Technology Driven University and Community College Collaboration: Faculty Training on ARM Microcontrollers

Nasser Alaraje[1], Aleksandr Sergeyev[1], John Reutter[2], Craig Kief[3], Bassam Matar[4], David Hata[5]
[1]Michigan Technological University, Michigan - USA
[2]J. F. Drake State Community & Technical College, Huntsville, AL - USA
[3]University of New Mexico, Albuquerque, NM - USA
[4]Chandler Gilbert Community College, Chandler, AZ - USA
[5]Portland Community College, Portland, OR - USA

Abstract--**The electronics world is undergoing a transformation in the underlying technologies used to create new products for the world's consumers. The movement to reconfigurable electronics using microcontrollers is sweeping the electronics world in the rush to create smaller, faster, and more flexible consumer and industrial devices. Microcontrollers are becoming one of the most exciting devices in history. At the core content of microcontroller technology is ARM microcontroller, the ARM processor is an industry standard with annual sales of 5 billion units, and it will increase as the demand for powerful, low-power electronics increases. An engineer's and technician's exposure to this technology is critical in order to remain competitive. To meet this industrial needs, university programs are updating curricula with courses in ARM microcontroller technology. Partners on this project have years of successful National Science Foundation (NSF) projects, educating and training hundreds of instructors and introducing thousands of students to advanced technologies. This paper will discuss the offering of a Professional Development workshop on ARM microcontrollers for electrical engineering technology faculty as part of an NSF grant. The project goals are to provide colleges with up-to-date educational equipment, educational resources and promote best practices to enable instructors to teach advanced technologies.**

I. INTRODUCTION

Industrial, commercial, and consumer electronics of all types have experienced a transformation over the last decade, brought on by revolutionary advances in reconfigurable components such as FPGAs, Systems-on-Chip (SoC's), and ARM-based microcontrollers. These advances have placed more computing resources with lower power requirements and greater flexibility at engineers' disposal than at any other time in history. As educational institutions at all levels endeavor to make effective use of new technology, they are often impeded by long learning curves and entrenchment in existing curricula. Two-year and four-year graduates in STEM fields must be prepared to work with new, re-configurable systems. In the last decade, programmable logic devices have become prevalent and FPGA-based re-programmable logic design has become the design media of choice. As a result, industrial use of FPGA and microcontroller technology in digital logic design is increasing rapidly. Correspondingly, the need for highly qualified logic technicians and engineers with FPGA and microcontroller expertise is also increasing rapidly. To meet the need for these design skills, university programs are updating curricula with courses in hardware description languages and programmable logic design. A recent survey was sent to government and industry, designed to gauge the necessity of providing this training. Forty organizations responded and the results showed overwhelming support for incorporating FPGA design skills into two- and four-year electrical and computer engineering technology programs. Results showed that almost 80% of respondents view knowledge of FPGA and microcontrollers as a critical skill for making graduates more employable and marketable [1]. Responding to this need, The Community College and its partner institutions (including Michigan Technological University, University of New Mexico, and Chandler-Gilbert Community College) proposed to utilize highly-qualified academic and industry-experienced resources to develop and implement online and technology-enabled courses and learning projects that will be scaled up to reach significant numbers of diverse instructors and students over a large geographic area. These collaborative efforts will satisfy this critical need for trained instructors and students in the technology of reconfigurable solutions.

II. RESEARCH BACKGROUND

Scientists, engineers, and technicians trained on modern re-configurable electronics will change the way digital logic systems are designed and delivered. Modern digital electronic design has changed significantly over the last decade, making schematic design largely a thing of the past. Recently, the complexity of circuitry has grown to hundreds of millions or even billions of transistors in a single chip. As a result, computer-aided design has become the industry standard for entering, evaluating, and testing designs. These technologies have become closely coupled with new "re-configurable" electronic devices that include FPGAs, microprocessors, and advanced microcontrollers. Virtually every electronic system created today uses at least one of these new devices, from large automotive and energy equipment to hand-held medical devices and household items. To meet these needs, universities and community colleges need to update programs and provide faculty development in re-configurable systems.

A recent market study reports the global market for reconfigurable electronics systems is expected to reach US$250 billion by 2020. North America's share of this global market represents 34% [8]; it is expected to remain the largest market in coming years. In order to sustain the projected 8-10% growth from 2014 to 2020 [2], a well-trained workforce must be amassed. Existing programs cannot meet future needs. Indeed, a survey conducted in 2014 identified that 40% of US employers are already having difficulty finding the right people to fill jobs [3]. A list of the ten jobs that US employers have difficulty filling begins with technicians (primarily production/operations, engineering or mathematics) and engineers. Additionally, there are major gaps in critical skillsets in the US. US organizations spent $164B on employee training in 2012 [4]. The US faces an alarmingly high replacement rate for STEM professionals [5, 6] of 23-30%. It is estimated that, during this decade, employers will require an additional 2.5 million STEM workers [7, 8].

Microcontrollers are becoming one of the most exciting devices in history. The average future homeowner will have every aspect of their home designed around them. While an FPGA can serve as a control system, every other device – from lights, home electronics, and appliances – will be interfaced through microcontrollers. With these tools, a homeowner will be able to log into their "home" and control every electronic component from their handheld device. This same will likely be true for cars, businesses, and limitless other possibilities through the use of microcontrollers. An "Internet of Things" can only be possible with modern microcontrollers. One microcontroller can manage hundreds of sensors through a single I2C bus. A microcontroller is a small computer on a single integrated circuit, containing a processor core, memory, and programmable input/output peripherals, as shown in Figure 1. The microcontroller the team uses for the course is the TI ARM [9], which is based on an ARM processor. The ARM processor is an industry standard. Isuppli, a well-known market research firm, states that sales of ARM processors, currently at 5 billion units per year, will increase as the demand for powerful, low-power electronics increases [10, 11]. An engineer's and technician's exposure to (and training in) this technology is critical in order to remain competitive. The benefits that microcontrollers have over FPGAs are their small size, low power consumption and analog capability. Microcontrollers can be mounted in everything from light switches to microwave ovens. Large, complex systems often have an FPGA as the main control system (a hub) and microcontrollers to control individual components (spokes). It isn't necessary for technicians to be experts in all aspects of these technologies; however, they need at least a working knowledge of these systems.

Research [12] identifies faculty development as a major concern. Universities need to develop programs to allow their faculty to advance professionally [13]. This project enables updating of the Embedded Systems curriculum to meet the expectations of industry by supplying qualified engineers and scientists who have extensive hands-on experience with current design tools. Additionally, the approach for faculty development targets the faculty members who acknowledge the need to update the curriculum but do not have the time or training to pursue it. Professional development plays a crucial role in the career-long growth of faculty via theory, research, and collaboration with colleagues. Additionally, it opens doors for better understanding of instructional concepts and teaching practices [14]. Professional development connects faculty across disciplines and career stages, diversifying learning to the benefit of all.

III. CURRICULUM DEVELOPMENT: MICROCONTROLLER FACULTY PROFESSIONAL DEVELOPMENT WORKSHOP

This workshop will begin by exploring the world of microcontrollers: Who uses them and why? The hardware interface will be examined, and instructors will learn how the

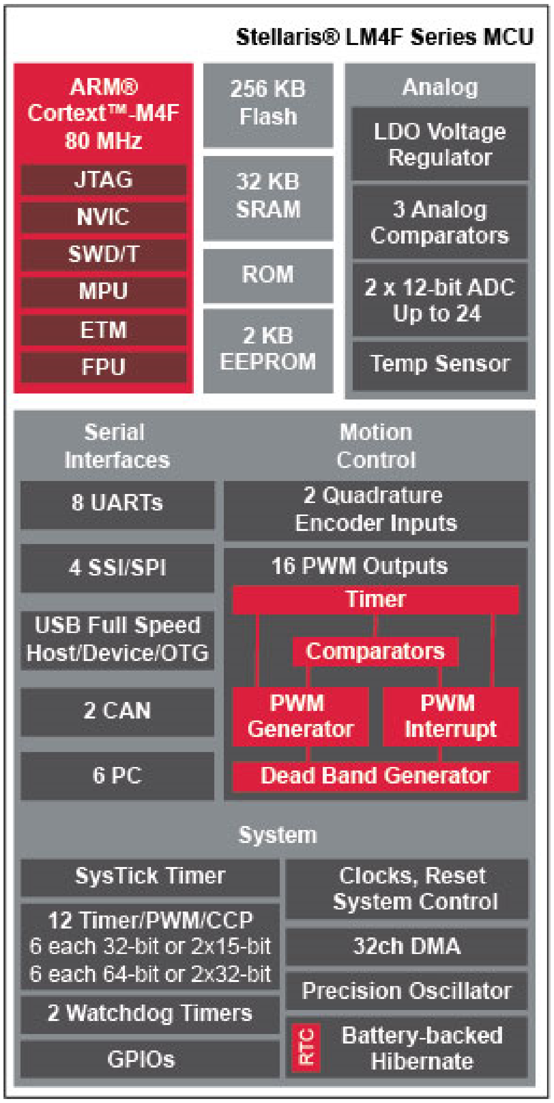

Figure 1: ARM Overview

interface provides input and output using easy to follow examples. Items such as Temperature Sensors and Timers are used in simple projects. This class is designed to help faculty learn how to fully utilize the hardware. The design tool uses a free software environment. At the end of the workshop, each instructor will receive a free prototype platform and free design environment software. Figure 2 shows the Microcontroller course flow. Topics will include: Microcontroller 101, Hardware Overview, and Intro to Programming. Participants will not only learn how to operate the microcontroller but how it works and how to do advanced designs such as those involving I2C busses and accelerometers. After teaching this for the past few years, the team has realized that there is a requirement for teaching programming languages to instructors for them to be successful. As such, a portion of each workshop is dedicated to a review of programming languages.

Our approach is for the workshops to be taught by a combination of skilled university and community college instructors. By having both types of instructors presenting the workshops, it allows instructor attendees (who themselves will be from both community colleges and universities) to realize that the infusion of this type of technology is possible in their type of school. The laboratory component of the workshop is defined using a sequence of interchangeable laboratory modules. Flexibility enables them to be tailored by individual instructors. The workshop is designed to introduce the basics of microcontroller technology to instructors. By the end of the workshop, instructors will be capable of doing simple projects and will understand the microcontroller hardware and design tools. Texas Instrument's ARM microcontroller was chosen for the workshops based on the wide popularity of the ARM processor and the excellent (and free) design tools.

Hardware Development Environment: Tiva™ C Series TM4C123G LaunchPad Evaluation Board

The Tiva™ LaunchPad Evaluation Board is a low-cost evaluation platform for ARM® [15] Cortex™-M4F-based microcontrollers. The Tiva C Series LaunchPad design features the TM4C123GH6PMI microcontroller. It provides an excellent platform for exploring all the options the Tiva family of microcontrollers provide. Some features include: In-circuit-debugger, I/O headers, USB connection, RGB LED, USB to Serial converter, and Pushbuttons. Digilent has an Orbit board that provides expanded capabilities to the Tiva platform such as OLED display, Expandable PMOD connectors, Potentiometer, Switches, Push Buttons, LEDs, and I2C headers. Figure 3 shows both Tiva LaunchPad and Orbit board.

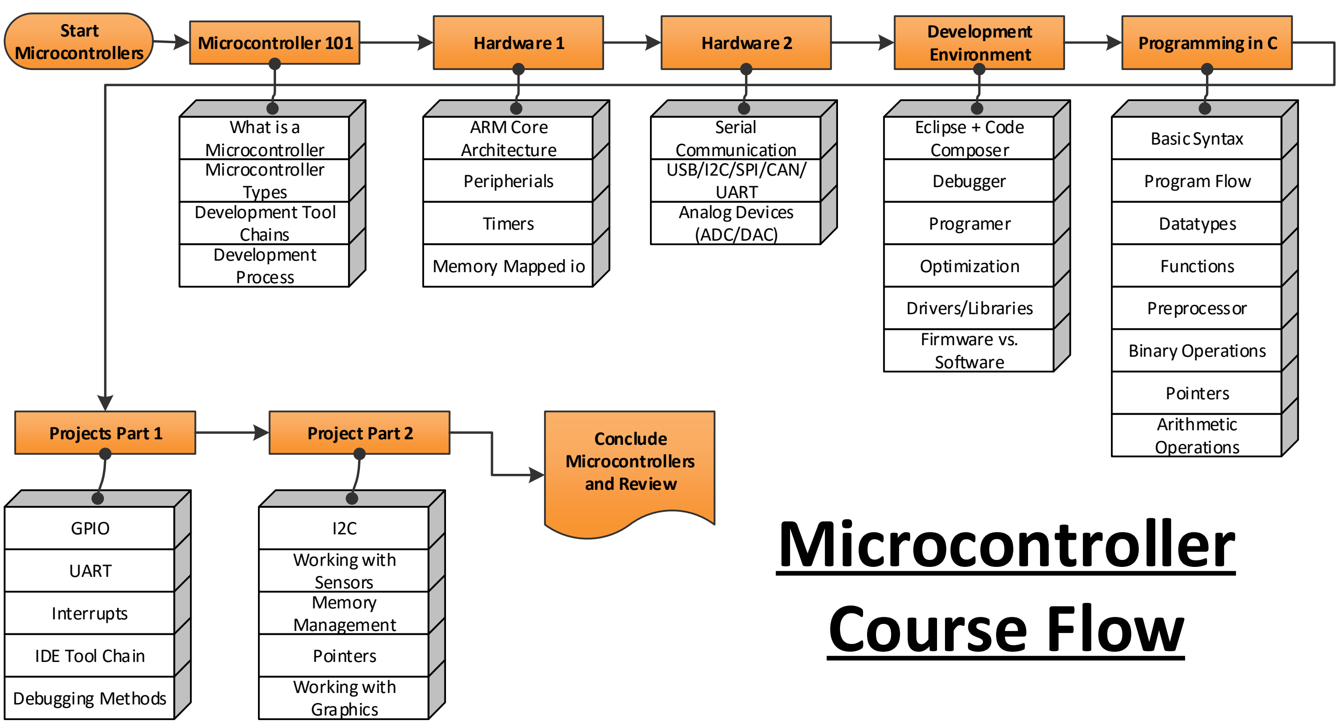

Figure 2: Microcontroller Course Flow

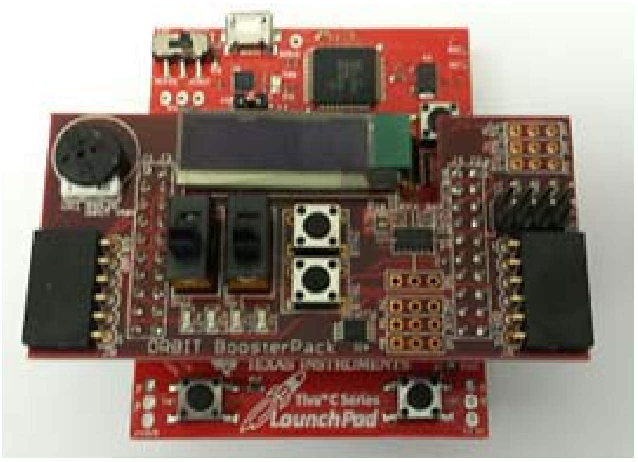

Figure 3: Tiva LaunchPad and Digilent Orbit

IV. HANDS-ON LABORATORIES EXERCISES

A set of nine laboratory exercises were developed. These labs consisted of an introduction to the Tiva LaunchPad™ software used to code, compile, and program the Tiva TM4C (formerly Stellaris LM4F) series of ARM Cortex-M4 microcontroller, an introduction to the basics of the C code syntax and how it is used in the TI implementation of the ARM processor, a lab focusing on Digilent Orbit Board which provides expanded capabilities to the Tiva platform, a lab focusing on application program interface and interrupts, a lab on serial communication, a lab focusing on Analog- to - Digital converter, and finally a complete project of integrating Analog-to-Digital converter with serial communication. Following is a description of each laboratory exercise.

Lab 1: Introduction to Tiva LaunchPad™ Software

This lab is designed to familiarize the participant with using many of the common aspects of the Tiva LaunchPad™ software. Participants will receive sufficient instruction and guidance so that individuals will be able to install the software and prepare for the following laboratories where the hardware will be plugged in and a simple project will be accomplished. Participants will download and install the software that will be used to perform the work associated with TI ARM based processors utilizing the Tiva evaluation kit with the optional Digilent daughter board (Orbit).

Lab 2: Introduction to Tiva LaunchPad™ Evaluation Kit

This lab is designed to familiarize the participant with using many of the common aspects of the Tiva LaunchPad™ Evaluation Kit. The evaluation kit features programmable user buttons and a Red, Green, RGB LED for custom applications. The stackable headers of the Tiva C Series TM4C123G LaunchPad BoosterPack XL Interface make it easy and simple to expand the functionality of the TM4C123G LaunchPad when interfacing to other peripherals with Texas Instruments' MCU BoosterPacks. Participants will receive sufficient instruction and information so that individuals will be able to connect the Tiva board for the first time and create a simple project that lights an LED. Participants will be introduced to the building and debugging process within the Code Composer Studio (CCS v6) environment.

Lab 3: Blinking Lights

The goal of this lab is to continue to build upon the skills learned from previous labs. This lab helps the participant to continue to gain new skills and insight on the C code syntax and how it is used in the TI implementation of the ARM processor. Each of these labs add upon the previous labs and it is the intention of the authors that the student will build with a better understanding of the ARM processor and basic C code.

Lab 4: Digilent Orbit Board Introduction and LEDs

The goal of this lab is to continue to become familiar with the compiler and understand the use and modification of a "main.c" file. Participants should also begin to be exposed to C "functions." In addition, the Digilent Orbit board [16] is introduced in this tutorial. The Orbit was built for academic purposes for learning how to do small projects. It provides expanded capabilities to the Tiva platform for doing more. At the simplest level, it provides additional LEDs, switches and buttons. This lab is very similar to the Blinking Lights lab but it is accomplished using the Digilent Orbit board.

Lab 5: Application Program Interface (API) and Interrupts

The goal of this lab is to introduce the concepts of the API and interrupts. API is a set of routines, protocols, and tools for building software applications. A good API makes it easier to develop a program by providing all the building blocks. The designer then integrates the building blocks, commonly referred to as a set of functions. These functions are contained on Read Only Memory (ROM) inside the microcontroller. The beauty of the API functions are that they reduce the amount of resources used and thus the amount of power consumed. This is very important for low power applications. To use a given function, the designer needs to call the function and pass the function parameters list. Interrupt concept is also introduced in this lab.

Lab 6: UART Serial Communication

The goal of this lab is to introduce the concepts of the UART and how it is implemented on the ARM processor. A Universal Asynchronous Receiver/Transmitter, abbreviated UART, is a block of circuitry which transmits data between the serial and parallel forms. They are usually paired up with communication standards like RS-232. It usually takes bytes of data and transmits them in a sequential fashion. UART Modules are embedded into many microcontroller systems including TIVA microcontroller. The objective of this lab will not be to fully understand a UART (that can be done by using Google), it is to understand how to design a project utilizing UART on the Tiva board. Participants will learn how to enable the UART port and how to configure associated pins.

Lab 7: Temperature Sensor

The goal of this lab is to introduce the temperature sensor and then the utilization of the UART to display the room temperature on the computer. The ORBIT board is equipped with Microchip Technology Inc.'s [17] TCN75A digital temperature sensor that converts temperatures between -40°C and +125°C to a digital word, with ±.1°C accuracy. The TCN75A product comes with user-programmable registers that provide flexibility for temperature-sensing applications. Participants will learn how to configure I2C. Inter-Integrated circuit protocol (I2C) is a bi-directional bus with efficient data transfer to multiple slaves. The whole process is controlled by merely two wires: synchronous data line (SDA) and synchronous clock line (SCL), which allows to save space while designing any hardware system. TIVA I2C offers many functions apart from providing the bi-directional data transfer through a two-wire design and interfaces to external I2C devices such as serial memory, networking devices, LCDs and tone generators.

Lab 8: Accelerometers

The goal of this lab is to introduce the concept of the accelerometer. The ORBIT board is equipped with the ADXL345, a small, thin, ultralow power, 3-axis accelerometer with high resolution (13-bit) measurement [18]. The ADXL345 output data is formatted as 16-bit 2's complement and is accessible through either a SPI or I2C digital interface. The ADXL345 is well suited for mobile device applications. It measures the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion or shock. Participants will configure I2C, read the accelerometer data, and toggle the proper LED to provide tilt measurements.

Lab 9: Capstone Project

This lab acts as a capstone to the entire ARM Microcontroller Workshop. This integrating experience develops participant competencies in applying technical skills in solving a design problem. It covers various topics previously discussed and adds some even more advanced techniques and algorithms. It also gives a good real-world application of what can be accomplished with Microcontrollers.

V. WORKSHOP EVALUATION AND ASSESSMENT

Assessment is a vital part of any curriculum reform project and helps provide useful information for workshop enhancements and determining if the workshop has met its objectives. An evaluation plan has been implemented for the project that uses a value-creation evaluation framework to determine the merit or worth of the project. To date, evaluation activities have measured the "Immediate Value" and "Potential Value" of the project sponsored activities. Evaluation activities are now focusing on measuring the "Applied Value" by tracking students impacted by outreach activities and surveying educators who participated in the microcontroller workshops. The "Realized Value" produced by the project will focus on the number of students from outreach activities that enter two-year technical programs and the number of graduates from two-year technical programs who have a working knowledge of microcontroller technology.

Workshop attendees gain "immediate value" by participating in workshop activities. This immediate value is gained through the information presented and the activities, e.g. presentations and laboratory exercises. Immediate value is assessed through pre-workshop and post-workshop surveys. The post-workshop surveys will also point to "potential value," i.e. the intent to integrate workshop material into the classes that they teach, or in other professional activities, if they don't teach. The "Applied Value" surveys have been conducted during fall semester 2014 and spring semester 2015. The survey queried all educators who have attended the microcontroller workshops since the project began. Over one-quarter of the educators who attend a workshop apply their knowledge and deliver microcontroller instruction at their institution. During the 2014-15 academic year, these educators reported that approximately 23,000 student-hours of microcontroller instruction were delivered. This instruction in microcontroller technologies impacted 225 students in two-year colleges and 235 students at four-year institutions. Regarding Immediate Value, 48 faculty attended (25 community college instructors, 23 four-year engineering technology professors). Twenty-nine out of 48 (60%) educators currently teach microcontrollers in their classes. On the other hand, for potential values, thirty-nine out of 48 (81%) educators plan to incorporate workshop material into the classes that they teach, either during the 2015-16 academic year or the 2016-17 academic year.

"Realized value" is the number of potential students who actually enroll in two-year technical programs and the number of graduates from two-year technical programs who enter the technician workforce. Enrollment data and graduate information will be obtained via surveys sent to partner sites and workshop participants. Table 1 summarizes the survey data for community colleges and Table 2 summarizes the survey data for four-year colleges and universities. Note: A "student-hour" of instruction equals one student receiving one hour of instruction and is computed on a class-by-class basis.

TABLE 1: "APPLIED VALUE" SURVEY RESULTS FOR FALL SEMESTER 2014 AND SPRING SEMESTER 2015 AT COMMUNITY COLLEGES

Category (Community Colleges)	Fall 2014	Spring 2015	Total for Year
No. of Educators	6	7	13
Students Impacted	119	106	225
Instructional Hours	322	114	436
Student Hours	5,749	1,532	7,281
Gender:			
Male	100	99	199
Female	8	7	15
Ethnicity:			
Caucasian	71	87	158
Hispanic	13	8	21
Asian/Pacific Is.	7	6	13
African-American	8	3	11
Native-American	0	1	1
Other Ethnicity	9	1	10

TABLE 2: "APPLIED VALUE" SURVEY RESULTS FOR FALL SEMESTER 2014 AND SPRING SEMESTER 2015 AT FOUR - YEAR COLLEGES.

Category (Four-Year Colleges)	Fall 2014	Spring 2015	Total for Year
No. of Educators	4	7	11
Students Impacted	127	108	235
Instructional Hours	349	372	721
Student Hours	7,419	8,301	15,720
Gender:			
Male	116	97	213
Female	11	11	22
Ethnicity:			
Caucasian	49	63	112
Hispanic	35	25	60
Asian/Pacific Is.	26	12	38
African-American	7	5	12
Native-American	0	0	0
Other Ethnicity	10	3	13

A total of 23,000 student-hours of microcontroller instruction was delivered at the college level during the 2014-15 academic year. The number of student-hours of instruction delivered at the four-year level was double that delivered by community colleges and may reflect a greater ability to apply the technology or the need for greater depth of instruction at the four-year level.

The gender data shows that females are a distinct minority in microcontroller classes and that the class is composed mainly of students of Caucasian ancestry. Students of Hispanic and Asian/Pacific Islander ancestry make up a higher percentage at the four-year level than in two-year, community college microcontroller classes.

Interest in professional development workshops similar to those offered through the project seems to remain high. Registrations are adequate to fill workshops and the project continues to draw educators from across the country. To date, over 100 community college and university faculty members have been trained to provide deeper instruction to their students utilizing the modules provided during the workshops. Several thousand secondary school students have been exposed to career information about the electrical engineering technology field. Reports on the best practices developed by the project team have been disseminated through publication in related journals, through presentations at conference, and through local workshops conducted by the team members. Students trained on the technologies discussed at the workshops will be better prepared to develop new products and push the envelope of technology evolution in the electrical engineering field.

VI. CONCLUSION

Digital systems sit at the heart of the technologies that most enrapture the young. This paper discusses the offering of two-day ARM-based microcontroller's workshops for electrical engineering technology faculty as part of the National Science Foundation - Advanced Technological Education grant. Curriculum resources and workshop materials are also being made available to faculty in other electrical and computer engineering technology programs. The educational materials are shared directly with participating faculty who attend the workshops and made available electronically through a project web site. This professional development provides both two-year and four-year electrical engineering technology faculty with the pedagogical and subject matter knowledge, digital teaching tools, and teaching strategies that will attract and effectively prepare students for STEM careers in reconfigurable electronics and other advanced electronics fields. For the United States to remain competitive in electronics technology, universities and community colleges need to continually update programs and facility resources, and provide ongoing faculty development to include the latest information about reconfigurable systems. Assessment results showed that during the 2014-15 academic year, microcontroller workshop participants reported approximately 23,000 student-hours of microcontroller instruction. One third of these student-hours were in two-year programs and two thirds in four-year programs. Interest in professional development workshops similar to those offered through the project remains high. Registrations are adequate to fill workshops and the project continues to draw educators from across the country.

ACKNOWLEDGEMENTS

This work was supported by the National Science Foundation – Advanced Technological Education Award No. DUE- 1205169.

REFERENCES

[1] Alaraje, N., Sergeyev, A. V., (2013) " From Theory to Implementation: Meeting Industry Needs through University & Community College Collaboration in Digital Logic Design Progress Report," 2013 ASEE Annual Conference & Exposition Proceedings, Atlanta, Georgia.

[2] Transparency Market Research (2015), [Online]. Available: http://www.transparencymarketresearch.com/pressrelease/embedded-system.htm. [Accessed: 22 September 2015]

[3] ManpowerGroup: Annual Talent Shortage Survey. [Online]. Available: http://www.manpowergroup.com/talent-shortage-explorer/#.VAnGjvmwJ8E. [Accessed: 31 March, 2016]

[4] American Society for Training and Development Report. [Online]. Available: http://www.astd.org/Professional-Resources/State-Of-The-Industry-Report. [Accessed: 31 March, 2016]

[5] Deek, F.P., Kimmel, H., & McHugh, J., (1998) “Pedagogical changes in the delivery of the first course in computer science: Problem solving, then programming”, Journal of Engineering Education, 87, 3, pp. 313-320, July 1998.

[6] Replacement needs in 2008-18, 2008 National Employment Matrix title and code, Bureau of Labor Statistics. [Online]. Available: http://www.bls.gov/emp/ep_table_110.htm. [Accessed: 31 March, 2016]

[7] Liming, D. and Wolf, M "Job Outlook by Education 2006-16", The Office of Occupational Statistics and Employment Projections, BLS

[8] Terrell, N., "STEM Occupations", The Office of Occupational Statistics and Employment Projections, Occupational Outlook Quarterly 2007, BLS

[9] The Cypress Corporation 2014. [Online]. Available: http://www.cypress.com/?id=1353. [Accessed: 24 September 2014].

[10] ISUPPLI, "ARM Processors to Ship in Nearly One-Quarter of Notebook PCs in 2015", [Online]. Available: http://www.isuppli.com/home-and-consumer-electronics/news/pages/arm-processors-to-ship-in-nearly-one-quarter-of-notebook-pcs-in-2015.aspx. [Accessed: October 17, 2014].

[11] Computer Weekly Website. "Chip maker ARM boosts profits by 44%". [Online]. Available: http://www.computerweekly.com/news/2240106620/Chip-maker-ARM-boosts-profits-by-44. [Accessed: October 17, 2014].

[12] Ocon, R. (2009). Promoting Faculty Development Using Industry Consulting Activities. ASEE Annual Conference & Exposition.

[13] Zeidman B., (2003). “ The future of programmable logic”, Embedded System Design, Oct 2003.

[14] Altany A., (2012). “Professional Faculty Development: The Necessary Fourth Leg”, Faculty Focus, June 29, 2012.

[15] Texas Instrument, 2015. [Online]. Available: http://www.ti.com/tool/ek-tm4c123gxl. Bureau of Labor Statistics, 2014. [Online]. Available. [Accessed: December 20, 2015].

[16] Digilent, 2015. [Online]. Available: http://digilentinc.com/Products/Detail.cfm?NavPath=2,396,1181&Prod=ORBIT-BOOSTER. [Accessed: December 20, 2015].

[17] Microchip Technology Inc., 2015. [Online]. Available: http://ww1.microchip.com/downloads/en/DeviceDoc/21935a.pdf. [Accessed: December 20, 2015].

[18] Analog Devices, 2015. [Online]. Available: http://www.analog.com/static/imported-files/data_sheets/ADXL345.pdf. [Accessed: December 20, 2015].