Abstract

A consortium of 13 Historically Black Colleges and Universities (HBCUs) has been collaborating for more than three years implementing experiment centric pedagogy (ECP) in over forty courses that involve circuits and electronics. ECP is enabled in this project through the use of mobile, inexpensive personal electronic instrumentation; usually Digilent's Analog Discovery (AD). Most of these courses have been in the circuits and electronics sequence in electrical and computer engineering programs. A subset of the faculty involved in this effort has also used the same approach to support hands-on learning in introductory engineering courses, both focused on general engineering and specifically on introduction to ECE. This program was initiated and funding obtained because the group recognized that integrating hands-on learning is one of the key approaches that has been proven to be effective in improving retention by making the learning experience engaging and motivating for students. The introduction of AD board based ECP has been shown to be successful in a variety of instructional settings. This project has benefitted from and inspired similar work by faculty at other universities who have been officially and unofficially affiliated with the 13 HBCUs. In this paper we will report on the impact of ECP on the first year engineering student experience at institutions both inside and outside the HBCU project.

Keywords

Hands-on Learning, Analog Discovery Board, Electrical Engineering Practicum, Virtual Instruments, Experiential Learning, Hand-held Mobile Devices

Introduction

In 2013, Howard University, in collaboration with Alabama A&M University, Florida A&M University, Hampton University, Jackson State University, Morgan State University, Norfolk State University, North Carolina A&T State University, Prairie View A&M University, Southern University, Tennessee State University, Tuskegee University, and University of Maryland Eastern Shore, received an NSF grant entitled, *Experimental Centric based engineering curriculum for HBCUs*.[1-10] The project is built on activities, delivery modalities, infrastructure and a collaborative support structure that enable project-based, experiential-based, and technology-based learning experiences. The purpose of this research program is to examine the impact on student learning, recruitment and retention of using experiential learning strategies and personal instrumentation in student learning activities in ECE courses in the HBCU ECP schools. Analog Discovery Boards are portable devices designed to provide the full functionality of traditional benchtop electronic laboratory instruments. They provide more options for students because they can use the devices outside of the classroom setting, in fact, essentially anywhere and anytime. The AD boards were used as supporting tools for traditional electrical engineering classes, but did not necessarily supplant the use of traditional laboratory equipment.

The overall goal of the project is to increase the number of highly qualified and prepared African American engineers and for all students to have a better understanding of technology and its role in STEM education. Another key goal for the grant is to promote wide spread dissemination of portable hands-on mobile devices through proactive collaboration between the 13 schools, outside schools, industry and government partners. All collaborating partners are using portable hands-on hardware coupled with a model of pedagogy that emphasizes experimentation. There is a need to determine if hands-on learning will be successful for students of color. The literature shows that many students of color are not entering the STEM fields or leaving the STEM majors due to instructional practices not suited to their needs or the perception that the STEM field is not real world [11, 12]. This project has been able to demonstrate that one way of solving this problem is the use of experiential-based learning Experiment Centric Pedagogy, in which experimentation always plays a central role both inside and outside the classroom.

The 13 HBCU ECP schools have implemented significantly more than the 39 courses that were planned in the original proposal. All began with their introductory circuits course and then expanded to additional circuits and analog electronics courses, digital electronics, design and project courses and the topic of this paper, first year courses. The students served are roughly 75% African American and 75% male. 25% of the students are 1st year. ECP activities have been implemented in lab and lecture classes and have been used in homework. Students do the activities about equally as individuals or in groups. Instructor demos are also used, but less often. For details on the other courses, the variety of assessment and evaluation tools utilized, the impact of instructor experience, the variety of learning environments, examples of activities, and connections to other published work, please see the references that specifically address this project.[1-10]

The schools participating in this project work with very similar student bodies and benefit from a strong collaborative effort to improve the learning environment experienced at all institutions. However, the individual courses and programs the students experience varies widely, especially in the first year. In addition, the schools where the original Mobile Studio and similar pedagogical approaches were developed, had not implemented their ideas in year one. Thus, the HBCU ECP project had to break new ground to make a significant impact on first year EE or CpE student education. In this paper, we look at what the opportunities have been for implementing ECP in year one and the successes of this project in making it happen along with a description of the tools that have made it possible. Specific examples of candidate courses for adoption of ECP are discussed. Finally, some opportunities for additional application in year one are presented.

Personal Instrumentation

The personal instrumentation marketplace is growing and changing rapidly. One of the earliest successful products – Mobile Studio – is no longer available. It was designed by and manufactured for a university with no intention of spinning off a commercial enterprise. When other products became available, it was replaced in the classroom, mostly by Digilent's Analog Discovery. The AD board is a full set of test and measurement devices (a 5MHz, 2-channel oscilloscope; two arbitrary waveform generators, ±5V DC power supplies; 16 digital I/O channels; a spectrum analyzer; a logic analyzer; a network analyzer; a DC voltmeter, etc.) equivalent to much more expensive desktop instruments when connected to a laptop computer. The board is controlled using software called WaveForms. The low cost and portability of this personal instrumentation enable the delivery of experimental centric, ECE educational experiences in almost any context, including fully online[13]. In addition to Analog Discovery, National Instruments' myDAQ and Analog Devices ADALM1000 have also been used and the marketplace continues to expand. The most recent version of the AD board (AD2) costs roughly the same as a circuits textbook, when bundled with the Digilent parts kit. Thus, it is reasonable, in many cases, for students to purchase their own boards and have unlimited access. However, with most students now renting their books and the cost of a university education so high, the business models used at the 13 partner institutions are based on loaning the boards to students either class-by-class or for the entire term. The latter also allows students unlimited access, but involves a larger investment on the part of the institution. In all cases, at least a small minority of students purchase their own boards.

First Year Experiences with Experiment Centric Pedagogy at HBCUs

The undergraduate electrical engineering (EE) and computer engineering (CpE) programs at the 13 partner schools are not organized in the same manner, so opportunities for the implementation of ECP for 1st year students are not available everywhere. Table 1 lists the disciplinary (i.e. ECE) or general engineering courses in which it is possible to utilize ECP. One school (FAMU) has no engineering courses; three schools (NCAT, TNSTATE, and UMES) have only courses on programming or general design. Four (AAMU, HOWARD, MORGAN, PVAMU) have an Intro to EE/ECE course and three have Intro to Engineering (HAMPTONU, NSU, SUBR). One school has only introductory Digital Logic (JSUMS) where they have not formally yet made use of the AD board, but a few students do. The fact that students will use these learning tools even when they are not required is very encouraging. Typically in Intro to ECE, ECP content and methodology is found throughout but less so in Intro to Engineering. Finally, one school (TUSKEGEE) introduces DC circuits in the 1st year in their Circuits I course. The approaches taken by the 13 schools are representative of what is seen throughout the US with a few exceptions. Notably, there is not a design methodology course built on a personal instrumentation platform. Examples follow.

Table 1: 1st Year Disciplinary and Engineering Course Offerings

University	Course #	Course	Cred	Circuits Starts Yr 2
AAMU	EE 101	Intro to EE	3	Yes
	EE 109	Engineering Computing	3	
FAMU		No 1st Yr courses listed		Yes
HAMPTONU	ENGR 101	Intro to Engineering	2	Yes
HOWARD	EECE 102	Intro to ECE	1	Yes
JSUMS	EN 212	Digital Logic	3	Yes
	ENL 212	Digital Logic Lab	1	
MORGAN	ENGR 105	Intro to ECE	3	Yes
NCAT	ECEN 101	Eng. Problem Solving with Matlab	3	Yes
NSU	EEE 100	Intro to Engineering	3	Yes
	EEE 101	Engineering Problem Solving	2	
PVAMU	ELEC 1021	Intro to ECE Lab	1	Yes
SUBR	ENGR 120	Intro to Engineering I	2	Yes
	ENGR 130	Intro to Engineering II	2	
TNSTATE	ENGR 1020	Freshman Engineering Seminar	1	Yes
	ENGR 1151	Computer Engineering Graphics	1	
TUSKEGEE	EENG 0192	Freshman Engineering Design	3	
	EENG 0221	Linear Networks and Circuits	3	
	EENG 221L	Linear Networks and Circuits Lab	1	
UMES	ENGE 100	1st Yr Orientations with Engineering	1	Yes
	ENGE 150	Modern Engineering Design	3	
	ENGE 170	Programming Concepts for Engineers	3	

Intro to Engineering and Engineering Problem Solving (NSU)

During year one, they introduce the use of the AD board and its WaveForms controlling software so students are better able to do experiments when they get to their first formal circuits course in year two. They cover series and parallel circuit combinations; forward and reverse biasing of LEDs as representative of all diodes; voltage sources and LED responses. They do projects on a heartbeat sensor using piezoelectric detection, LED traffic lights and LED displays with music. It is while doing the projects that the students make the greatest use of the AD platform.

Intro to Engineering (HAMPTON)

As at NSU, the use of ECP focused on an initial introduction of the AD hardware and WaveForms software, followed by Ohm's Law project activities. The students were from ECE and Chemical Engineering, along with some in a 5-year MBA. Students indicated increased interests in using the AD board in the intro class and said looked forward to using the board in other courses. Comments from freshmen students were usually along the line of "You should give us more experiments with the AD board." As a result, the use of AD boards is active in 2nd and 3rd year courses.

Intro to ECE (MORGAN)

This is a required course for all ECE majors and taught in two sections in classrooms with benchtop instrumentation. The instructors in both sections cover introductory circuit theory (series and parallel resistance combinations, Ohm's Law, and Kirchoff's voltage and current laws) and require students to conduct hands-on sessions using the traditional instrumentation in groups of 2 to 3. A pilot of ECP student content growth was conducted with one section using only regular lab equipment as the control (n=21), while the students in the other section (treatment, n=24) used the personal laboratory instrumentation inside and outside the classroom in addition to the regular laboratory equipment. The module studied addressed the Voltage Divider. Prior to instruction, students were assessed via a project developed pre-test on two circuits, one simple and one more difficult. After completion of the treatment or control instructional modules, students were then given a post-test on similar material. Findings were used to address the following question: *Do students who receive ECP, supported by AD boards, make greater gains than those who participated in traditional pedagogy?* The use of this data to address this and other questions is discussed elsewhere[10]. The results clearly demonstrated that students in introductory engineering classes who received ECP made significantly greater gains than those who received traditional instructional practices, most notably on high difficulty items.

Intro to ECE – Practicum (PVAM and HOWARD)

In the summer of 2015, the EE-Practicum was introduced to the project by its developer – Bob Bowman of RIT. The EE-Practicum is a cloud-based book[16], with experiments that use the AD boards and electronic parts kits to facilitate hands-on learning and self-exploration. All the experiments in the EE Practicum book use the AD boards for signal generation, display, and measurements. There are 15 chapters in the Practicum covering a very broad range of topics in EE. Starting fall 2015, it is used for Intro to EE classes at PVAMU and HOWARD. The hand-held mobile technology, the AD board, continues to be used to engage freshman ECE students[8]. The mobile technology and the ELEG 1021 class at PVAMU allowed the students to learn basic laboratory skills, be introduced to basic circuit analysis tools, and to experiment with electronic devices and electronic circuits. Analysis of post-survey results indicates that the students viewed the use of the AD board as a very positive experience. Overall, the students were satisfied with the use of the hand-held technology, noting that they had adequate time to practice the use of the AD board and that the board supported their learning needs.

Freshman Engineering Design and Introductory Circuits (TUSKEGEE)

In the design course, which focuses on the engineering design process, graphics and ethics, ECP with the AD board is implemented in a manner similar to the first two examples. The students are introduced to the AD Board and basic ideas of linear components and circuits. Unique within the 13 partner schools, DC (actually low frequency) circuits are also taught in first year Intro Circuits, using the AD board. Recently, because everything is so much lower in frequency in this course, other options besides the AD board were investigated to see if there were any less expensive choices for courses like this that may also be taken by other majors. In addition, lower frequencies may enable some functionality not available with the AD board. The only candidate at a much lower price (about 20% of the AD board) also had some attractive capabilities – the Analog Devices ADALM1000 (M1K) board. To achieve such a low price, the designers reduced the sampling rate so that it is only able to make reliable measurements up to audio frequencies. Also, it operates between 0V and 5V which requires time varying signals to have an offset of 2.5V. On the plus side, it uses 16 bit converters and can output up to 200mA. It has two analog channels and DC supplies, but only 4 digital channels.

The two analog channels are configured as Source Measure Units (SMUs). This is a significant departure from what students usually encounter in circuits or electronics lab. An SMU combines a sourcing function and a measurement function on the same pin or connector. It can source voltage or current and simultaneously measure voltage and/or current. It integrates the capabilities of a power supply or function generator, a digital multi-meter (DMM) or oscilloscope, a current source, and an electronic load into a single instrument. Most SMUs are "DC" instruments, however with the bandwidth and 100 kS/s speed, it can be considered as more of an "AC" SMU allowing the measurement of complex impedances. Because of its unique capabilities, it is possible to design experiments to directly measure both voltage and current and thus nearly directly determine both Norton and Thevenin equivalent circuits experimentally. This added to the fact that it was shown that it could reproduce the measurements possible with the AD board (most experiments in this course were able to be re-written for the M1K), make it possible to dramatically reduce the costs of offering a course using ECP as long as the frequencies are kept low. More students will be able to purchase their own boards and ECP can be implemented even when educational resources are highly constrained.

Intro to ECSE (RPI)

The content implemented by the 13 partners followed one of three paths to their classrooms. The majority originated in courses at RPI as part of the Mobile Studio Project,[15] and were modified at Morgan State to meet the needs of their student body. These modified modules were then adopted or adapted by the other partners. The second source of content was from outside institutions with practitioners recruited to share their ideas at HBCU ECP workshops. The EE Practicum is a prime example. The third is original content from the participants. There was no 1st year course at RPI when the project began, but, inspired by the work described above, one was developed in fall 2015 with its instructional design incorporating as many of the new ideas used in the project as possible.

The new ECE course piloted in AY2015-16. Since this course was developed to be the first discipline requirement for ECE students, its major focus is on preparation for several courses including circuits, electronics, signals & systems, electromagnetics, digital logic and embedded systems. A second key focus is to address the transition from high school to college. With the assistance of a STEM high school teacher, the electrical science topics students generally see in high school were identified so that they could be reinforced and built on during the first third of the course. A blend of learning experiences is utilized in a flipped class with online videos to be viewed at home, very short discussions and extensive hands-on learning experiences in class, the use of personal instrumentation (AD board) so that students can work on all course activities without spatial and temporal limitations, the use of piazza to obtain answers to questions 24/7, open shop times to help students with weaker backgrounds, online problem sets to prepare for in-class activities, required attendance to facilitate teamwork, the use of Matlab and Python for data analysis and system control; and a culminating design project. One of the first activities students complete is a short survey on their background, interests and knowledge of some basic concepts. Roughly, about 25% of students have a lot of AP and transfer courses, often with credits sufficient for sophomore status. About 25% have no AP. The remainder have 2-4 courses like Calculus I/II and Physics I. Thus, there is no way to design a one-size-fits-all course. The personalized instruction possible with the blend of learning activities has been very responsive to the needs of all students. All course content is readily available online at http://intro-ece.org.

Conclusion and Future Opportunities

The HBCU ECP project has successfully implemented Experiment Centric Pedagogy in all first year courses that could reasonably be expected to contain at least some circuits and electronics content, with the possible exception of digital courses. The latter remains an opportunity for the project, one that should not be difficult to make happen because there are already several examples of second through fourth year digital courses already implemented at partner schools. Other course that could benefit from this approach are design courses, which would benefit from more hardware-based hands-on activities, and programming courses because the AD board and similar devices are generally quite easily programmable in the most popular languages of the moment like Python. Finally, the successes of the existing courses should inspire those schools that presently do not have a hands-on Intro to ECE or Engineering, to add one to their programs as these courses have inspired such a course at the school where this pedagogy originated.

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