Journal of
INDUSTRIAL
TECHNOLOGY

Volume 26, Number 3 - October 2010 through December 2010

Design and Evaluation of a Microcontroller Training System for Hands-on Distance and Campus-Based Classes

By Dr. Steve Hsiung, Dr. John Ritz, Mr. Richard Jones, and Mr. Jim Eiland

Peer-Refereed Article
Applied Papers

KEYWORD SEARCH

Computer Programming
Computer Technology
Distance Learning
Electricity
Electronics
Internet
Teaching Methods

The Official Electronic Publication of The Association of Technology, Management, and Applied Engineering • www.atmae.org

Design and Evaluation of a Microcontroller Training System for Hands-on Distance and Campus-Based Classes

By Dr. Steve Hsiung, Dr. John Ritz, Mr. Richard Jones, and Mr. Jim Eiland

Steve Hsiung is an associate professor of electrical engineering technology at Old Dominion University. Prior to his current position, Dr. Hsiung had worked for Maxim Integrated Products, Inc., Seagate Technology, Inc., and Lam Research Corp., all in Silicon Valley, CA. Dr. Hsiung also taught at Utah State University and California University of Pennsylvania. He earned his BS degree from National Kauhsiung Normal University in 1980, MS degrees from University of North Dakota in 1986 and Kansas State University in 1988, and PhD degree from Iowa State University in 1992. Steve can be reached at shsiung@odu.edu.

John M. Ritz is professor and Graduate Program Director for STEM Education and Professional Studies at Old Dominion University in Norfolk, VA. John can be reached at jritz@odu.edu.

Richard Jones has been teaching at ODU since 1994. He is a retired United States Navy Submarine Service Lt. Commander with sub-specialties in Ballistic Missile, Torpedo, Sonar, and Radio systems. He has previously taught Mechanical Engineering Design at the United States Military Academy and Electrical Engineering at the United States Naval Academy. He holds a BSEET from Oklahoma State University and a Master of Engineering in Electronics Engineering from the Naval Postgraduate School at Monterey, California. Richard is currently focusing his research on methods of teaching accredited upper-level electronics labs synchronously via the internet. Richard can be reached at rljones@odu.edu.

Mr. Eiland has been the Assistant Professor of Electronics at Blue Ridge Community College, Weyers Cave, VA. since 1983. Over the past 26 years he has taught every ETR prefix course the Computer and Electronics Department has offered. He has been actively involved in web deployment of technology related coursework, developing coursework, developing teaching aids and developing state of the art experiments utilizing his own research and development experience. For the past 12 years Mr. Eiland has been the owner/engineer of JEELAND R&D which provides design support to defense contractors, local industry and inventors. James can be reached at EilandJ@brcc.edu.

Abstract

The purpose of this project was to design a low cost microcontroller trainer that is affordable ($130) for students to keep and improve student learning. The design eliminated institutional budget constraints for lab equipment and overcame obstacles in teaching digital microprocessor/microcontroller related courses that are delivered through distance learning and campus-based formats. Use of this trainer in conjunction with supporting curriculum provided opportunities to students in rural and urban areas to learn with hands-on experimentations of current technology concepts and become better prepared to qualify for high-tech jobs. The training system's hardware and software were tested and evaluated through workshops, university, and community college courses.

Introduction

Microcontrollers have become ubiquitous embedded aids in our daily lives. They are compact, single-purpose computers running embedded application software that are widely used in modern electrical and electronic devices and systems to control operations, such as temperature settings of ovens, remote control of television sets, or extended features of cell phones. Automobile mechanics must work with microcontrollers to control fuel mixtures and ignition timing. Because microcontrollers are so important to our high-tech world, demand is high for workers trained to design, maintain, and integrate them into current and future products. Many people who want the training, however, cannot take time away from work or family obligations to enroll in engineering and/or technology programs on traditional college and university campuses. To accommodate the needs of these potential students, this training system provides a workable alternative solution to implement hands-on distance learning and teaching.

Digital electronics and microprocessors/microcontrollers are major components in today's high-tech world and important subjects in Electrical, Electronic and Computer Technology (EECT), and related curricula. In order to educate students in these fields and accommodate the growing needs of distance learning, the methods of delivering these educational materials must be enhanced. Studies, done by Michael (2001), show there are obstacles in delivering hands-on education in distance learning environments, but issues can be resolved with modified instructional strategies. Currently, most of the solutions to laboratory related courses in distance learning are to use computer simulations and sometimes Internet virtual labs, which have fundamental difficulties in solving the hands-on obstacles (Bernard et al., 2004). For example, the circuit design, testing, implementation, debugging, and performance verification can not be covered by the pure use of software simulations or virtual laboratories (Michael, 2001; Gokhale, 2007). In addition, the cost of laboratory exercises and experimentation is another issue of concern for instructors and students.

A low-cost and portable microcontroller training system can provide hands-on learning opportunities in geographically dispersed areas as well as for on-campus students to learn current technology concepts and become better prepared to qualify for high-tech jobs. Furthermore, since the student gets to keep the training system after course completion there is an excellent opportunity for subsequent learning, product development and individual research. The following sections provide the description of a microcontroller training system, including hardware and software designs, and its implementation and evaluation in a distance learning environment.

The Need for a Hands-on Microcontroller Training Platform

According to findings in Gokhale's (2007) studies, the effective integration of computer simulations into lecture-lab activities enhances the understanding and performance of students. Michael (2001) reported that the reliance on the use of only computer simulations to enhance product creativity was not supported. To simply apply computer simulations in distance learning classes will not be effective to support students' full understanding of the course concepts, especially when it related to learning by doing materials. Michael added that there must be an association with hands-on experiments or laboratory activities to achieve the maximum learning results, which is a key in understanding engineering concepts.

There are courses that can easily fit into the distance learning format, but there are also curricula that have fundamental difficulties in offering the course material on-line. The most common problems are found in courses that require hands-on laboratory experimentations/exercises and their associated high costs, such as those offered in the engineering and technology areas. The implementation of virtual labs in which students can remotely log onto and control the laboratory equipment to perform the required exercises via the Internet will solve some of the learning difficulties, but they have their limitations, especially, when considering tests, experiments on real circuits and software designs, troubleshooting, and

Table 1. Compatible PIC training system

Trainer Board Name	***PIC Training System***	**Easy PIC 6**	**PIC TUTOR**	**PIC Starter Kit, Deluxe**	**BASIC Stamp 2pe Board**	**Low Pw Demo Board**
Manufacture	***ODU NSF CCLI Type I***	**Mikroe Elektronika (2009)**	**AMS (2009)**	**MCPros (2009)**	**Parallax Inc. (BASIC, 2009)**	**Microchip (2009)**
USB	***2***	2	1	1	1	No
ZIF Socket w MCU	***40 Pin ZIF***	No	Yes	No	No	No
Parallel Port	***Yes***	No	No	No	No	Yes
Power Requirement	***DC or AC***	DC or AC	DC	DC	DC	DC
Serial Comm.	***Yes***	Yes	Yes	Yes	Yes	Yes
PIC Programming	***Yes***	Yes	Yes	Yes	Yes	Yes
Debugging	***Yes***	Yes	Yes	Yes	Yes	Yes
RS232 Interface	***Yes***	Yes	Yes	Yes	Yes	Yes
7 Segment Display	***4 7-Segments***	No	No	Yes	No	No
LCD Display	***24*2***	16*2	16*2	16*2	No	Yes
Input & Indicator	***12***	8, No Ind.	2, No Ind.	8	Yes/ Extra	2, No Ind.
Output & Indicator	***28***	36	4	8	Yes/ Extra	4
I/O Buffer	***Full Buffered***	No	No	No	Yes/ Extra	No
Keypad	***3*4 or 4*4***	4*4 Buttons	3*4 Only	3*4 Only	No	No
Debounced Switch	***8***	No	No	No	No	No
SPDT INT Input	***2 Switches***	No	2 Switches	No	No	No
EEPROM	***64K***	No	No	No	No	No
DAC	***12 Bits***	No	No	Yes	No	No
OP-Amp	***Dual OP-Amps***	No	No	Yes	No	No
RF Wireless Comm.	***2.4 GHz***	No	No	No	Yes/ Extra	No
SPI Interface	***Yes***	No	No	No	No	No
Optical Isolation	***8 Channels***	No	No	No	No	No
Power FET Driver	***8***	No	No	No	No	No
Terminal Block	***8***	No	No	No	No	No
DC Motor Control	***2***	No	Yes/ Extra	Yes/ Extra	Yes/ Extra	No
Stepper Motor Con.	***2***	No	Yes/ Extra	Yes/ Extra	Yes/ Extra	No
Breadboard Interface	***Yes (6.5"*2.25")***	No	Yes/ Extra Cost	Yes (3"*2.25")	No	No
Expansion Port	***Yes***	Yes	No	Yes	Yes	No
Board Size	***8"*10"***	10"*10"	5"*7"	12 Boards	1.35"*2.75"	3"*7"
Sensor	***2* Potentiometer***	1 * Potentiometer	No	LDR	Yes/ Extra	Tempera ture
IR Transceiver	***No***	No	No	No	Yes/ Extra	Yes
Curriculum Package	***Yes***	No	Yes/ Limited	No	No	No
System Manual	***Yes***	Yes	Yes	Yes	Yes	Yes
Price	***$130.00***	**$139.00**	**$383.36**	**$857.50**	**$69.99**	**$129.99**

debugging in microcontroller control related material. It can be a major obstacle to students in understanding the concepts in remote locations. Also, it is often challenging to visualize the course instructional materials without letting students actually build the circuits and test their designed software on real hardware setups. Without a common training system platform, it has been increasingly difficult for teachers to guide and assist students in troubleshooting their circuits/systems and provide them with proper suggestions or answers to their problems in a remote environment. On average, this significantly increases the time required to assist students performing laboratory work online when compared to students taking the course on campus. The distance learning students spend more time in understanding the same course materials, since they can only obtain help from teachers via Internet postings, chats, e-mail discussions, or telephone calls.

The cost of learning in designing microprocessor/microcontroller applications is another major issue for implementing distance learning programs, because students usually need to purchase parts and equipment themselves to meet the course requirements. This significantly increases the cost of the hands-on courses; often these financial burdens force potential students to have second thoughts in selecting these areas of study. Converting the course to computer simulation would reduce these costs, but the authors consider hardware hands-on experiences to be vital to the success of microprocessor related laboratory courses. The project idea is to design and then provide a pre-assembled training system with associated instructional modules at an affordable price via a bookstore or vendor arrangement.

There are several PIC (Programmable Interface Controller; microcontrollers made by Microchip Technology Inc.) training platforms commercially available. Table 1 compares the capabilities of the most commonly used systems based on the availability, suggestion, and actual evaluation of the products against this project PIC trainer. This project training system surpassed the competition in the variety of programming choices, numbers of I/O and buffer protections, display options, external EEPROM (25A256, 2009), DAC, OP-Amp (MCP4821, 2009), RF module with SPI interfaces, and high power motor drivers with optical isolation features. Most importantly, the specifically designed curriculum modules (collaboratively designed by both two- and four-year institutions) fit the academic community's needs; instructors can select from different training modules to specifically cater to their course needs.

The microcontroller training platform described next is designed to address hands-on distance learning problems and associated cost issues. Use of this training platform, with a mixture of Internet-based real time audio, video, e-mail, chat, conference meeting, computer simulation, troubleshooting guidance/demonstration, and one-on-one individual consultation can enhance the distanced students' learning experience equivalent to that of their on-campus counterparts.

Project Objectives, Curriculum, and Hardware Designs

The research team transformed their ideas for this learning system into project objectives. These included:

- **Training System Development:** Design and develop the hardware and software for a training system board that uses PIC medium family members, such as PIC16F84A (2010), PIC16F88 (2010), and PIC16F877A (2009), for two- and four-year institutions in the areas of digital, microprocessor/microcontroller, automation control, and senior project courses to directly resolve the problems of cost and learning from a distance.
- **High and Low Level Programming Languages:** This system will serve as a common platform for high and low level software programming design, hardware circuit trouble shooting, evaluation, and final project control.
- **Hardware Modules and Components:** The training system will be designed with many basic modules such as power supply, input/output switches, keypad, interrupt inputs, LED outputs, LCD display, serial interface, parallel interface, PC communication interface, high power motor driver, sensing, etc. It also will have the flexibility to accept advanced module connections for future expansions.

Due to the differences in program design and missions in the two- and four-year institutions that participated in this project, an extensive information exchange was used to help the team members to reach consensuses on curriculum modules. After many discussions and exchanges of experiences among the design team members, a common list of instructional topics was developed. The design team members selected the following units to develop the curriculum modules that can be integrated into various courses:

<u>Session #</u>	<u>Content</u>
0.	**Microcontroller Technology:** A Brief History of Microprocessor Development, Differences between Microcontrollers and Microprocessors, Microcontroller Applications, Microprocessor Architectures, Memory Types, Microcontroller Packaging/Appearance, PIC16F84A, PIC16F88, and PIC16F877A Memories
1.	**Gates, Number Systems & PIC Environment:** Different Number Systems, Number System Conversions, Logic Gates, Logic Arithmetic (Add & Subtract), Header File and Source Codes, The Environment and Software Operations, and Header File and Source Codes

Session #	Content
2.	PIC Instructions in Assembly Language Programming: Assemble Language Format, PIC Instruction Sets and Registers, 16F84A, 16F88, and 16F877A Internal Blocks and DRAM Distributions, C, Z, and DC Flags in STATUS Register, Setting and Clearing Bits, Logic and Math Operations, and Addressing Modes
3.	**I/O Interface:** PIC Embedded System Designs, Use of Internal Oscillator and External Resonator, Ports Configuration, I/O Port Interface, DIP Switches Inputs, LED Controls, and 7-Segment Interface
4.	**Assembly Language Software Designs:** Programming Controls, Flowcharts, Counters, Loops, Time Delays, Subroutines, DRAM Memory Banks, and PRAM Memory Pages
5.	**The Uses of WDT:** CONFIG Register Configuration, Watch Dog (WDT) Configuration, Controls, and Applications
6.	**The Uses of IRQs:** Source of Interrupts, Flags and Enable Setup, Interrupts Handler, IRQ Configuration, Polling vs. IRQ, IRQ Service Routines, Prioritize IRQ Services, and Multitask Applications
7.	**Parallel Data Communication:** Parallel Interface, Data Transmission Protocol, Long and Short Table Lookup Implementations, and LCD Module Interface
8.	**3*4 or 4*4 Matrix Keypad:** Software Debounce Designs, Key Decoding Designs, Matrix Keypad Interface Designs, Interface Software Design, and Testing and Verification
9.	**Stepper Motors:** Unipolar and Bipolar Stepper Motors, Stepper Motors Interface, H-Bridge, Driver, Speed, and Direction Designs/Controls
10.	**DC Motors:** H Bridges Controls, DC Motors Interface, Driver, Speed, and Direction Designs/Controls, and PWM Controls

PIC Training System Hardware and Software

After finalizing the session topics, work began on the hardware design. The initial goal was to design a hardware circuit that would both enable PIC microcontroller programming and provide limited debugging functions. The specifications required developing the PIC microcontroller programming of the PIC flash and EEPROM memories were obtained from the manufacture Microchip web site (PIC16F87/88, 2002; PIC16F87X, 2003). Designs of the PC parallel/printer port hardware and software used to program the PIC microcontroller flash and EEPROM memory were widely available on the Internet, and these were modified for use in this project by the design team members (PIC16F8X, 2003). However, due to the limited availability of PC parallel ports on newer computers (particularly laptop computers), it was determined that a USB programming port would also be needed. Nevertheless, available software in the public domain using a USB port was limited, mainly because hardware designs varied and the accompanying software differed for each design. After consultation with Microchip Inc. engineering support, it was decided that the project board would rely on the USB drivers embedded in Microchip's public domain PICKIT2 (2010) software (see below).

To provide limited debugging functions on a PIC processor, an understanding of the "Background Debugger Control" and the "On-Chip Debugger" specifications was essential; however, there was a lack of sufficient documentation of these materials (On-Chip, 2001). After consultation with Microchip Technology Inc., it was found that full documentation of the debugger routines is usually not available to the general public and is only shared with Microchip's affiliated third party tool development companies. Following extensive research, trial and error, and additional consultation with Microchip design engineers, it was suggested that the best approach would be to use the available Microchip public domain software.

It was decided that Microchip's "PICKIT2" hardware and software architecture would be followed for the design of this development system (PICKIT2, 2010). In implementing this scheme, the system would be designed around the "PICKT2" USB communication criteria, thereby using a dedicated PIC18F2550 microcontroller.

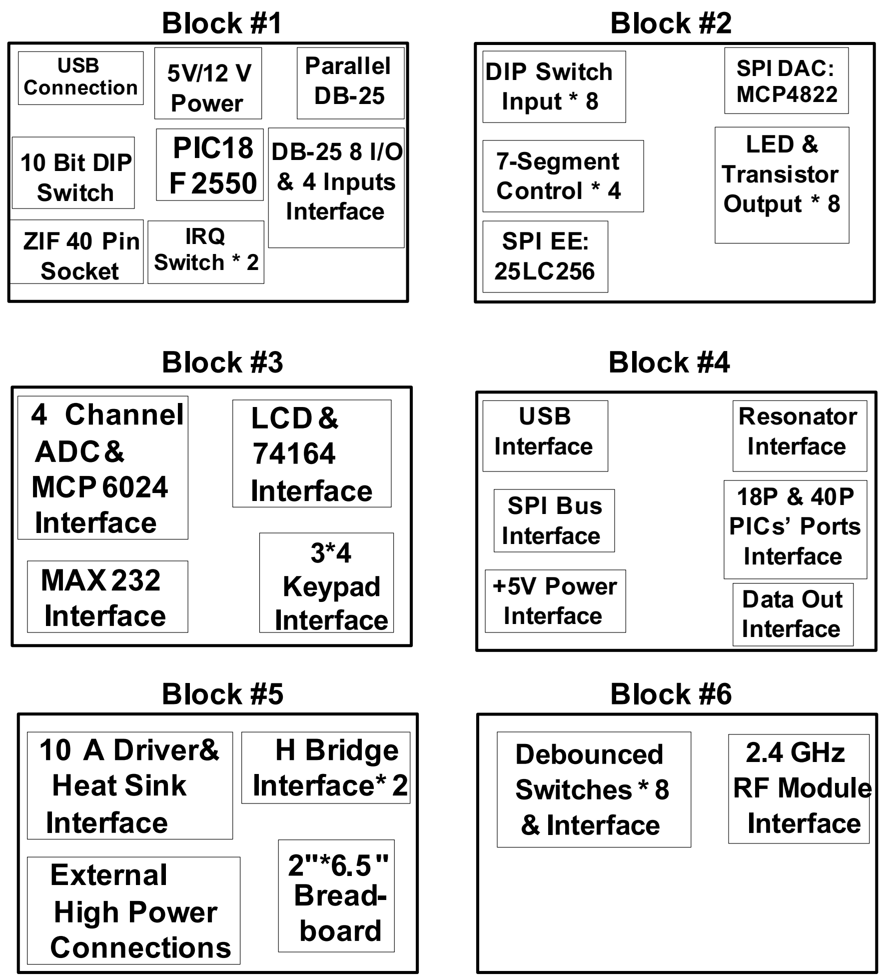
To be able to better communicate with the project team members and create clear and effective documentation, hardware blocks were used to initiate different design ideas. The hardware block design was also aimed toward better links in fulfilling the needs of the curriculum sessions listed earlier. The core circuit design, shown in Block #1 of Figure 1, was tested and verified with the "PICKIT2" software. The USB port uses "PICKIT2" software and the DB25 parallel port uses "ICPROG" software (ICPROG, 2010). Additionally, the DB25 parallel port can also be used for high level language programming controls in C or C^{++} running Microsoft Visual Studio (Hsiung & Ward, 2006). After four revisions of the hardware functional blocks that were mutually agreeable to the participating colleges, a final circuit design was completed. Figure 1 shows a block diagram representing the training system hardware.

Printed Circuit Board (PCB) Implementation

Based on the bill of materials from the designed circuits (Eagle, 2009), there are a total of 205 electronic components/parts needed on the PCB. The goal was to make a PCB that had to be less than a standard 8.5”*11” page size format for easy transportation. When implementing the designed circuits into a desirable PCB, there were several factors that needed to be considered:

1. All the parts should be used in a through-hole format; any surface mount component will make the assembly and troubleshooting very difficult.
2. Even if footprints and prices for the surface mount parts are lower, they do not justify the difficulty in replacing and updating the training system in the future.
   Not all the available parts’ footprints for the PCB layout software can be perfectly matched with the parts from available venders, so making customized footprints is necessary.
4. Different adjustments on the parts’ footprints are critical to the design process.
5. To better meet budget constraints, an adjustment on parts’ footprints with available parts should work coherently during the PCB layout designs.
6. A four-layer PCB is preferable because of ease of layout, but the PCB manufacturing cost has forced the design to be a double-sided board.
7. The size of the training PCB can only shrink to its absolute minimum of 8”x10” to host a total of 205 electronic components. This makes the routing a very challenging task. The auto route function performed by the software will not be able to do the job. Several trials and manual routes were used to meet the goal.
8. High power and low power sections of the circuits should be separated.
9. The routing traces of the high power signal should be wider in order to carry higher current.
10. High frequency components, such as the USB, resonators, and SPI bus lines, should be placed as close as possible to their communication partners.
11. All the interface connectors should be placed around the 2.2”x6.5” breadboard for easy access in building interfaces.
12. All the low power, USB, DB25, and ribbon cable connections are placed at one side of the PCB and all the high power connectors for motor controls are placed on the other side. These arrangements are designed for user friendliness and easy access in performing laboratory experiments.

Figure 1. PIC microcontroller training system with PCB function blocks



After applying these PCB design considerations, a final assembled PCB for this PIC training system is presented in Photo 1.

<u>Training System Workshop Evaluations</u>

This newly designed training system was evaluated through three workshops: (1) ASEE (American Society for Engineering Education) Annual Conference in Pittsburgh, PA, on June 22, 2008, (2) NAIT (National Associate of Industrial Technology) Annual Convention in Nashville, TN, on November 21, 2008, and (3) VTEA (Virginia Technology Education Association) Annual Conference in Richmond, VA, on August 5 & 6, 2009. The assessments from all workshop attendees were positive and the majority strongly agreed with the academic application in on-campus and distance learning microprocessor/microcontroller related courses. Table 2 presents the summary results of the data gathered from the assessments of this project at the sponsored workshops. Due to this project’s popularity/strong interest, there were also mini-grants provided by ASEE for $960 and NAIT for $500 to support the operational costs of the workshops.
A total of 36 teachers attended the

workshops including:

- 4 from community colleges,
- 6 from high schools, and
- 26 are university faculty.

The assessment results are based on a 5-point Likert scale (5 = Strongly Agree, 4 = Agree, 3 = Uncertain, 2 = Disagree, and 1 = Strongly Disagree):

Following are the individual assessments of the workshop participants. Table 3 is the ASEE08 workshop assessment, Table 4 shows NAIT08 workshop evaluation, and Table 5 presents VTEA09 two days workshop assessments.

Students' Evaluation

There were also 105 students who used the PIC training system and completed voluntary survey evaluations on the training system:

- 3 students from OC in Fall 2008 quarter,
- 31 students from BRCC in Fall 2008 and Spring 2009 semesters,
- 13 students from TCC in Summer 2009, and
- 58 students from ODU in Fall 2008, Summer 2008, and Spring 2009 semesters.

Table 6 presents the summary of participated student attitudes toward the training system.

Conclusions and Suggestions

In addition to the goals of this project, several additional results were achieved. First, this has been a rewarding educational experience for the research team members. Team members: Old Dominion University (ODU), Blue Ridge Community College (BRCC), Olympic College (OC), and Tidewater Community College (TCC) have realized the vast amount of work required to develop new training hardware, software, and accompanying instructional support materials. It was a challenging learning experience for everyone on the design team.

Also there are current demands for this type of training system. This was determined through conversations with

Photo 1. The assembled PIC training system

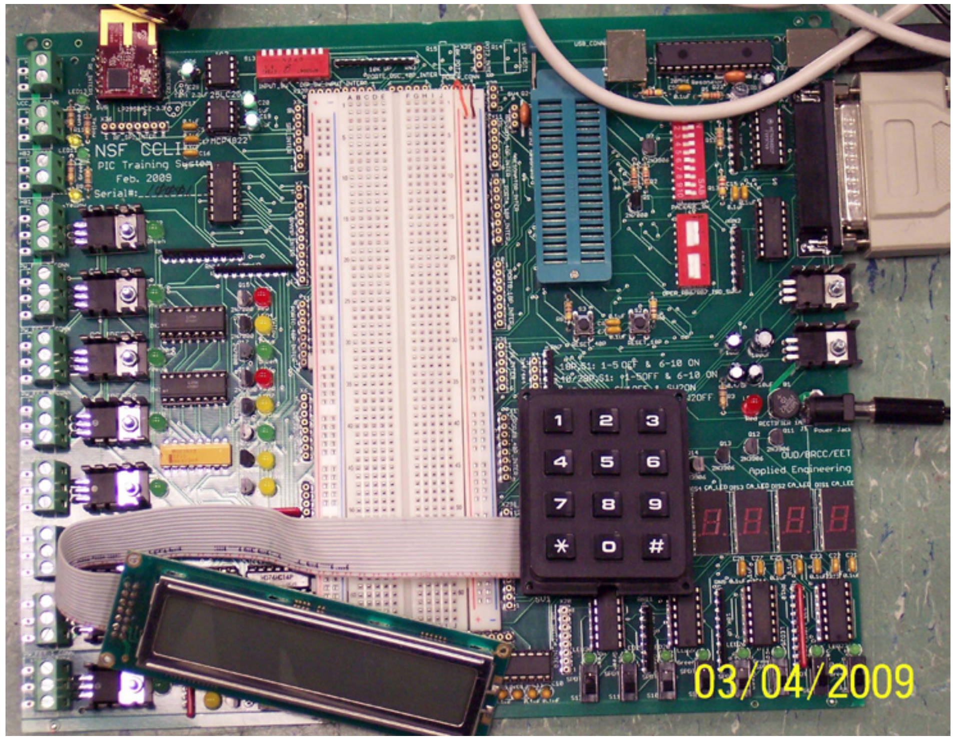


Table 2. Summary of Workshop Assessment Results

#	Subject	ASEE08	NAIT08	VTEA09	Total Average
1	Trainer system designed for program and lab needs	4.10	4.29	4.45	4.28
2	$130 price of the trainer justified	4.60	4.83	4.73	4.72
3	Will adopt the training system for on-campus classes	3.54	3.83	4.47	3.95
4	Will adopt the training system for distance classes	3.33	3.83	3.79	3.65
5	Course support curriculum materials	3.93	4.33	3.93	4.06
6	Addition of wireless communication/ control	4.00	4.00	4.00	4.00

faculty during conference meetings and the feedback received from workshops. The team has learned that there is a common concern about the obstacles in implementing hands-on distance learning – a lack of a good effective and affordable teaching platform.

Since the beginning of this project in April 2007, several groups of students at BRCC and ODU have been involved in organizing electronic components, assembling PCBs, evaluating and testing assembled PCBs, testing circuits, and completing surveys for evaluating the effectiveness of this training system. Responses were positive during their learning experiences while assisting with this project.

The other issue for this project was the budget; there were always cost increases and lack of sufficient funds to get the project completed. Spending more time and paying attention to details enabled the research team meet the optimal goals without jeopardizing the quality of the project. The original

Table 3. ASEE 08 workshop evaluation summary

#	**Question** *5 = Strongly Agree … 1 = Strongly Disagree*	**Rating** 5	4	3	2	1	Mean N	
1	Do you think the interface connectors' layout is sufficient for this training system?	9	6				15	4.60 Strongly Agree
2	Does this training system design fit your program needs?	3	7	4			14	3.93 Agree
3	Does this training system meet your current lab exercise needs?	3	6	4		1	14	3.71 Agree
4	Does this training system provide sufficient options in peripheral circuits' for different interface exercises?	8	6	1			15	4.47 Agree
5	Does the price of $130 justify this training system cost?	9	6				15	4.60 Strongly Agree
6	Does this training system software provide sufficient options for your lab exercises?	4	10				14	4.29 Agree
7	Do you think a wireless RF module is necessary for this training system?	5	3	3			14	4.00 Agree
8	Do you think a wireless IF module is necessary for this training system?	4	4	4			12	4.00 Agree
9	Do you feel the curriculum package is sufficient to cover your uP/uC courses?	3	7	4			14	3.93 Agree
10	Do you think you would like to adopt this training system for your face to face campus courses?		9	2	2		13	3.54 Agree
11	Do you think you would like to adopt this training system for your distance learning courses?		4	4	1		9	3.33 Uncertain
12	Does this workshop assist you in the lab courses preparation and implementation?	8	3	3			14	4.36 Agree
13	Is this workshop useful to your academic needs?	5	7	3			15	4.13 Agree
Overall Workshop Assessment		9	4	1			14	4.27 Agree

Comments:
-Not enough time to understand the potential of the system. System seems well designed and provides detailed documentation.
-Great work so far; could use a user-centered design revision so other institutions could use it without developer's knowledge.
-Need to find an appropriate textbook to parallel the system.
-Excellent workshop and excellent project.
-It is very comprehensive and informative for my future use with digital control of electric machinery.
-Excellent workshop. Hands-on is important tool to learn better.
-Need to be able to reprogram without taking out wires.
-The training board has some connecting bugs with the software. Sometimes it can connect; sometimes it cannot.

Table 4. NAIT 08 workshop evaluation summary

#	**Question** *5 = Strongly Agree … 1 = Strongly Disagree*	**Rating** 5	4	3	2	1	Mean N	
1	Do you think the interface connectors' layout is sufficient for this training system?	12	3				15	4.80 Strongly Agree
2	Does this training system design fit your program needs?	9	4	2			15	4.47 Agree
3	Does this training system meet your current lab exercise needs?	9	3	1	1		14	4.13 Agree
4	Does this training system provide sufficient options in peripheral circuits' for different interface exercises?	11	3				14	4.79 Strongly Agree
5	Does the price of $130 justify this training system cost?	12	2	1			15	4.73 Strongly Agree
6	Does this training system software provide sufficient options for your lab exercises?	9	5			1	15	4.40 Agree
7	Do you think a wireless RF module is necessary for this training system?	6	4	3		1	14	4.00 Agree
8	Do you think a wireless IF module is necessary for this training system?	4	4	4			12	4.00 Agree
9	Do you feel the curriculum package is sufficient to cover your uP/uC courses?	6	3	4		1	14	3.93 Agree
10	Do you think you would like to adopt this training system for your face to face campus courses?	10	4			1	15	4.47 Agree
11	Do you think you would like to adopt this training system for your distance learning courses?	6	3	3		2	14	3.79 Agree
12	Does this workshop assist you in the lab courses preparation and implementation?	11	2			1	14	4.57 Strongly Agree
13	Is this workshop useful to your academic needs?	11	3		1		15	4.60 Strongly Agree
Overall Workshop Assessment		**7**	**1**				**8**	**4.88 Strongly Agree**

Comments:
-Excellent presentation and this workshop has been of excellent value to me.
-Good hardware lab design.
-Not use distance learning and like to have direct contact with students.
-This type of course is not current offered; these questions are difficult to answer with no prior knowledge.
-This workshop is ideal for those involved in training future electrical engineering & product designers.
-Add some coding in .ASM would be have been helpful.
-Would like to talk you about implementing this item in possible package/kit format.
-Excellent and outstanding workshop containing high academic values on pedagogic, training, & course curriculum.

Table 5. VTEA09 workshop evaluation summary

#	Question	Rating 5	4	3	2	1	Mean N	
1	Do you think the interface connectors' layout is sufficient for this training system?	4	1	1			6	4.50 Strongly Agree
2	Does this training system design fit your program needs?	2	2	2			6	4.00 Agree
3	Does this training system meet your current lab exercise needs?	3	6	4		1	6	3.83 Agree
4	Does this training system provide sufficient options in peripheral circuits' for different interface exercises?	4	2				6	4.67 Strongly Agree
5	Does the price of $130 justify this training system cost?	5	1				6	4.83 Strongly Agree
6	Does this training system software provide sufficient options for your lab exercises?	4	2				6	4.67 Strongly Agree
7	Do you think a wireless RF module is necessary for this training system?	1	4	1			6	4.00 Agree
8	Do you think a wireless IF module is necessary for this training system?	1	4	1			6	4.00 Agree
9	Do you feel the curriculum package is sufficient to cover your uP/uC courses?	3	2	1			6	4.33 Agree
10	Do you think you would like to adopt this training system for your face to face campus courses?	1	4		1		6	3.83 Agree
11	Do you think you would like to adopt this training system for your distance learning courses?	2	2	1	1		6	3.83 Agree
12	Does this workshop assist you in the lab courses preparation and implementation?	3	2	1			6	4.33 Agree
13	Is this workshop useful to your academic needs?	3	2	1			6	4.33 Agree
Overall Workshop Assessment		**3**	**2**	**1**			**6**	**4.33 Agree**

Comments:
-Great instructor.
-The information may be a little much for general HS program.
-RF will be more as nice to have it.
-Use it in distance is a great tool if the school is going to have it.
-I need to learn this tool in distance learning applications.

Table 6. Students' evaluations summary

#	Instruction Module	OC Campus: 3 Students	BRCC Campus: 31 Students	TCC Campus: 13 Students	ODU Campus: 33 Students	ODU Distance: 25 Students	Total Average
1	Institution Course(s) Involved	ELECT227/ 237/228/238	ETR273/274	ETR261	EET320/325	EET320/325	N/A
2	Curriculum Topic Covered	1-8	1-8	1-7	1-11	1-11	N/A
3	Microcontroller Technology	4.63	4.24	4.77	3.84	4.37	4.37
4	Number Systems	4.96	4.09	4.78	4.63	4.78	4.65
5	Assembly Language	4.58	4.09	4.46	3.96	4.71	4.36
6	I/O Interfaces Controls	4.72	3.97	4.13	3.72	4.56	4.22
7	Software Designs	4.84	4.27	4.50	4.00	4.56	4.43
8	Uses of Watch Dog Timer (WDT)	5.00	4.43	4.73	4.25	4.80	4.64
9	Using IRQs	4.67	3.61	4.27	3.60	4.38	4.11
10	Parallel Data Communications	3.67	3.62	N/A	3.85	4.26	3.85
11	Matrix Keypad Interface Designs	4.38	3.29	N/A	3.73	4.31	3.93
12	Trainer Hardware & Software	3.13	4.28	4.52	4.20	4.63	4.15

goal for the cost for this training system board was set to be approximately $100, but the current bill of material calls (Eagle, 2009) for a total expense of $124.19, not including assembly cost. This would have increased the budget by over 25%. However, by increasing the search for components and negotiating volume purchases, it is expected that the bill of material cost can be lowered by 15%-20%. Using the students' help (with pay) in PCB fabrication can lower the cost of assembling the system, and at the same time teach students manufacturing processes, quality control, and troubleshooting skills. It also provides students with practical training experience for their future employment.

The prime goal was to make affordable technology-related course materials, activities, hardware, and software available to students who do not have access to on-campus college and university laboratory equipment in microcontroller related training that is required for many high-tech careers. This project produced microcontroller prototype hardware and software and instructional materials needed to support the distance delivery (real time two way communications between students and instructors) of several microprocessor related courses. Without allowing students to actually build circuits and test their designed software programs on real hardware setups using a common platform, it is very hard for them to understand the course content through distance learning programs. This project has fulfilled the hands-on distance learning and teaching needs of both students and instructors.

The evaluations and feedbacks from three workshops and students were all positive that highlight the value and contribution of this project. As this project evolves, individual laboratory activities are also being developed to reinforce student learning and skill development in programming concepts as well as providing a platform for individual student research and development after course completion. The expected outcomes will be better trained/educated students who will qualify for positions in the technical knowledge-based workforce.

References

25A256/45LC256 Data Sheet. (2009). Microchip Technology Inc. DS21822F. Retrieved from http://www.microchip.com/.

AMS. (2009). Burning Software Corporation, PIC Training & Development System, Retrieved from http://brunningsoftware.co.uk/learnmic-m.htm

BASIC (2009). BASIC Stamp, Parallax Inc. , Retrieved from http://www.parallax.com/Store/ Microcontrollers/SICStampModules/tabid/134/CategoryID/9/List/0/SortField/0/Level/a/ProductID/451/Default.aspx

Bernard, R.M., Abrami, P.C., Lou, U., Borokhovski, E., Wade, A.W., L. et al. (2004). How does distance education compare with classroom instruction? A meta-analysis of the empirical literature. *Review of Educational Research*, *74*(3), 379-439.

Eagle. (2009). Easy Applicable Graphical Layout Editor, Version 5.1, Cadsoft Inc. Pembroke Pines, FL: Cadsoft Computer.

Gokhale, A. (2007). Effectiveness of computer simulation for enhancing higher order thinking. *Journal of Industrial Teacher Education, 33*(4), 36-46.

Hsiung, S. & Ward, D. (2006). Design Software and Hardware for PC I/O Control. *Journal of Engineering Technology*, 23(1), 16-24.

ICPROG. (2010). IC-Prog Prototype Programmer, from http://www.ic-prog.com/index1.htm,/

MAX232-MAX249 Data Sheet. (2009). Maxim Integrated Products, Retrieved from http:///www.maxim-ic.com/

MCP4821/MCP4822 Data Sheet. (2009). Microchip Technology Inc. DS21953A, Retrieved from http://www.microchip.com/

MCPro (2009). Microcontroller Pros Corporation, E-Blocks PIC Starter Kit, deluxe, Retrieved from http://microcontrollershop.com/product_info.php?cPath= 112_95&products_id=845

Michael, K. (2001). The effect of a computer simulation activity versus a hands-on activity on product creativity in technology education. *Journal of Technology Education*. *13*(1), 31-43.

Microchip. (2009). Technology Inc., Development Tools, Retrieved from http://www.microchip.com/stellent/idcplg?IdcService=SS_GET_PAGE&nodeId=1406&dDocName=en021545

MikroElektronika. (2009). Development Tools, Retrieved from http://www.mikroe.com/en/tools/easypic6/

On-Chip Debugger Specification. (2001). Microchip Technology Inc., DS51242A.

PIC16F84A Data Sheet. (2010). Microchip Technology Inc., Retrieved from http://www.microchip.com/

PIC16F88 Data Sheet. (2010). Microchip Technology Inc., Retrieved from http://www.microchip.com/

PIC16F877A Data Sheet. (2010). Microchip Technology Inc., Retrieved from http://www.microchip.com/

PIC16F87/88 Flash Memory Programming Specification. (2002). Microchip Technology Inc., DS39607B.

PIC16F87X EEPROM Memory Programming Specification. (2003). Microchip Technology Inc., DS39025F.

PIC16F8X EEPROM Memory Programming Specification. (2003). Microchip Technology Inc., DS30262E.7.

PICKIT2. (2010). Pickit2 Development Programmer/Debugger, Retrieved from http://www.microchip.com/stellent/idcplg?IdcService=SS_GET_PAGE&nodeId=1406&dDocName=en023805