New Orleans JAZZED about Engineering Education

Paper ID #17055

The Implementation of Experimental Centric Pedagogy in 13 ECE Programs - The View from Students and Instructors

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Abstract

This paper presents findings from a multi-year project that is initiating experimental centric approaches to learning in electrical engineering courses at 13 Historically Black Colleges and Universities. The tool supporting to experimental student-centered learning at these institutions was an Analog Discovery Board (ADB). The content or setting of use reflect introductory, circuits, and supporting electrical engineering courses. The students were 1st, 2nd, and 3rd year undergraduates enrolled in EE courses; the unique audience represents students enrolled in HBCU colleges. In this paper, the authors discuss how integration of the innovative Mobile Studio concept was used to increase the amount of student-centered learning and document its impact on student outcomes. The authors begin with an overview of theories that inspired the design of the project and of technology supported learning. Descriptive narrative explains the real-time usability of the ADB that was developed. Results focus on the impact of experimental centric instruction on students' immediate learning and their affect toward learning. The findings also discuss facilitators and barriers to implementation and potential needs for sustainability.

Keywords

Circuits, electronics, hand-on experiments, mobile experiments

Introduction

Teaching 21st Century students require major change in how we instill, transfer and refine knowledge and skills. Todays' undergraduate enrollees are part of a new generation that has been raised, not only socially, but educationally, on hands-on manipulatives, technology, and push-button access. Their expectation of instant fulfillment is no longer met by traditional methods of teaching that emphasizes passive approaches to learning; rather, they not only expect but, because of their prior experiences now require strategies that encompass visual stimulation, experimental/authentic learning, and community-based practices.[1] Constructivist, constructionist, and action based learning theories provide the key pedagogical foundation needed to change instruction in higher educational settings.[2] Instructional methods based on these theories provide the structure and environment that fosters problem-solving, critical thinking, experimental activities, inquiry, and collaboration.[3] The use of technology plays a key role in these instructional settings by making access to and manipulation of information an integrated part of the process; when used to help construct students' knowledge base via experimentation and role-played problem solving technology contributes to learning and knowledge retention.[4-6] Beichner et al.[7] and Dori et al.[8] found that an active, student centered learning approach combined with educational technology yielded "significantly better learning outcomes than the traditional lecture/recitation approach".

In no field is the need for reform of educational practices more important than that of STEM content. Because of changes in K-12 education, STEM students are entering the college experience with a background in hands-on constructivist learning; they are expecting and learn best via hands-on technology supported, active learning. In addition, continued advances in technology coupled with the needs surrounding a growing content base and real-world problems within STEM indicates that constructivist learning will best serve future professional demands. 21st Century STEM graduates must be not only be well versed in today's current content and

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skills but also able to transfer that knowledge to new situations, new data, and new problems. The development of a constructivist-learning base, supporting individual and group based discovery learning, has been shown to be an effective way of helping students to obtain and retain, and transfer STEM concepts and skills. When used in the STEM domain, this methodology allows learners to explore and tryout new concepts in relationship to what they already understand using trial and error to develop or strengthen understanding. Through the use of web-based tools as well as local technology, students' STEM learning can be scaffolded to meet both individual and group needs and can be tied to real life experiences, data sets, and simulated outcomes.[9] Rodd and Newman[10] reported positive outcomes as a result of technology supported hands-on learning in STEM education; higher education students who had access to technology supported, technology guided, and technology reinforced learning; outcomes included more positive attitudes toward learning the content, greater retention of direct content, and greater transfer to other areas.

Several successful models of hands-on discovery learning, based on constructivist learning, have been developed within the engineering education domain[11,12]. One noted approach, the Mobile Studio concept, was developed to facilitate learning through the use of a hand-held technology, in place of traditional laboratory equipment, that can be used with a laptop anytime, anywhere. This technology, a mobile analog discovery board, has been shown to support active learning by increasing real life, hands-on experience for students; current evidence indicates that that use of the device when coupled with discovery learning promotes content acquisition, problem solving, and transfer of information for content related to electrical engineering and physics.[13,14] Additional literature shows that the use of this device and its curriculum can be transferred with relative ease to new instructors and new educational settings without loss of impact

A review of this literature, however, notes a major limitation of these studies—transfer to different students types. Several studies[14] have begun to examine variations in outcomes by student typology (e.g. learning style, gender, and English as primary language); however, no concerted effort has been made to determine if use of hands-on experimental based learning is successful for students of color. The need for this research is obvious when examined in light of current engineering recruitment and retention literature. Employment in the field of electrical engineering is believed to remain steady for the next two decades.[17] Despite this need, of 11,261 graduated bachelor students in the 2013-2014 academic year; only 405 (3.6%) were classified as African American.[15] In addition only 42 (3.6 %) of graduating PhD. students in the field of electrical engineering self-classified as African American. There is a high need to recruit, retain, and advance students from this ethnic group into the field of Electrical Engineering; a review of recruitment/retention literature shows that many students of color are either not entering the field or are leaving the field because of lack of interest, a perception that it is not related to their real world, or that instructional practices do not meet their needs[18]. One potential way of solving this problem is the use of hand-held experimental/discovery based learning. It is hypothesized that through this approach, students of color can be introduced to concepts that are related to their real world; problems can be introduced that will create and maintain interest; and students will see the relevance of the content they are learning to their future professional and personal lives. In addition, this approach will support and reinforce the STEM learning approaches with which they are familiar via K-12 STEM, thereby increasing their confidence and comfort in learning new or advanced concepts. Because there is limited literature that supports the use of constructivist based, hands-on experimental learning as a support for learning and

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recruitment/retention within this growing group of students, a full cycle of research. These studies need to include the training of faculty, the implementation of experimental approaches, immediate learning outcomes, and long-term recruitment, retention, and professional advancement indicators.

Purpose of the paper

This paper presents results of research on the impact of integrated hand-held mobile technology used in support of experimental centric learning within electrical engineering courses at Historically Black Colleges and Universities. The purpose of the study was to determine if the uses of a mobile analog discovery board would significantly impact immediate student learning and student affect toward learning and to identify important lessons-learned and/or conclusions that could help improve the instructional pedagogy in engineering education for underrepresented minority students.

Background of the Study

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 funding for an National Science foundation (NSF) grant entitled, "*Experimental Centric Based Engineering Curriculum for HBCUs*". The project advances a process which will create a sustainable "HBCU Engineering Network" that is focused on the development, implementation, and expansion of an Experimental Centric-based instructional pedagogy in engineering curricula used in these HBCUs.

The goal of the project is to increase the number of highly qualified and prepared African-American engineers, and all students, to have a better understanding of technology and its role in STEM education and the policy associated with it. Another key goal for the grant is to promote wide spread dissemination of portable hands-on mobile devices through proactive collaboration between educational institutions and industry partners. Collaborating partners are each using portable hands-on hardware coupled with a model of pedagogy (i.e., blended learning—a combination of lecture and hands-on activities in class; traditional—hands-on activities are completed outside of class time; etc.) to provide instruction in their courses.

As part of this process, the project has provided professional development to faculty at the 13 sites on the use of experimental-centric, hands-on, constructivist learning with a special emphasis on the use of an Analog Discovery Board. Each site has also developed and is piloting revised curriculum that focuses on this approach. As of June 2015, over 50 curriculum modules were developed that focus on introductory, circuits, and advanced EE content. These modules were piloted in the Spring, Summer and Fall of 2014 and refined for further use. Presented in Appendix A are three examples of use.

Participants in the Current Study. In the Spring/Summer of 2015, the developed curriculum materials continued to be used in the 13 HBCU's across a variety of instructional settings including classrooms, labs, practicum experiences, and a combination of graded and non-graded

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experiences. Data were collected from over 400 students during this period; 420 students completed pre surveys and 315 completed post surveys. Of these, 213 student participants yielded matched forms (68% of the possible post data). Findings of this paper are based on the matched (pre and post) data set ensuring that all respondents had full access to the treatment as delivered at their site.

Of the matched data set (see Table 1), 73% self-reported ethnicity as Black, 7% as Hispanic, 4% as multi-racial; the remaining students reported as Asian (9%) or White (7%). Of these, 76% were male, and 16% indicated that English was not their primary language. Major disciplines of study included Electrical Engineering (63%), Computer Science/Computer Engineering (20%) and Mechanical Engineering (8%); the remaining 20% of disciplines included Industrial Engineering, Business, and other engineering and STEM majors. Approximately 25% of the students were enrolled in their first year of study, 25% were in their second year, and 33% were enrolled in their third year. Prior to use, student self-reported their preferred modes of learning to be instructor-provided case-studies/examples (80%) and instructor demonstrations (86%); lecture and small group assignments were the least preferred pedagogies.

Table 1. Student Demographics (n=213*)

Gender	**Gender %**	**Discipline of Study**	**Major %**
Male	76	Electrical Engineering	59
Female	24	Computer Science	13
Ethnicity	**Ethnicity %**	Mechanical Engineering	8
Black	73	Other**	20
Asian	9	**Degree Progress**	**Degree %**
Multi-racial	4	1st year	25
White	7	2nd year	25
Hispanic	6	3rd year	33
English Primary Language	**Language %**	4th year	17
Yes	84	Graduate/5th year	<1
No	16		

**student data represent matches between 420 pre surveys and 315 post surveys*
***Students self-reported majors in Industrial Engineering (5%), Business (5%) and other Engineering and STEM related majors (10%)*

Application of the AD Board. Use of the AD Board, as a tool to support experimental centric learning practices within electrical engineering content, was shown to be successful across a variety of instructional settings and uses. Verification and validation of these uses is based on instructor description, student identification and evaluator observations.

Table 2. Pre and Post Use of AD Board in Varied Instructional Modalities

Instructional Modality	**Pre**		**Post**	
	Median Response	**% Used 6+ times**	**Median Response**	**% Used 6 + times**

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Location/Setting of Use*				
In a class setting	Never	10	3 times	33
In a lab setting	Never	14	3 times	40
As part of homework assignment	Never	11	3-4 times	38
Method of Use*				
Instructor Demonstration	Never	13	3-4 times	26
Cooperatively with a peer	Never	15	3 times	46
Independently	Never	12	5 times	46

**selection of multiple responses allowed*

Variations by Learning Setting. The most frequently occurring settings identified within the pilots consisted of: 1) traditional classrooms (e.g. instructor centered, emphasis on transmittal of theory with limited integration of the ADB and experimental centric learning introduced for students to practice new concepts), 2) lab settings (e.g., student- centered, emphasis placed on practicing and discovering concepts introduced via separate lecture based formats; lab instructors and lecture instructors were not always the same), and 3) as part of assigned homework (e.g. project and problem-solving work assigned to students as extensions of either traditional or lab based activities; sometimes for credit, sometimes for extra credit, sometimes volunteer activity). Additional settings included studio or blended classrooms (alternating teacher and student centered learning with integrated hands-on learning) and individual project use (e.g. use of the ADB as part of senior design or extra credit research).

Prior to use, typical student had no experience with the AD Board/Experimental Centric pedagogical approach. A small number of students had had prior in-depth use (greater than experiences); further examination indicated that these students were enrolled in advanced classes, had used the ADB in a pilot class the year before, and in some cases now served as the TA for a lower level class. End of term responses indicated that after completion of the term the typical student had used the AD Board at least 3 times in class settings, 3 times in a laboratory setting and 3-4 times in as part of a homework assignment. Overlapping or simultaneous use of the AD Board (e.g. in class/lab/ and homework) varied by institution. At most new pilot sites use was primarily within the laboratory setting and reflected supplemental or substitutional use for prior lab experiments usually resulted in standard reports. In these new pilot settings, the instructor for the lab might not be the content course instruction and varied on degree of experience with the AD Board and with experimental centric instruction.

At sites where use reflected re-use, instructors had more familiarity with the device and were noted to be either refining previous curriculum or were expanding use to new modules and/or new courses. The experience level of the Teaching Assistants (TA), if present, varied across the sites; in some new-use settings, the TA had the primary responsibility of helping students while instructors had limited contact. At other sites, the instructor provided hands-on demonstration and assistance and was teaching the TA use at the same time. During interviews, student indicated a need for compatible presentations/use between classes and labs and between instructors and TAs. Many noted that lack of instructor-direct involvement indicated a lack of importance in the use.

Use as independent homework was found to vary by stage of implementation across the sites (newer pilot sites used the approach had less use as part of homework; more experienced sites,

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working on expanding and refining use documented more homework support). Homework use was noted to support both traditional class instruction and lab work. In newer use settings, this homework often was for extra credit or exploratory purposes and was an extension of regularly assigned work. As use became more embedded and the instructor(s) more familiar, inclusion in homework reflected advanced opportunities to practice/learn material.

Variations by Instructional Use. Method of use also varied by site with multiple uses found at each of the 13 settings. The key methods of use included: 1) instructor demonstration (e.g., faculty active; student passive, instructor usually at the front of the classroom); 2) cooperative (e.g. student-student dyad or triad collaboration working on a specific assignment in classroom and in lab settings); and 3) independent (e.g. autonomous student use; assigned or volunteer).

Prior to involvement in these studies, a small number of students reported that they had experienced some form of pedagogical use of the ADB either via instructor demonstration (15%), cooperatively with a peer (15%) or independently (12%.) This number of students (24-30) were generally upper level, located at sites with multiple terms of use, and using the AD Board as part of special projects. After involvement in the current studies, the typical student had experienced instructor demonstrations 3-4 times per term, had worked at least 3 times with a peer, and at least 5 times independently. Of these students, 46% of the students had worked cooperatively with a peer and independently. In addition, the amount of experience with instructor demonstration had doubled to 26%. Typical students experienced this type of use at least 5 times per term. Instructor and student interviews, evaluator observations, and a review of module descriptions indicate that in many cases these instructor demonstrations were used as advance organizers to increase student interest and motivation, to prepare students for use in lab settings, and to review potential uses in the real world. The most frequently used method of instructor demonstration supported content with case studies and examples followed by hands-on practice. Some homework assignments also were completed in cooperative dyad/triads; students reported that this use was not as successful if they only had access to one AD Board; if each had access, students reported greater collaboration and sharing of finding instead of just cooperation across assigned tasks. While a similar number of students reported independent use, (at least 5 times a term) interpretation of this finding is less clear as this also may include those students who were part of cooperative groups or who took the lead in lab experiments.

Outcomes

A key purpose of the current study was to determine if student involvement in experimental centric, hands-on learning would affect indicators of learning. This study focused on changes in indicators of pre-requisites to learning, immediate classroom outcomes, and potential transferability of learning.

Short-Term Impact. Overall, students viewed use of experimental centric ADB supported learning as a positive experience. Most of the students perceived that the use of the AD Board was relevant to course content (80%), reflected that content (77%), and noted that it allowed them to practice course content (78%). These students noted that experience with the modules allowed them to experience real world practices (75%). Overall, the students were satisfied with the experimental approach, noting that they had adequate time to practice use of the AD Board and that this use supported their learning needs.

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Multiple domains of short-term learning known to influence constructivist experimental learning were shown to be supported during these pilots within circuits' content. This included pre-requisite affective changes need for learning to occur. Approximately 78% of the students reported changes relative to attention of/to the need to learn as reflected by growing perceptions of importance of knowledge of the ADB in preparing to become an engineer, followed by a growing confidence in learning/working in the content (73%) supported by increased motivation (72%) to learn the content. Correlated to these changes is a perception that knowledge had increased (78%). This finding supports a constructivist learning pattern of improved pre-requites affective learning constructs that lead to higher self-perceptions which in turn re-enforces and strengthens attention, motivation and confidence in learning, resulting in greater perceptions of knowledge and ability, thereby creating an increasingly positive cycle of affective support for experimentation and lessens fear of failure and wiliness to try new approaches to problem solving.

Table 3. Initial Changes Reported by Students

	Perceived Changes	**% ***
Immediate Learning	My knowledge has increased as a result of use	78
Pre-requisite to Learning	The hands-on ADB is important in my preparation as an engineer	78
Pre-requisite to Learning	My confidence in the content area has increased because of use	73
Pre-requisite to Learning	Using the ADB motivated me to learn the content	72

**Number represents percentage of participants who responded "Strongly Agree"/"Agree" on post-survey; n=267*

When queried, a notable 88% of the students enrolled in experimental centric classes reported that use of the AD Board helped them to learn more. Subsequent follow-up questions as to how the process of use helped to support this learning actions related to both affective pre-requites of learning and immediate outcome received high agreement scores. Actions related to affective pre-requisites include helping students to develop interest (69%), to become motivated to learn content (74%), to become confident in learning course content (74%) and more specifically to become confident in completing lab assignments (68%). Specific areas of learning noted included recalling course content (72%), learning about practical applications of AC/DC circuits (72%), thinking about problems in graphical/pictorial/practical ways (72%), and developing skills in problem solving within the content area (76%). These skills were reported by 72% of the students as helping to directly improve their grade which they viewed as an expression of their level of knowledge and professional ability.

Table 4. How the Method Helped Learning

	Areas of Growth	**%***
General Outcome	Helped me to learn more	88
Immediate Learning	Develop skills in problem solving in the content area	76
Immediate Learning	Think about problems in graphical/pictorial or practical ways	72

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Immediate Learning	Learn how AC and DC circuits are used in practical applications	72
Immediate Learning	Recall course content	72
Immediate Learning	Improve grades	72
Pre-requisite to Learning	Develop confidence in content area	74
Pre-requisite to Learning	Become motivated to learn course content	74
Pre-requisite to Learning	Develop interest in the content area	69
Pre-requisite to Learning	Confidently complete lab assignments	68

**Number represents percentage of participants who responded "Strongly Agree"/"Agree" on post-survey; n=267*

Table 5. Initial Long-Term Outcomes

General Effects of Use of the AD Board	**%**
Enhanced my professional abilities	88
Work collaboratively with fellow students	80
Transfer knowledge/skills to problems outside the course	76
Develop different ways of solving problems	75
Apply course content to new problems	72
Develop attitudes of self-direction and self-responsibility	71

**Number represents percentage of participants who responded "Strongly Agree"/"Agree" on post-survey; n=267*

Long-term Impact. Changes in support of sustained learning that reflected both experimental centric pedagogy as well as long-term professional goals also were noted by 80% of the students. This included improvements in areas directly related to general professional skills such as ability to work collaboratively with others (80%) and developing attitudes of self-direction and self-responsibilities (71%). Students also self-reported initial outcomes directly related to problem solving and transferring skills to new areas that would allow for advanced learning and professional placement. This included increasing their ability to develop different ways to solve problems (75%), being able to apply course content to new problems (72%), and transferring their knowledge and skills to problems outside the course (76%). During interviews, many students noted that the opportunity provided by the use of the AD Board and hands-on experiments helped them to feel more confident in their problem solving and that they often reflected on their trial attempts during these experiences. Many referenced characteristics related to visual and kinetic learning styles that were supported with use, noting use of pictorial imagery as an aid to alternative approaches and citing specific experiments that they had conducted that allowed them to "try different ways".

ABET Indicators. Documentation of student growth directly related to professional outcomes as students involved in the experimental centric pedagogy were asked to respond to a selected series of ABET indicators. Because of the relationship of affective pre-requisites and subsequent learning outcomes, students were asked to indicate the importance of learning each outcome or skill and their preparedness in preforming that outcome both before participating in the program and after exposure to and use of experimental centric learning via the AD Board. Three overall findings are supported by these data. First, students generally perceive these indicators as

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important but do not perceive themselves as prepared in these domains. Second, involvement in this program appears to increase students' perceptions of preparedness in these skills but also is decreasing their perceptions of the importance of these skills. Third, concurrently with this change, the difference in perceptions between importance and preparedness in a skill is impacted via participation in experimental learning via the AD Board; the difference between importance and preparedness is less at post than at pre assessment.

Table 6. ABET Outcomes

General Effects after use of the AD Board	% *Spring/Summer 2015							
	Importance			Prepared			Importance – Prepared	
	Pre	Post	Change	Pre	Post	Change	Pre	Post
Ability to apply scientific knowledge to engineering tasks	72	60	-12	34	36	+2	27	24
Ability to design experiments	62	54	-8	29	37	+8	33	17
Ability to interpret data	77	61	-16	40	38	-2	37	32
Ability to design system, component, process to meet need	72	58	-14	28	38	+10	44	20
Ability to function effectively on multi-disciplinary team	69	58	-11	38	41	+3	31	17
Ability to communicate effectively as a public speaker	61	53	-8	30	37	+7	31	16
Knowledge of contemporary issues	58	46	-12	25	31	+6	33	15

**Number represents percentage of participants who responded "Very Important" or "Important" on a 4 point scale*

As an example, when looking at results for "ability to apply scientific knowledge to engineering tasks", 72% of the participants viewed this as an important task prior to the course but this decreased to 60% at post completion, a negative change of 12%. A notably lesser number of students perceived themselves prepared at pre (34%) but, while still notable lesser when compared to importance, an increased number of students (34%) reported being very prepared at post. A similar trend was found for "ability to design an experiment" and "ability to design systems, components, and processes to meet desired needs". For both of these constructs, pre-importance was markedly higher than pre-preparation; post-importance also was found to be higher than post preparation ratings. The change from pre-to post however while showing a decrease in importance showed in increase in preparation. Students reported increases in perceptions of preparation accompanied by a decrease in perception of importance. Overall, the difference between importance and preparation, while still not in balance is becoming closer.

The observed negative correlation between the perception of importance and perception of preparation possibly could be explained by noting that the data from Table 6 seems to generally indicate some connection between perception of importance and recognized deficiency in a particular outcome. For all considered ABET outcomes, all pre-importance percentages are relatively high (i.e., above 58%) whereas the pre-preparation percentages are systematically

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low (i.e., below 40%). In other words, students tend to assign greater importance to skills that they need but do not have. With this observation in mind, it is reasonable to expect a decrease in the perception of importance of an outcome whenever the level of preparation of students increases. Although, in general, the difference between importance and preparation is not always balanced, it appears to be more so for the design- and communication-outcomes.

Benefits, Barriers, and Needs Related to Continued Use

Faculty, administrators, students, and local assessment personnel reported multiple benefits and needs as the project is continued. Benefits noted by faculty, students, and administrators included the ability to provide more hands-on practice and more examples of use that tied into real world and real professional challenges. Students noted that this use lead to greater knowledge about engineering, the engineering profession, and also increased their desire to stay in the field and to be part of research that would "change the world". Faculty noted that students who were in introductory and lower level courses were asking higher levels of questions, were more at ease in questioning each other, and wanted more time to try out their own idea and that involvement in the program made them more self-reflective in their teaching and in their work with students and colleagues as they taught and practiced "real world" problem solving. Advanced students noticed that the approach would have been valuable to have throughout their program and encouraged integration and expansion with increasing opportunities for both shared and independent use. Administrators observed that involvement in the program was encouraging faculty and students to be more global in their thinking about the content, the pedagogy, and the overall needs of program graduate and were supportive of the project, aware of its potential, knowledgeable of faculty involvement, and involved in providing resources.

Although the program was over-whelming viewed as an improvement in pedagogy participants did note several barriers to implementation and sustainability. A key barrier identified by almost all faculty and students was the availability of the AD Board as a tool for experimental learning. Students and experienced faculty reported a need for one AD Board per student; this did not preclude the use of collaborative learning, but all reported, that if "tinkering" is to take place, students need the opportunity to do "play and share", not "share playing". Students and faculty also identified a need for fully integrated use throughout the semester and cross course use as students advanced; this change would require full curriculum review and training for all faculty as well as more resources. Faculty and administrators also noted a need for support from upper level administration if the change is to be sustained and rewarded.

Needs identified by participants as the program reflected enhanced and expanded reflected means of meeting these barriers This included line items in budget or tuition/fees that would address the acquisition of more boards, internal and external professional development that would allow for learning about experimental centric learning and the use of the AD Board as well as other tools, development and sharing of curricula including assessment tools that would encourage integration efforts, and opportunities to include these changes in the professional reward system. Both faculty and students identified a need for more resources that would support initial use including videos, power points, and specific curriculum. Students specifically requested attention to inclusion across curriculum, beginning with use integrated into introductory courses. Several faculty also noted a need to include other STEM instructors (e.g.

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Physics) as part of the program; others noted a need to reach out to industrial partners to find ways to include experimental approaches as part of internships and advanced studies.

Summary

This paper has presented findings from a multi-year project that is initiating experimental centric approaches to learning in electrical engineering courses via the use of an AD Board. The audience emphasized in the paper reflects participants in introductory, circuits, and supporting electrical engineering courses. The students reflect 1st, 2nd, and 3rd year undergraduates enrolled in EE courses; the unique audience represents students enrolled in HBCU colleges. Data considered in this study captures a varied instructional setting comprised of classroom demonstrations, labs and practicum experiences. It also includes both graded and non-graded experiences. Moreover, the matched data incorporates survey responses of 213 students from 13 distinct institutions. The relatively large size of the data and its multi-faceted diversity accurately captures some of the salient issues of engineering education as they pertain to under-represented minorities, and should provide a high level of confidence in the conclusions drawn from the study.

Findings indicate that faculty and students are benefiting from the use of the AD Boards. Students and faculty report increases in constructs reflecting required affective pre-requisites to learning, including interest in content, motivation to learn, and confidence in ability to learn. Increases in these variables appear to be yielding positive student percepts of their knowledge, their interest in remaining in the degree program, and their ability to function as a professional engineer. In addition, during interview, an increasing number of students are expressing interest in graduate programs and research positions.

Use of the experimental approach appears to be having a slight positive impact on ABET indicators. Students expressed slight changes in differences between perceptions of importance and preparation of selected skills. These findings, resulting from exposure in only one class, indicate the potential for change as students are involved in multiple course integration.

As the research in this area continues, faculty and students have noted several barriers to use of the process and have suggested potential means of meeting these barriers. These include ensuring that more standardized approaches and expanded curriculum modules are piloted, that use of the AD Board as a support for experimental centric learning allow for more independent use both in the classroom and as homework, that use of the approach be integrated in both class and lab settings, and that use be expanded to course pre-requisites as well as follow up/advanced courses.

Overall, the use of experimental centric approaches to learning and teaching appears to offer a promising method of increasing and enhancing circuits based classes so that future engineers will be better able to meet the needs of a rapidly changing world. Further research is needed on the role of faculty teaching style, specific course content, and long-term achievement outcomes. Plans are in process for expansion to Year Three goals and training and resources are being set aside for this use.

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Appendix A Descriptions of Use

Example 1: Measuring the discharge characteristics of primary batteries

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In this example students use the ADBs to measure the capacity of commercial AAA and AA batteries. The experimental set-up is shown in the inset of figure 1(a) and consists of a battery in parallel with a resistor (R). The ADB is used to measure the voltage as function of time. The total capacity of the battery can be computed by integrating the discharge curves as a function of time and dividing by R, $C(t)=1R\int V(\tau)d\tau t_0$ and is presented in figure 1(b). In these experiments we used R = 3.75 Ω in the case of the AAA battery and R = 5 Ω in the case of the AA battery. The integration is performed numerically in MATLAB using the trapezoidal rule. In the example shown in figure 1 the total capacity of the batteries was estimated at 773 mA·h in the case of the AAA battery and 2,112 mA·h in the case of the AA battery. These values agree relatively well with the nominal capacity specified by the manufacturer. The current example can be easily extended to measure the discharge and charge characteristics of secondary batteries. In addition, it can be extended to estimate the specific capacity and energy density of primary and secondary batteries.

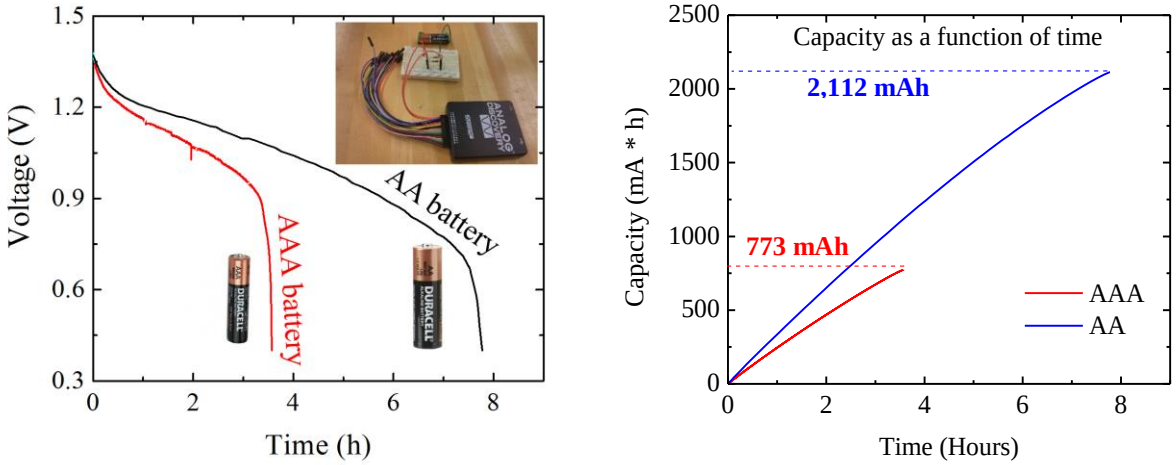

Fig. 1. Discharge characteristics and experimental set-up of two commercial AAA and AA batteries (left) and computed capacity (right).

Example 2: Studying first-order and second order transient circuits

First-order and second-order transient analysis can be easily analyzed using the ADB. The experiment requires only the ADB, a computer or laptop, a resistor, a capacitor, an inductor, optionally a breadboard to connect the wires. The schematics of the first-order transient circuit, the experimental setup, and the measured voltages across the capacitor are represented in figures 2 and 3. The students are using the mouse to measure the transient time in each experiment and compare it with the theoretically computed values. In the case of the RLC circuit the students are changing the values of the resistor and capacitor to analyze the transient response under different conditions (i.e. overdamped, underdamped, and the critically damped response). This experiment can also be modified to extract the values of the resistor, capacitor, or inductor by measuring the time constant and period of damped oscillations. In addition, it can be used to calculate the damped natural frequency or damping ratio in RLC circuits.

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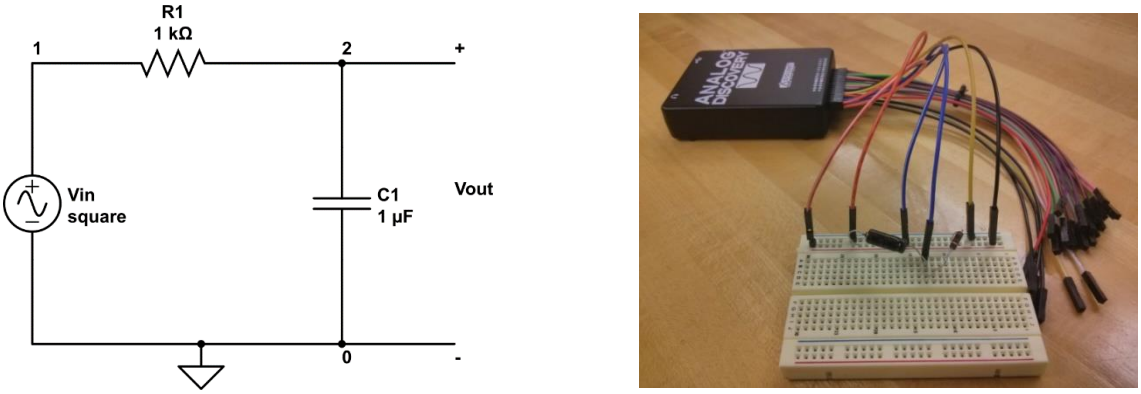

Fig. 2. RC circuit setup.

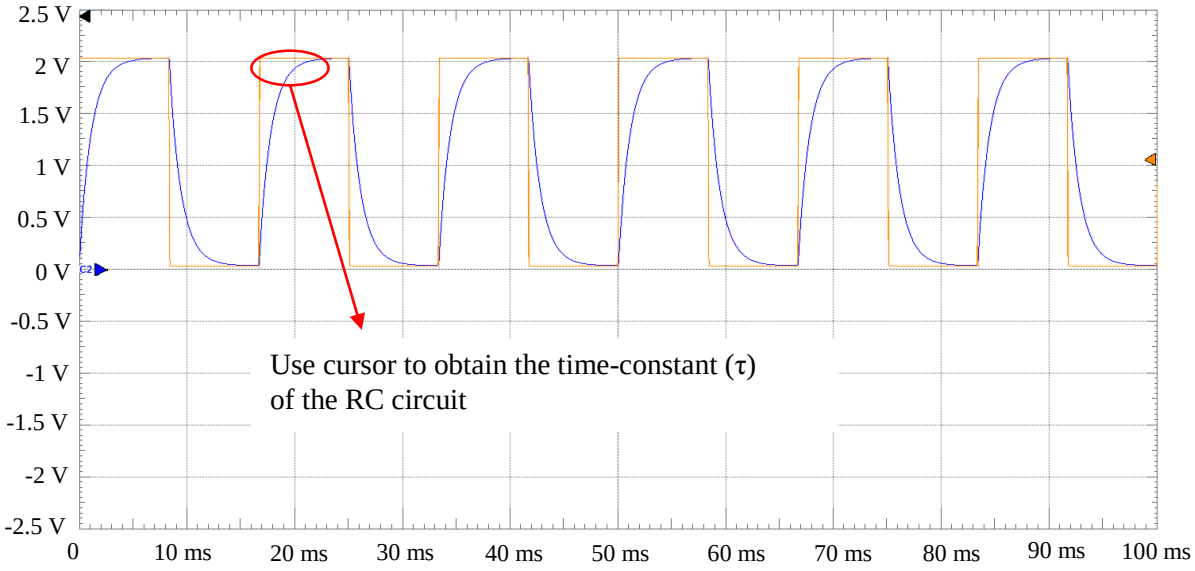

Fig. 3. Voltage across the capacitor measured using the ADB.

Example 3: Design of bandpass and band-reject filters

RLC resonant circuit, shown in figure 4, can be used to build both bandpass and band-reject filters. The ADB has a virtual instrument, Network Analyzer that allows one to obtain the Bode plot of a circuit. 1st year students, in introductory engineering class, build a RLC circuit and use the Network Analyzer of the ADB to obtain the Bode plot of the circuit. 3rd year students, in Electric Circuit class, design bandpass and band-reject filter, through the use of the RLC resonant circuit, that meet some specifications, such as center frequency, bandwidth, quality factor, cost of designed filter, and the number of the components used in the design. The students use the ADB to determine the magnitude response to the filter. Figure 5 shows the Bode plot of the bandpass filter shown in figure 4. Whereas the 1st year students performed RLC circuit experiment in the lab under a close supervision of an instructor, the 3rd year students worked independently of the class instructor. They were given the ADB to take home and use the board to determine the frequency response of their designed filters.

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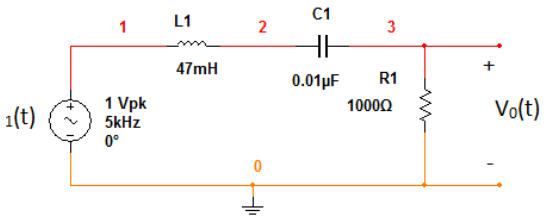

Fig. 4. (up) RLC resonant circuit

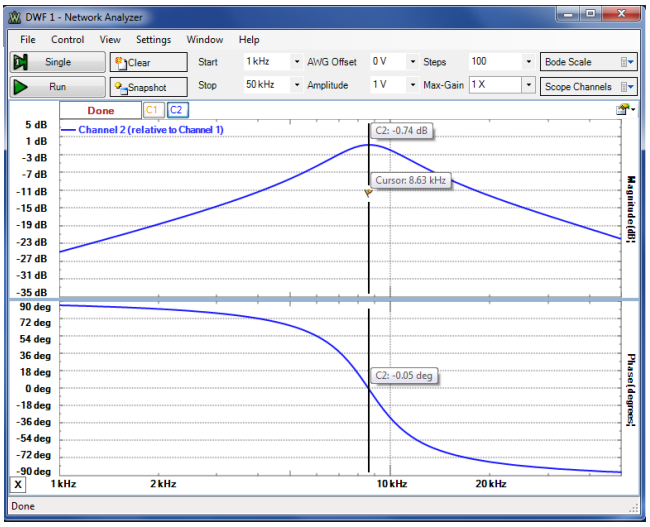

Fig. 5. (right) Bode plot of RLC circuit obtained using ADB network analyzer Appendix B

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