself. These updates may add functionality or correct some bugs present in the software stack the unit possesses.

Teachers must be able to find a way to make this process available and also make it approachable enough for non-technical users. Automatic updates are often used in these scenarios, but the fact that the device is capable of modifying its own software means dedicated interfaces should be included for the communications between servers and individual devices. Upon this request, K-12 teachers also learn how to setup dedicated communication ports in target devices.

Through this module, FPGA platform-based sample IoT designs and the detailed design process are given to teachers. This module is beneficial for K-12 teachers in Engineering, Computer Science, Information Science, and Physics, and they

(a) Learn how to select the appropriate development kits for specific applications and learn how to adapt the design templates provided by development kit vendors for new implementations.
(b) Explore existing open-source software resources which can be used for OS construction on top of the already constructed IoT hardware platforms;

Application-specific user interface development for special functionality and design efficiency.

(c) Learn how to debug the entire IoT system including the hardware platform and the firmware for specific applications; Understand different debug interfaces and their usages.

3.3. Software and Networking Module – 1.5 weeks Software and Networking Module: Systems and Networking Principles

The ubiquity of computer networking and mobile computing have a significant and pervasive effect on how we develop software and, consequently, on how we teach computer programming. As a result, it is no longer sufficient for modern programmers to acquire only the conventional programming skills. This module allows the teachers to participate in innovative research in modern system software and networking concepts.

For the programming part, we focus on solving massive parallelism problems using wait-free data structures. Although parallel and multi-threaded programming concepts had been known for several decades, until recently their applications had been limited to scientific programming. Even today, personal computers have only 2 to 4 computing cores, enabling only limited degrees of parallelism, which can be handled with classical synchronization solutions (semaphores, monitors, condition variables). The emergence of cloud computing and the Internet of Things brings computing systems distributed over thousands of computing cores to the common user. Novel programming architectures that can handle highly distributed, real-time applications including wait-free hash maps, ring buffers, vectors and linked lists exhibit the novel property that all threads make progress in a finite amount of time, an attribute that can be critical in real-time environments. This is opposed to the traditional blocking implementations of shared data structures which suffer from the negative impact of deadlock and related correctness and performance issues.

The teachers participate in the validation and testing of these data structures, their application of new hardware architectures and the extension of these concepts to new data structures such as self-balancing trees.

For a practical application, the participants apply these data-structures to the implementation of an embedded HTTP server application. The objective is to use Representational State Transfer (ReST) APIs which allow remote components to configure the IoT entity and read the sensory data. In the final phase of this project, the server is modified to work on the Raspberry Pi platform.

The teachers are involved in the PIs' ongoing research in the design and use of software tools for establishing software reliability, correctness, and efficiency. The participants are asked to use the existing research tools for program testing and performance monitoring in order to establish whether the software components developed meet their specifications and efficiently utilize resources. The participants also outline a plan for the future improvement and evolution of these research tools based on their experience with them.

Overall, this project helps gain deeper understanding of the methodologies and tools used for creating and testing modern software and mobile software elements. Specific deliverables of this work include:

(a) A collection of programming assignments and sample solutions that lays the foundations for programming the software stack for sensor and mobile communication and sensory data storage and retrieval. Fundamental concepts that are covered include computer programming using Java, data input and output, file systems, and operating systems.

(b) Software design and implementation for fast and efficient retrieval of sensory data from IO and disk.

(c) Software design and implementation for sensory data communication and transmission. The software supports the transmission of dynamic content over a computer network.

(d) A set of modifications to the computer programs mentioned above that allows them to function on a Raspberry Pi platform.

(e) A set of test modules that are used to evaluate the correctness, efficiency, and performance of the software programs mentioned above.

(f) The design of a mobile web server using Java that implements the capability of transmitting the sensory data over a computer network. This allows the RET teachers to learn about socket programming and its adaptation to mobile platforms.

The materials used in the principles and practice parts of the proposed modules are provided to K-12 teachers for use in classes on Computer Programming.

3.4. Mobile Programming Module – 1.5 weeks Mobile Programming Module: Participatory Sensing

The wireless sensor networks research has driven great innovations in the past decade and it is a very active research area. There are numerous sensor-networking applications we use in our everyday lives (e.g., garage openers, sprinkling systems, home security system, etc.).

Participatory sensing (also known as opportunistic sensing) is an applied research area where sensor networks and smartphones collaboratively provide many interesting and useful ubiquitous applications otherwise would not be possible. You can find answers to questions such as "what is my personal air quality today" or "how stressed is the city today". Some of these answers can be provided by integrating data from the sensors of many smartphones. For instance, the overall fitness of the inhabitants of a city can be estimated by integrating the number of steps walked days, as recorded by the Samsung Health app. Android phones have built-in sensors of three main types: motion, environmental, and position sensors. The motion sensors measure acceleration and rotational forces (e.g., accelerometers, gravity sensors, gyroscopes, and rotational vector sensors. The environmental sensors measure environmental conditions (e.g., barometers, photometers, and thermometers). Position sensors measure the physical position of the Android device (e.g., orientation sensors and magnetometers). This data can be complemented with data from other sensors are not on the device (such as sensors measuring the level of air pollution). Applications integrating data from the smartphone's own sensors, other smartphones and external sensors can make inferences about the quality of the air and can provide, for instance, recommendations to the user whether to take a walk today or not. In many cases, the phones can collect data without disturbing the user, and that is where the name of the "opportunistic" sensing comes from.

In this module, the teachers study the Android platform for smartphones and the Android development environment. Once they understand the Android basics, they write a simple Android application, which can be connected to our hardware platform (Raspberry Pi). In the final phase of this project, they learn about the design and development of an opportunistic sensing application on the Android platform. This software component collects the sensing data from the hardware platform using the data representation and the networking component created in the Software and Networking Module. Next, they explore how to use Android's API and obtain data from its environmental sensors. Finally, all sensing data is compiled and analyzed by the application, which produces a final report to the user. The Android platform used in the proposed modules is provided to K-12 teachers for their use in classes, and through this module, they

(a) understand the components comprising the Android platform
(b) are able to use various tools found in the Android development environment.
(c) learn how to write a simple Android application.
(d) gain ability to connect the Android application to Raspberry Pi hardware platform to receive sensory data based on guided steps.

4. EVALUATION AND ASSESSMENT

The Evaluation Team is led by the executive director of UCF STEM and consists of the PI, Co-PI, and Senior Personnel. In consultation with the UCF Office of Operational Excellence and Assessment Support, the Evaluation Team develops the instruments necessary to measure the teacher learning outcomes for the individual research modules as well as to identify appropriate venues for dissemination of the newly created modules and RET results. The team interacts with an external evaluator. External components are conducted by Program Evaluation and Educational Research Group (PEER), a service center in the College of Education and Human Performance (CEDHP) at UCF.

PEER is using traditional educational psychology methods of quasi-experiment, incorporating a pre- and post-test design, collecting multiple forms of descriptive information, data on the fidelity of the study, data on the dosage of the intervention, and outcome data. Descriptive statistics were used to describe results from quantitative data. Responses to open-ended questions were analyzed and categorized using open and axial coding to identify major themes [14]. The coding scheme was provided to another researcher who applied them to the data independently for verification. Any initial disagreements were discussed to reach consensus between researchers [15]. Some responses were coded to multiple themes and as a result, percentages may exceed 100%.

Two of the post-experience evaluation components are presented here as examples. According to the questionnaires filled out by the teachers by the end of the first year of the program, Teachers expressed to what extent they experienced leaning in this program. According to Table 2 in the annex, majority of teachers agreed they increased their knowledge of current issues in scientific and mathematical research. 78% expressed they gained great understanding of the applications of science, mathematics, and technology in everyday life, and increased their knowledge of the related careers. They all agreed on becoming familiar with new material and equipment suitable for their teaching. They rated this RET program from several aspects, highlighting the advantage of connecting with other teachers with similar interest throughout this program (Table 3 in the annex).

5. SUMMARY

Through a three-year program which aims at involving over 30 K-12 STEM teachers in research and engineering design experience at University of Central Florida, teacher participants learned about the essential elements of IoT such as sensor devices, and hardware and software interfaces. In this summer research program, teachers could start their research experience by choosing one of three different types of sensors, i.e., electrochemical, resonant, and strain sensors, depending on their teaching area. They worked with faculty mentors and learned how to interface and test the sensors and how to develop a program that would enable their system for remote control and testing. The novelty of this RET site program is in its use of the Train-of-Trainer (ToT) method along with the Universal Design for Learning (UDL) to enhance the educational impact, dissemination, accessibility, and engagement. According to this model, a cohort from the previous year will be invited to come back to teach and share their experiences with the next year's cohort.

The first year of the site program started in summer, 2017 by recruiting five middle and five high school teachers in STEM education from the neighboring Seminole, Orange and Brevard counties. Significant efforts have been made to recruit teachers serving underrepresented student populations. The teachers were engaged in an eight-week summer program hosted by the faculty mentors in their research laboratories. The organizing team worked closely with the RET cohort to implement their educational plan at the local school level to ensure they have the opportunity to disseminate the knowledge gained from this program. As a result, teachers could use their new knowledge for classroom teaching and present their findings to peer teachers.

We anticipate that teachers who have been trained through this RET program can use the materials and exercises in the curriculum when training future teacher trainees at their home schools and planned teacher workshops. Based on the ToT model, mentors/trainers with competencies will effectively mentor and facilitate knowledge acquisition and application in K-12 settings for other teachers.

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ANNEX A

TABLES

Table 1: RET Program Schedule

Week	Mon	Tue	Wed	Thu	Fri
1	Orientation Lab Tour	Lab Safety Library Orientation	Begin Research	Research	Research
2-7	Workshop	Research	Research	Research	Research
8	Workshop	Research	Research	Research	Presentations
Follow-up	Workshop Prep.	Workshop Prep.	Workshop Prep.	Teacher Workshop	Teacher Workshop

Table 2: Extent to which Participants Believed They Experienced Learning

Item	**Great extent**	**Moderate extent**	**Small extent**	**Not at all**
I gained a greater understanding of the applications of science, mathematics, or technology in everyday life.	77.8%	11.1%	11.1%	0.0%
I acquired greater understanding of fundamental concepts in science or mathematics.	55.6%	44.4%	0.0%	0.0%
I became familiar with new materials or equipment that I can use in my teaching.	77.9%	22.2%	0.0%	0.0%
I learned about innovative ways to use standard materials and equipment in my field.	55.6%	33.3%	11.1%	0.0%
I increased my knowledge of current issues in scientific or mathematical research.	88.9%	0.0%	11.1%	0.0%
I gained a greater appreciation of the difficulties some students encounter when learning science or mathematics.	44.4%	22.2%	22.2%	11.1%
I better understand how collaborative inquiry can be done successfully.	33.3%	44.4%	22.2%	0.0%
I became more proficient at using the Internet for communicating with colleagues and access information that will be helpful in my teaching.	66.7%	33.3%	0.0%	0.0%
I learned about magazines and professional journals that will be relevant to me as a teacher.	66.7%	22.2%	0.0%	11.1%
I increased my knowledge of careers that utilize science, mathematics, or technology.	77.8%	11.1%	11.1%	0.0%

Table 3: Participants' Ratings of the Overall Program

Overall, this RET experience...	**Strongly agree**	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**
Connected me with teachers who share similar interests	88.9%	11.1%	0.0%	0.0%	0.0%
Encouraged me to pursue my own interests	44.4%	22.2%	11.1%	22.2%	0.0%
Helped me better understand how to do research	55.7%	22.2%	22.2%	0.0%	0.0%
Helped me better understand how to use statistics	12.5%	12.5%	25.0%	50.0%	0.0%
Taught me about several major research approaches (e.g. experimental, survey, simulation)	44.4%	11.1%	33.3%	11.1%	0.0%
Was challenging	44.4%	44.4%	0.0%	11.1%	0.0%
Was fun	44.4%	55.7%	0.0%	0.0%	0.0%