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# Curricular Enhancement to Support Activity-Based Learning in Introductory Circuit Analysis Courses

**Dr. Shiny Abraham, Tuskegee University**

Shiny Abraham is an Assistant Professor in Electrical Engineering Department at Tuskegee University. She received the B.E. degree in Telecommunication Engineering from Visveswaraiah Technological University (VTU), India in 2007 and Ph.D. from Old Dominion University, Norfolk, VA in 2012. Her research interests span the areas of wireless communication, cyber security, optimization using Game Theory and engineering education research. Her current research includes optimization in power systems, cyber security analysis in smart grids, software defined radios and cognitive radio networks. She is a member of the IEEE and ASEE, a technical program committee member for IEEE Globecom, ICC, ICCCN and VTC conferences, and a reviewer for several international journals and conferences.

**Dr. Naga Korivi, Tuskegee University**

Naga Korivi is an Assistant Professor of Electrical Engineering at Tuskegee University. His interests are in engineering education, and research in areas including silicon photonics and micro- and nano-technology for applications in sensing, life sciences, and energy.

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## Abstract

Traditional Circuit Analysis courses introduce undergraduate Electrical Engineering students to fundamental concepts of electric circuits and networks, while providing them hands-on experience in accompanying laboratory sessions. A drawback of this conventional approach is that it restricts student creativity and circuit-building and troubleshooting skills to the confines of a laboratory. This paper proposes the use of Analog Discovery Boards (ADB) in conjunction with regular classroom learning sessions and collaborative group sessions in order to create a stepping stone towards introducing active and design-based learning in introductory circuit analysis courses. This paper presents information on the implementation of ADB activities, and observations on formative and summative assessments.

## Introduction

Introductory Circuit Analysis courses are aimed at providing undergraduate students with a foundational knowledge of electric circuits, and preparing them for the Electrical Engineering (EE) Curriculum. These courses are conventionally taught as a combination of in-class lecture sessions and accompanying laboratory exercises, both tried and tested instructional methods. However, in addition to imparting knowledge, it is crucial that learning activities be designed to challenge students, stimulate their curiosity, and engage them in hands-on activities that are not limited to the laboratory [1].

This paper proposes the integration of an activity-based learning approach in the EE curriculum with the use of Analog Discovery Boards (ADB) by Digilent Inc. This enhancement allows students to build, analyze and visualize circuits using the USB-powered Analog Discovery platform, a personal computer, and a basic analog parts kit. This opens the door for a variety of learning activities that include in-class experimentation, take-home exercises, group activity sessions, and design-and-learn projects among many others. Our work aims to create an environment for a student that is conducive to innovation and creative thinking; while providing an experience of all three learning modalities: Visual, Auditory and Kinesthetic. Designing such hands-on sessions for students, ties theory and practice, and enables them to acquire technical skills that are crucial and necessary in the engineering workforce. The authors believe that experiments based on ADB type learning kits provide students useful hands-on experience in building and troubleshooting circuits with physical components, which is not possible by computer-based simulation activities. These ADB exercises are intended to help students carry this hands-on experience from the laboratory to a workstation at their homes or in lecture classes. Hence, the authors believe that ADB based experiments are more beneficial to students than corresponding simulation-only activities. The authors implemented these ADB experiments as a combination of in-class, take-home and laboratory exercises. The Circuits I and II lecture courses also have associated conventional laboratory sessions with experiments based on lecture topics.

The authors have employed formative and summative assessment tools to validate the efficacy of this approach as an effective pedagogical method when compared to traditional lecture-only-based methods. The formative assessment strategies include observations during class experiments and discussion sessions. The summative assessment strategies will focus on the outcome of the approach using tools like questionnaires, tests and projects. In addition, pre and post surveys will be administered in order to gauge the student's understanding and skill level before and after the hands-on experience. The AD boards have been partially integrated in Circuit Analysis I and II courses over the duration of two semesters, and the results, although preliminary, have been positive. Current and future work includes continued efforts for a comprehensive integration of the boards into the Electrical Engineering curriculum.

The underlying goal of this work is to promote innovation and creativity through education, and to better prepare undergraduates for careers in the electrical engineering workforce. The authors are affiliated with Tuskegee University, a HBCU (Historically Black Colleges and Universities), and hence their efforts are directed towards underrepresented minority students, however, the authors believe that this work will also be applicable to a broader spectrum of electrical engineering students in the United States.

## Overview of the Analog Discovery Board

The Analog Discovery is a USB-powered, small, portable, and low-cost multi-function instrument that was developed by Digilent in conjunction with Analog Devices Inc [2]. Its small-size and portability makes it ideal for use in a variety of environments to measure, record and generate analog and digital signals. Driven by the PC-based Waveforms software, the Analog Discovery can be configured to work as one of the several traditional laboratory instruments. Its functionalities include but are not limited to that of ±5V DC power supplies, two-channel oscilloscope, two-channel waveform generator, spectrum and network analyzers, voltmeter and digital input/outputs.

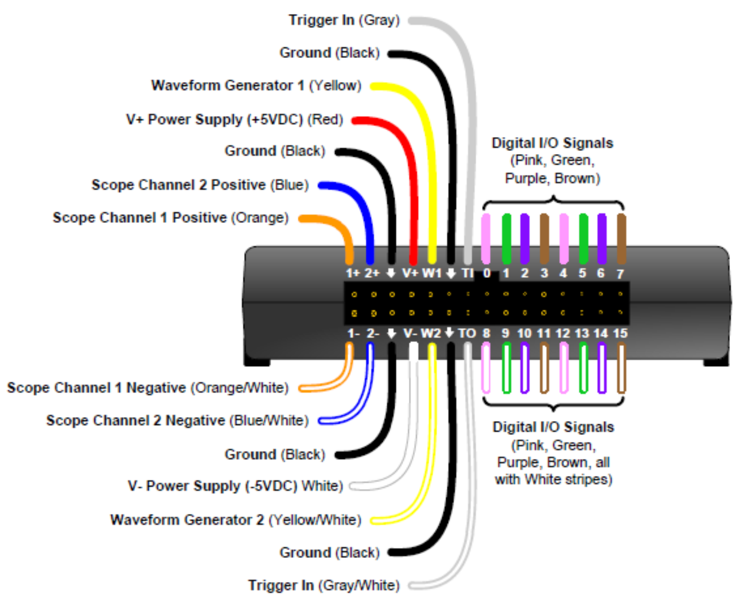


**Figure 1:** Pin-out diagram of the Analog Discovery [2]

## Implementation in the EE Curriculum

The authors integrated Analog Discovery based activities in their Circuit Analysis I and II courses over a period of two semesters. The following pedagogical engagement techniques exposed Freshman/Sophomore EE students to the ADB, and contributed to the development of an innovative and creative learning environment, both in-class and out-of-class.

a) Active and Collaborative Learning: The National Survey of Student Engagement (NSSE) has set five benchmarks of effective educational practice, one of which is active and collaborative learning [3]. Students tend to learn more when they are actively involved in the learning process and are challenged to find applications in real-world problems. Traditional engineering education is often mistaken to be "active learning" by default, owing to the fact that it is primarily problem-oriented, and that it has laboratory co-requisites. Prince [4] defined the core elements of active learning to be i) introducing activities into the traditional lecture and ii) promoting student engagement. Extensive research has been carried out in the area of collaborative/cooperative learning, the basic premise of which is the theory of social interdependence [1, 4, 5, 6]. Positive interdependence (cooperation) has proven to yield higher individual achievement when compared to negative interdependence (competition) or individualistic learning approaches. Collaborative learning also provides a natural environment that promotes effective teamwork and interpersonal skills, both of which are crucial requirements in the engineering workforce.

Choi et.al [7] presented a pedagogical approach that introduces active learning in power electronics courses by combining industrial-grade technology with interactive learning strategies to reinforce the basic concepts of power electronics. This approach was well-received by their students, most of whom chose to pursue graduate school or a career in the power/energy related area. An application of active learning in microwave circuit design courses was presented by Pejcinovic [8], wherein lecture and laboratory sessions were merged in order to enable students to design, build and test active and passive circuits, and receive immediate formative feedback from instructors. These initiatives cater to undergraduate students in their junior or senior years, and propose hands-on activities that are restricted to the laboratory. In their efforts to introduce active and collaborative learning in introductory circuit analysis courses, the authors of this paper have integrated Analog Discovery-based in-class and out-of –class group exercises in the course curricula. With in-class experiments, the process that leads to student activity and engagement is "learning", "doing" and "reflecting", while out-of-class experiments follow "recall", "doing" and "reflecting". Research has shown that introducing activity into lectures can significantly improve recall of information [4].

In both courses, students were trained on the use of the ADB, after which they were provided the boards for use throughout a semester. The Circuits I course had 21 students in total over the course of two academic semesters; Spring and Fall 2014, and the activity groups were chosen by the instructor. In this course, students worked in ad-hoc groups of two or three to build, visualize and analyze circuits based on concepts learned in class. Examples of those concepts include Voltage and Current Division, Series and Parallel Resistors, Kirchhoff's Current and Voltage laws, Nodal and Mesh Analysis, and Thevenin's Equivalent Circuits. The Circuits II course had 19 students in total over the course of the Spring and Fall 2014 academic semesters. In this course, students formed groups of two or three by their own choosing. In the Circuits II course, students were taught concepts such as AC voltage dividers, filters etc., and they conducted experiments using the board to simulate the functions of a function generator, and oscilloscope. All measurements were to be recorded, tabulated and subsequently analyzed by each student.

a) Design-based learning: Design-based learning is in itself a complex cognitive process. Consider the key distinction between convergent and divergent styles of questions/thinking/learning; Convergent questions attempt to converge on and reveal "facts", whereas divergent questions attempt to diverge from facts to the possibilities that can be created from them [9], and a greater part of the electrical engineering curricula focuses on developing convergent thinking. Successful electrical engineering graduates will be expected to contribute towards both traditional and emerging technologies, and hence it is imperative that our undergraduate students, the future engineers, have design skills that transcend a basic understanding of fundamental concepts. Dym [9] states that "effective inquiry in design thinking includes both a convergent component of building up to asking deep reasoning questions by systematically asking lower-level, convergent questions, and a divergent component in which generative design questions are asked to create the concepts on which the convergent component can act".

The authors have introduced simple design-based learning activities in their Circuits I and II courses using the Analog Discovery for a 'Design-your-own-circuit' experiment. Student teams are asked to design their own circuits based on certain constraints such as the minimum number of voltage sources, meshes, supernodes, target mesh currents and node voltages, AC voltage dividers, filters etc. Teams then build and analyze their circuits, record measurements, discuss observations and write a technical report. In addition to acquiring design skills, students acquire problem-solving, team-building, and technical communication skills.

## Evaluation and Assessment

The authors evaluated and assessed this integration over the course of two semesters Spring 2014 and Fall 2014.

*a)* Formative assessment: Since formative assessment takes place during the learning process, it could be considered as one of the easiest and quickest ways to observe and assess student growth. The primary goal of classroom observation and discussion is for the instructor to adjust ongoing teaching and learning based on the observations made and the feedback received. The authors observed that watching students in action, while they translated theory to practice, helped correct misconceptions and incorrect understandings of concepts at an early stage. Further observations include enhanced enthusiasm for participation in the learning process, a heightened awareness of individual contributions and accountability within the group, and a sense of camaraderie and empathy that shaped their ability to perceive and think differently than they normally do.

The authors believe that the single-most informative take-away from the Analog Discovery exercises was the observation that it boosted students self-confidence. Research has shown that effective use of student teams has powerful positive impacts on minorities and women in terms of achievement and attitudes [10, 11].

*b)* Summative assessment*:* A summative assessment was done by administering a survey to students of both courses after they had been provided experience on the ADB, and related learning of some electrical engineering concepts. The responses of the survey formed an important part of the summative assessment. Respondent data from surveys conducted in the semester of Spring 2014 are discussed here. A similar survey was conducted in Fall 2014, however, was not available at the time of preparing this manuscript. The survey consists of questions primarily designed to gauge the impact of the ADB–based experience provided to the students. Prior to administering the survey to the students, the authors encouraged the respondents to review the survey and seek clarification on any item they had difficulty in understanding. Where applicable, the authors elaborated on the meaning of certain words and phrases in the survey such as “Professional abilities”. The student responses to survey questions were typically in the form of selecting a numerical value or rank that they considered appropriate. In discussing the data from the respondents, the average score or rank value pertaining to specific survey questions are discussed below. Considering the sample size, it can be considered a reasonable approach to average the scores or ranks on the survey questions so as to provide a numerical value for the choices made by the students. Survey question #1 asked respondents to indicate their level of agreement on four statements pertaining to their experience with the ADB-based learning. Question #1 and its responses are shown in Figure 2. It can be seen that the average score is close to 1 in the case of the Circuits II course, indicating that the respondents strongly agree on the four beneficial aspects listed from their hands-on experience with the electronic boards. For the Circuits I course, the average score ranged between 1.57 and 2, indicating that the respondents in Circuits I agreed on the aspects of this question. The slightly higher average score in Circuits I may be attributed to the beginner level nature of students of this particular course.

| **Hands-on experience with the electronic board has:** | | | | | | |
|---|---|---|---|---|---|---|
| 1. Enhanced my understanding of nodal and mesh analysis / voltage divider circuits and their working | 1 | 2 | 3 | 4 | 5 | 6 |
| 2. Enhanced my understanding of the working of function generators, oscilloscopes, and the measurement of circuit parameters | 1 | 2 | 3 | 4 | 5 | 6 |
| 3. Given me experience on setting up linear circuit experiments on a breadboard and analyzing them | 1 | 2 | 3 | 4 | 5 | 6 |
| 4. Enhanced my general understanding of linear networks and circuits | 1 | 2 | 3 | 4 | 5 | 6 |

**1= Strongly Agree  2= Agree  3= Slightly Agree  4= Slightly Disagree  5= Disagree  6 = Strongly Disagree**

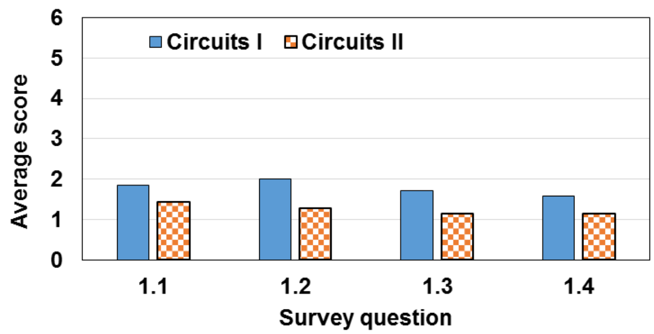


**Figure 2:** Student survey question #1 and average score of responses for this particular question.

Survey question #2 asked respondents to rank as per importance the four statements originally included in question #1. Question #2 and its responses are shown in Figure 3. In the case of Circuits II, the average rank in each case varied from 1.57 to 2.57. Question 2.3 received an average rank of 1.57, while question 2.4 had an average rank of 2.57. This indicates that the top ranking aspect for the Circuits II respondents was the experience gained in setting up and analyzing circuit experiments at a breadboard level. The worst ranking (least important) aspect was Question 2.4, the enhancement of the respondents' general understanding of linear networks and circuits. In the case of Circuits I respondents, the average rank ranged between 2.71 and 3.57 with Question 2.4 receiving the best rank (most important) and Question 2.1 receiving the worst ranking (least important). The differences in average ranks for the same questions among respondents of Circuits I and Circuits II is indicative of what they perceive to be important at their respective academic levels. Beginner level students (Circuits I) may find the ADB as an avenue to improve their overall understanding of circuits, while slightly more advanced students (Circuits II) may have a tendency to focus more on the aspect of building and analyzing circuits at the local level.

| Hands-on experience with the electronic board has: | Rank |
|---|---|
| 1. Enhanced my understanding of nodal and mesh analysis / voltage divider circuits and their working | |
| 2. Enhanced my understanding of the working of function generators, oscilloscopes, and the measurement of circuit parameters | |
| 3. Given me experience on setting up linear circuit experiments on a breadboard and analyzing them | |
| 4. Enhanced my general understanding of linear networks and circuits<br>**Numerical rank from 1 to 4 in order of decreasing importance** | |

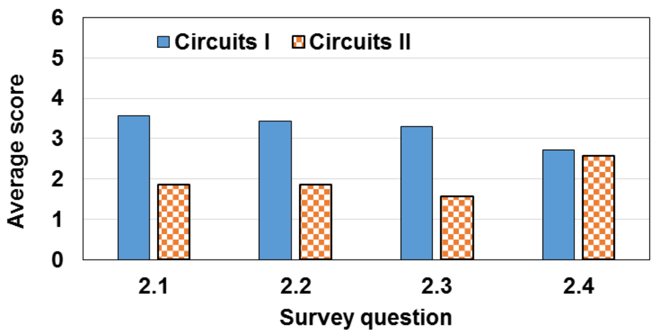


**Figure 3:** Student survey question #2 and average score of responses for this particular question.

Survey question #3 asked respondents to indicate their level of agreement on four statements pertaining to the length and breadth of the ADB-based learning experience. Question #3 and its responses are shown in Figure 4. The average score for Question 3.1 is very close to 1 for both courses, indicating that the respondents strongly agree that it would be more beneficial if they had the boards for the entire duration of the semester during the course. Question 3.2 had an average score only slightly higher than 1 for both courses, again indicating that most of the students strongly agree that it would be more beneficial if the boards were given to them during the entire course of their degree. Question 3.3 had an average score of 1.71 (which is closer to 2) for both courses. This means that the students of both courses agree that it would be more beneficial if the board was incorporated in a broader spectrum of electrical engineering lab courses. In the case of Circuits I, Question 3.4 scored an average of 1.71, which is closer to 2, while Circuits II had an average score of 1.29, which is closer to 1. This indicated that the Circuits II students strongly agreed on the benefits of having the board incorporated in a broad spectrum of lab and lecture courses in electrical engineering. The slightly higher score in the case of Circuits I can be attributed to the beginner level nature of students of this particular course.

| **I would consider it more beneficial if:** | | | | | | |
|---|---|---|---|---|---|---|
| 1. The board was given to me for an entire semester during this course | 1 | 2 | 3 | 4 | 5 | 6 |
| 2. The board was given to me for the entire duration of my degree | 1 | 2 | 3 | 4 | 5 | 6 |
| 3. This board was incorporated in a broader spectrum of electrical engineering lab courses. | 1 | 2 | 3 | 4 | 5 | 6 |
| 4. This board was incorporated in a broader spectrum of electrical engineering lab & lecture courses. | 1 | 2 | 3 | 4 | 5 | 6 |

**1= Strongly Agree** **2= Agree** **3= Slightly Agree** **4= Slightly Disagree** **5= Disagree** **6 = Strongly Disagree**

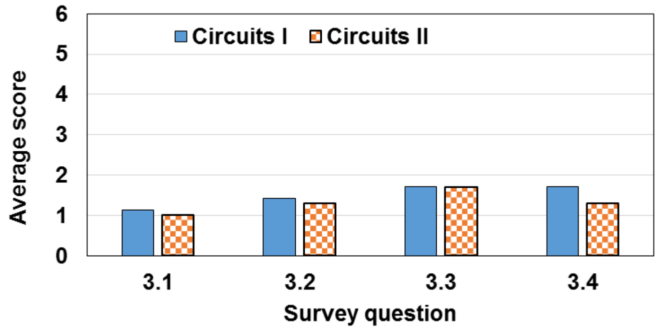


**Figure 4:** Student survey question #3 and average score of responses for this particular question.

Survey question #4 asked respondents to indicate their level of agreement on a statement pertaining to the overall beneficial nature of the ADB learning experience. Question #4 and its responses are shown in Figure 5. In the case of Circuits I, 4 out of 7 respondents strongly agreed that the electronic board based learning tool was a beneficial learning experience, while 2 students indicated agreement. In the case of Circuits II, it can be seen that 6 out of 7 respondents indicated strong agreement.

**Overall, I believe the use of portable hands-on hardware in experiments and lectures for this course has helped me learn more i.e. it was a beneficial learning experience.**

**(Circle one)**

**Strongly Agree    Agree    Neutral    Disagree    Strongly Disagree**

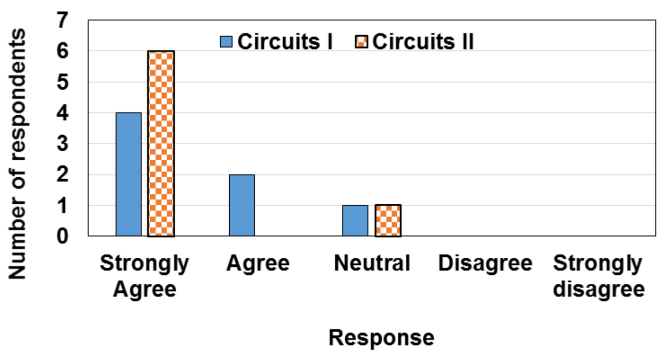


**Figure 5:** Student survey question #4 and average score of responses for this particular question.

Survey question #5 asked respondents to indicate their level of agreement on a statement pertaining to the overall improvement of professional abilities due to the ADB learning experience. Question #5 and its responses are shown in Figure 6. It can be seen the most of the respondents strongly agree that the use of the electronic board as a learning tool has enhanced their professional abilities.

**Overall, I believe the use of portable hands-on hardware in experiments in this course has improved my professional abilities.**

**(Circle one)**

**Strongly Agree** **Agree** **Neutral** **Disagree** **Strongly Disagree**

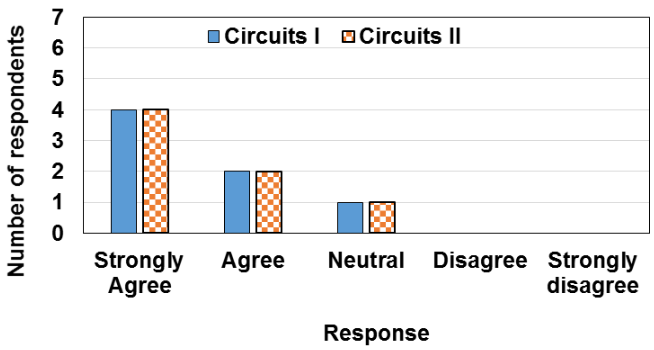


**Figure 6:** Student survey question #5 and average score of responses for this particular question.

Question #6 asked respondents to indicate their level of confidence in engineering at the end of the course. Respondents had to indicate this on a scale from 1 to 10 in the order of increasing confidence. Question #6 is shown in Figure 7. In the case of Circuits I, the average score was 8.43, close to halfway between 8 and 9, while for Circuits II, the average score was 8.86 which is closer to 9, corresponding with "high confidence". These responses agree well for the future use of tools such as electronic boards to enhance the students' learning experience.

**Please indicate your level of confidence in engineering at the end of this course.**

**(Circle one)**

**Low Confidence** **High Confidence**

**1 2 3 4 5 6 7 8 9 10**

**Figure 7:** Student survey question #6.

Another part of the summative assessment consisted of evaluating students' performance on exam problems on specific topics on which students gained prior ADB-based learning experience. There was at least one assigned problem on each of the selected topics. These same exam problems were given to another group of students in a prior semester (Spring 2014 for Circuits I/ Fall 2013 for Circuits II). All assigned problems were graded by the authors who were also the instructors for the Circuits I and Circuits II courses. Average grades scored in these questions in both courses are shown in Table 1. It can be observed that average grades increased in second semester when compared to the first. This may be attributed to the improved competence and confidence gained by the students in these topics as a result of the ADB based learning experience. In the case of Circuits II course, the difference in average grade does not appear significant, but somewhat appreciable (86.2 vs. 90). While further studies and more data could provide further elucidation in this context, the authors consider this difference indicative of the positive influences of the hands-on ADB activities on student learning.

**Table 1:** Average grade (%) in exam problems on specific topics.

| **Course & Semester** | **Average grade (%) in topic(s) evaluated** | |
|---|---|---|
| | **Source transformation** | **Thevenin's theorem** |
| **Circuits I (Spring 2014)*-before** | 59.3 | 47.8 |
| **Circuits I (Fall 2014) - after** | 84.4 | 62.5 |
| | **RLC circuits** | |
| **Circuits II (Fall 2013) - before** | 86.2 | |
| **Circuits II (Spring 2014) **- after** | 90.0 | |

*The ADB experience was introduced to Circuits I students in the second half of the Spring 2014 semester.
** Survey data is sent to third-party evaluators for assessment, and this data for the Circuits I and II courses were only available for Spring 2014. Embedded assessment data for Circuits I was available for Spring and Fall 2014, and this data for Circuits II was only available for Fall 2013 and Spring 2014.

The observations presented here indicate several positive outcomes from the use of the ADB to provide learning experiences. The positives include increased student interest in the course topics; increased student understanding of concepts, and improved confidence level in engineering in general. Overall, a high percentage of the students strongly agreed that the use of the boards provided a beneficial learning experience. The surveyed students overwhelmingly indicated a preference for more extended experiences in incorporating the boards in their learning. It should be noted that these are preliminary observations from small sample sizes. Consequently, it will be useful to conduct evaluation over larger sample sizes and over extended periods of time.

## Conclusion

Extensive research evidence has demonstrated the positive impacts of activity-based learning in student engagement, recall of information, innovation and creative thinking. This paper proposes the use of Analog Discovery Boards in introductory circuit analysis courses, and presents preliminary results that are supported by formative and summative assessment strategies. Overall, students enjoyed the exposure, and they believe that this curricular enhancement was a beneficial learning experience.

Future work includes integration of the Analog Discovery in higher level Electrical Engineering courses, Capstone projects, and undergraduate research projects. The impact of this effort on the transition of students between consecutive courses will also be studied.

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