Assessing Potential Impacts an Experimental Centric Approach can have in an Introduction to Digital Electronics Course

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Abstract

The electrical engineering program at Hampton University is engaged in a project to develop, implement, and expand an Experimental Centric Pedagogy (ECP) that is adaptive to a wide variety of fields. The ECP is being implemented at the various electrical engineering programs at Historical Black Colleges and Universities (HBCUs) to allow students of varying learning styles the opportunity to learn at their own pace and in their own environments, by providing them an alternative way to acquire technical skills and knowledge both in the classroom and outside. As the department is implementing the ECP approach across the curriculum, various courses have been targeted for primary implementations (i.e. Introduction to Engineering, Electric Circuits, and Engineering Electronics). In addition to these courses, the expansion of the implementation also focuses on other courses such as Introduction to Digital Electronics. In preparation for implementation in Digital Electronics, an assessment study was conducted using expected student outcomes based on comprehensive final exams for the past 8 years from a single instructor. The assessment study identified the following distinct questions on: (1) number conversion systems; (2) binary arithmetic; (3) basic logic gates; (4) Boolean algebra; (5) sum of products and Karnaugh mapping; (6) application of combinational circuits; and (7) application of sequential circuits, which were used to measure nine expected learning outcomes in the course. The assessment was used to identify topics to primarily focus on in regards to the implementation of ECP in digital electronics. The outcomes were categorized in three levels (<50%; 50-75%; >75%) to evaluate current proficiency. The evaluation shows that on average one outcome is in <50% level of performance, which is below basic understanding and three outcomes are in the basic understanding level(50-75% range). Therefore, the ECP approach does have potential to impact the expected student learning outcomes.

Keywords

Digital Electronics, Experimental Centric Pedagogy

Introduction

Among 14 National Academy of Engineering grand challenges is the challenge for engineers to advance personalized learning. Personal learning approaches range from modules that students can master at their own pace to computer programs designed to match the way it presents content with a learner's personality[1]. The engineering community is challenged to develop and implement educational models that engage students and embrace the computer enhanced pedagogical approaches. As a way to keep students engaged, multiple educational delivery models are continually enhanced for electrical engineering lectures and labs to allow learners to explore the realm of knowledge at their own pace. The delivery models can be categorized as traditional, web enhanced, online, or hybrid models. The traditional model approach is where the instructor offers face-to-face instruction in class and in labs. The web enhanced model could be defined as an enhancement to the traditional model through the use of an internet based course management system to handle course administration, assessment or content delivery while maintaining face contact with instructors. When the course delivery is completely web-based without any face contact with the instructor, the model is considered to be online. This model has generally been considered not to be ideal for electrical engineering on the basis of the need for hands-on laboratory activities. However, Astatke et al[2,3,4] at Morgan State University have demonstrated that the online delivery is possible through the Mobile Studio technology and pedagogy. An alternative model to the completely online delivery is a hybrid approach where the lecture material is delivered online and the students have face meetings for the labs.Swayne[5] showed that the hybrid model helped improve student interaction during the week. Swayne committed to develop simpler lectures incorporating an equal activity to better engage students plus added more pre-recorded video screen-shot examples, and short answer problems to the homework database. The instructor's commitment and effort in developing a hybrid course is similar to online model development as pointed out by Ernst[6] in concluding that the success of online education begins with the faculty commitment to the pedagogical model, particularly, with assessment. In 2010, it was reported that the 17 percent growth rate for online enrollments was significantly higher than the 1.2 percent growth rate of the overall higher education student population during the same time period[7].These studies have shown the need for new education delivery models to advance personalized learning or learning anywhere at any time so that students are active agents of their learning. In comparison, traditional classroom environments have been criticized for not providing essential contextual features that enable students to understand and apply information.[8]

The electrical engineering program at Hampton University is engaged in a project to develop, implement, and expand an Experimental Centric Pedagogy (ECP) that is adaptive to a wide variety of fields. The ECP is being implemented at the various electrical engineering programs at Historical Black Colleges and Universities (HBCUs) to allow students of varying learning styles the opportunity to learn at their own pace and in their own environments. The ECP focuses on students having tools to verify concepts, tinker anywhere and at anytime as one would do in a traditional lab setup. The concept has been developed from similar approaches such as Mobile Studio at Rensselaer Polytechnic Institute[9,10], Tessal at Georgia Tech[11],and Lab-in-Box at Virginia Tech[12]. The approach provides an alternative way to acquire technical skills and knowledge both in the classroom and outside. As the department is implementing the ECP approach across the curriculum, various courses have been targeted for primary implementations (i.e. Introduction to Engineering, Electric Circuits, and Engineering Electronics). In addition to these courses, the expansion of the implementation also focuses on other courses such as Introduction to Digital Electronics.

Digital Electronics Course

In preparation for implementation in Digital Electronics, an assessment study was conducted using expected student outcomes based on comprehensive final exams for the past 8 years (2007 – 2014). The assessment was based on 117 students and an average of about 15 students per class with one section per year and taught by the same instructor. The average grade point average (GPA) for the students at the beginning of the course was an average of 3.04 on a 4.00 scale and the averages for each year are shown in Figure 1.

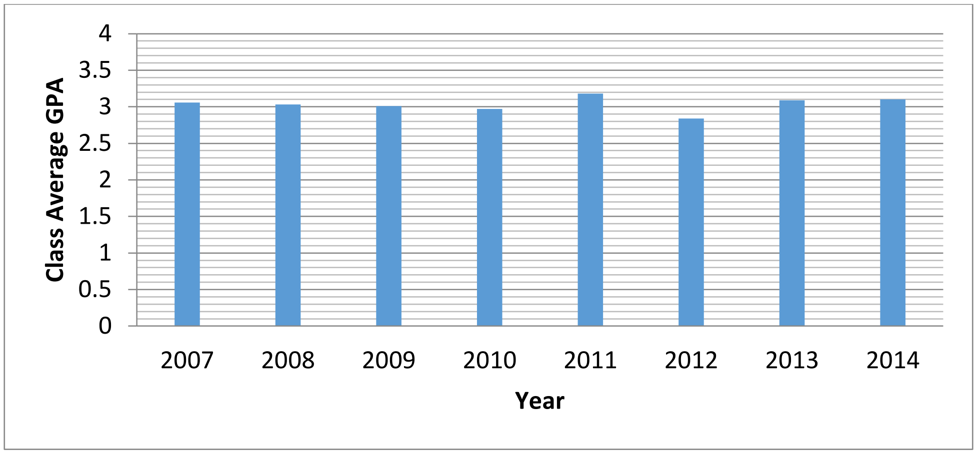

Figure 1: The Average GPA for the Digital Electronics Students

The general course is described to cover boolean algebra, combinational circuits, sequential circuits, analysis and design of sequential systems, multi-input system controllers, and asynchronous system design. In order to evaluate the outcomes of the course, the assessment study identified the following type of questions on: (1) number conversion systems; (2) binary arithmetic; (3) basic logic gates; (4) Boolean algebra; (5) sum of products and Karnaugh mapping; (6) application of combinational circuits; and (7) application of sequential circuits, which were used to measure nine expected learning outcomes in the course.

These questions addressed the following nine basic learning outcomes for the course:

1. Convert between various number systems.
2. Perform arithmetic operations in different number systems.
3. Apply basic laws of Boolean algebra and explain basic logic operations.
4. Evaluate Boolean expressions.
5. Analyze, interpret, and construct simple digital circuits.
6. Analyze, interpret, and construct timing diagrams related to basic gates and simple digital circuits.
7. Use Karnaugh maps and Boolean algebra to simplify circuits.
8. Describe basic combinational circuits such as encoders, decoders, and multiplexers.
9. Describe basic sequential circuits such as flip flops, registers, and counters.

This course was instructed as a lecture-only course and students did not generally get to construct physical circuits except for software simulations. In addition to electrical engineering students, other majors (Music Recording Technology, Math, and Chemical Engineering) did take the course during the period of assessment. Observations from a subsequent digital design course 1-2 years later have shown that the EE students did not retain the introduction to digital electronics knowledge as expected. Literature reviews[2-4,9-12] have shown that the experimental centric pedagogy approach may help students retain the knowledge as well as advance knowledge through portable hands on experimental technology. In the following sections, the results of the digital electronics comprehensive exams are presented based on the different concepts to help direct the prioritization for the ECP module development and use.

Table 1: Matched Question Types and Learning Outcomes

Question Type	Question Description	Outcome #
1	Number Conversion Systems	1
2	Binary Arithmetic	2
3	Basic Logic Gates	3,5,6
4	Boolean Algebra	3,4,7
5	SOP, K-MAP Simplification	4,5,7
6	Combinational Circuits	8
7	Sequential Circuits	9

The comprehensive exam finals were evaluated and scores captured per problem and each problem in the exam was either one of seven question types stated above. Table 1 matches the question type with the learning outcomes. Question type 4, 5, and 7 addresses multiple outcomes. This implies that in order for a student to be proficient in outcome 3 for example, they are expected to be proficient in both questions type 3 and 4 combined. Similarly, outcome 4 and 7 is based on question type 4 and 5. Three categories of proficiency are used: Level 1 (≥75%), the expected proficiency; Level 2 (50-75%), basic understanding; and Level 3 (<50%), not meeting basic understanding.

Number Conversion Systems

As a foundation to digital electronics, all the digital electronics students in the course are expected to have a better than 75%proficiency in the understanding of number system and codes. Every comprehensive exam had a question on the conversions between the binary, decimal, BCD, octal, and hexadecimal number systems. The comprehensive exam assessment on the student outcome on this question is shown in Figure 2 for the course offered every fall semester from 2007 to 2014.

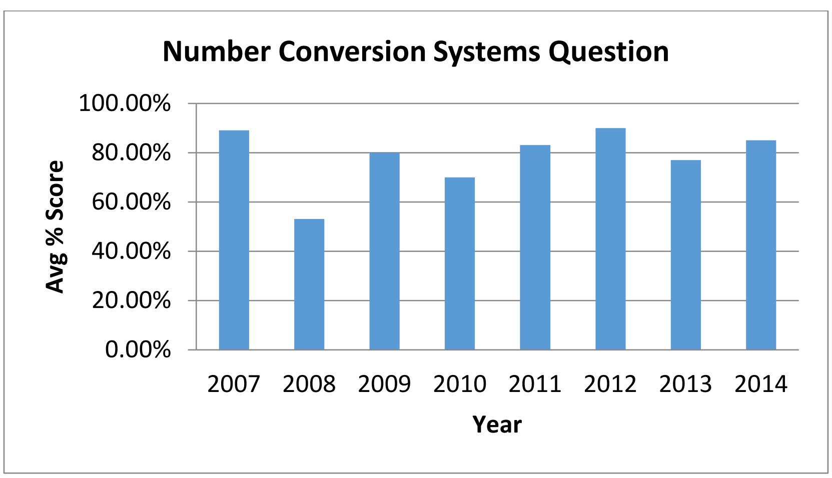

Figure 2: Overall Students Scores on Number Conversion Systems Questions

The overall outcome over the 8 years shows that the average score for 2008 was only 53% and in 2010 was at 70%; however, further analysis indicated that among electrical engineering majors the average score was actually 88% for 2008 and 80% for 2010 as illustrated on Figure 3.

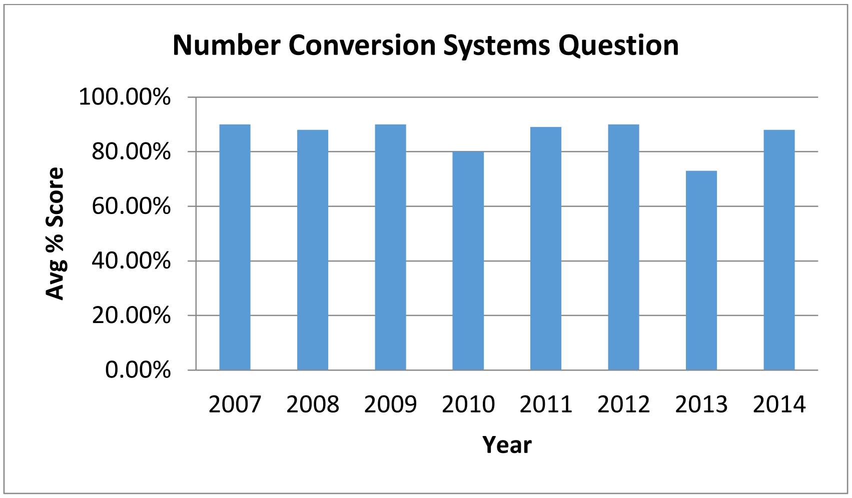

Figure 3: EE Students Scores on Number Conversion Systems Questions

During 2013, the EE students averaged 73% on this question and this outcome is mainly attributed to the fact that there were only 7 EE students and one student performed dismally; therefore rendering the score below the targeted proficiency level. In general, the EE students were 86% proficient in number conversion systems.

Binary Arithmetic

The students were expected to demonstrate understanding of the binary addition (and subtraction) as the basic arithmetic function especially using two's complement. The students are generally expected to convert positive and negative numbers to signed two's complement notation and performing the two's complement arithmetic. In addition they have to utilize the full-adder ICs to implement arithmetic circuits. The results indicate that in 2012 and 2013 the EE students on average achieved only basic understanding in binary arithmetic as illustrated in Figure 4.

The overall class and the EE students scored 74% and 73% in 2012 and 54% and 57% in 2013 respectively, which indicates that there was no difference between the EE students and the class in understanding this concept. A close look at the 2012 results showed that there were 2 students (1-EE, 1-MRT) who scored well below basic understanding causing the proficiency level to drop below the expected 75%. In 2013, 3 students (2-EE, 1-MRT) scored well below basic understanding causing the proficiency level to drop significantly and the impact of the 3 student scores had added significance due to the fact that there were only 7 EE students in the class.

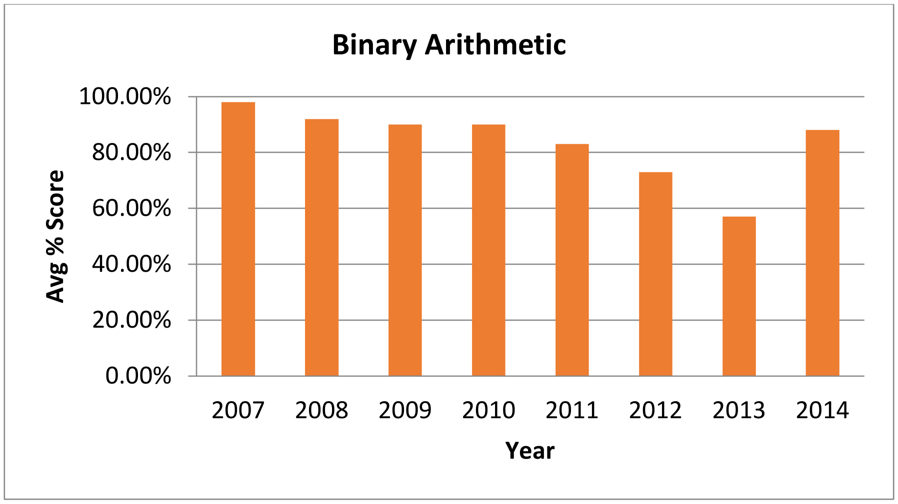

Figure 4: EE Students Scores on Binary Arithmetic Questions

Basic Logic Gates

In questions dealing with basic logic gates, the students are expected to demonstrate the understanding of basic gates through interpreting the symbolic representations, Boolean equations, truth tables, and timing diagrams. On average, the EE students were proficient at above 75% over the 8 years as illustrated in Figure 5. Additionally, all majors were proficient at above 75% in this question type.

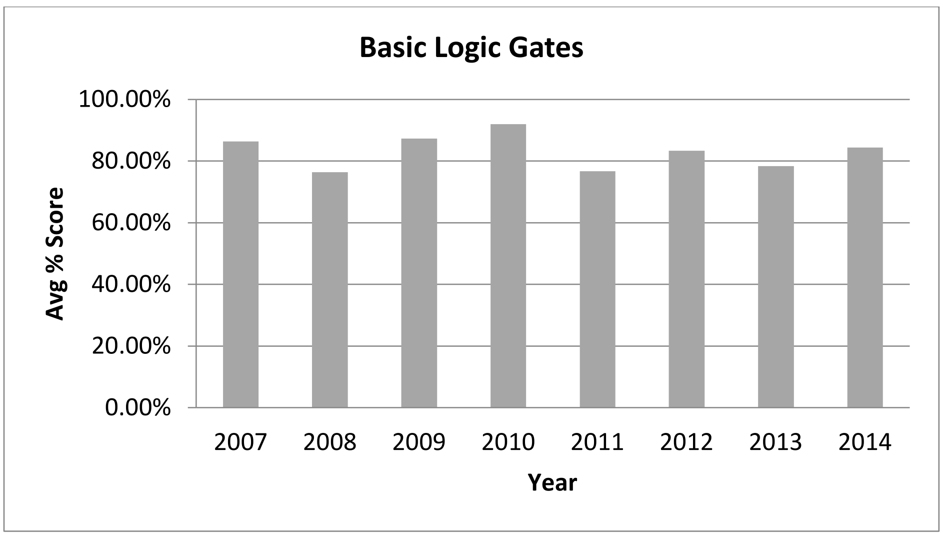

Figure 5: EE Students Scores on Basic Logic Gates Questions

Boolean Algebra

The application of Boolean laws and rules are critical to the understanding of digital electronic circuits design as this allows student to start tackling complex Boolean equations. The expectation from this question is that the students will demonstrate the utilization of Boolean laws, rules, and theorems to simplify Boolean equations to accomplish simplified equivalent circuits.

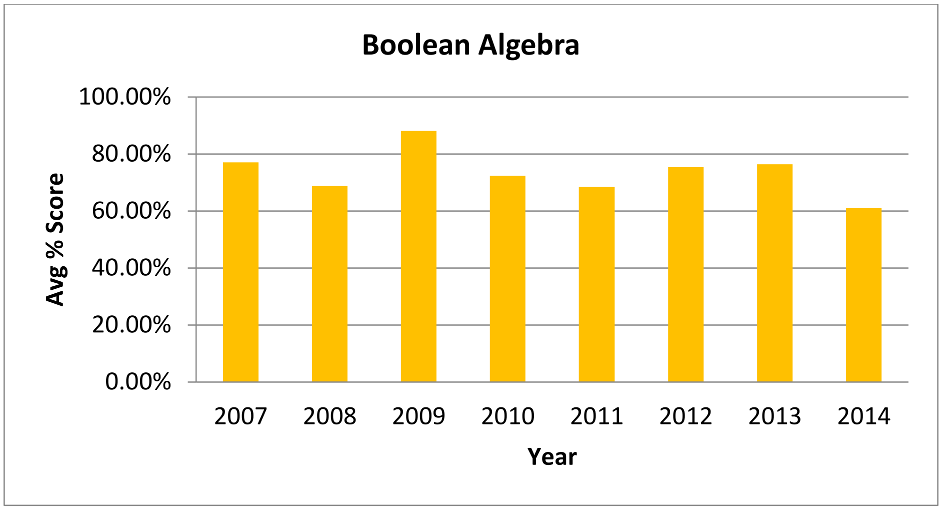

Figure 6: EE Students Scores on Boolean Algebra Questions

The students demonstrated that they had basic understanding of the application of boolean algebra throughout all 8 years and met the expected 75% average score in 4 out of 8 years. The trends were similar for both EE-students and all the other majors.

SOP and Karnaugh Mapping

The application of Boolean algebra in simplifying combinational circuits was continued in utilization of the sum of products (SOP) and Karnaugh mapping procedure to systematically reduce complex equations to their simplest form.

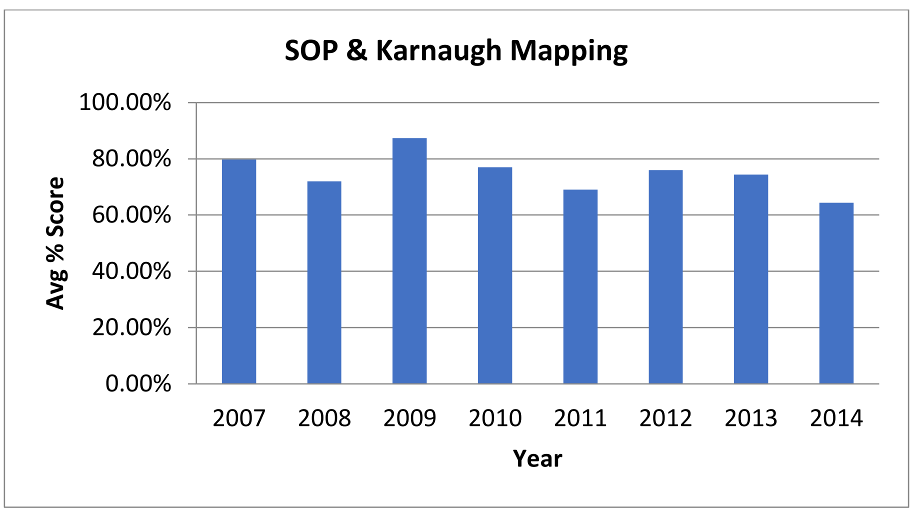

Figure 7: EE Students Scores on SOP and Karnaugh Mapping Questions

The evaluation of this question type was closely related to the response to the Boolean algebra question as expected. The EE students demonstrated that they had basic understanding of the application of sum of product concept and Karnaugh mapping all the years and met the expected 75% average score in 4 out of 8 years. The trends were almost similar for both EE-students and all the other majors; however, the year to year scores for this question type were slightly higher than the Boolean algebra questions. The overall class met the expected level 1 score in 3 out of 8 years.

Application of Combinational Circuits

This question is used to evaluate the understanding of functional logic circuits such as encoders, decoders, multiplexers, demultiplexers, parity circuits, adders, and comparators. The application of the knowledge obtained in conversion number systems, binary arithmetic, and basic logic gates is also demonstrated in this question type. The students are expected to describe the function of each combinational circuit including the basic design of the internal and external circuitry to perform the desired application. In addition, they should be able to utilize the various IC's to perform the required operations or applications. Although the level 2 basic understanding criteria were satisfied for all the years, it was barely met in 2009 for EE students. On average all majors did not meet the basic understanding level averaging a score of 40% in 2009. Over the 8 year period, this question type response met the expectation of 75% for 3 out of 8 years and 2 out of 8 years respectively for EE students and all majors. Therefore, the subject matter of combinational circuits should be considered for early ECP module implementation.

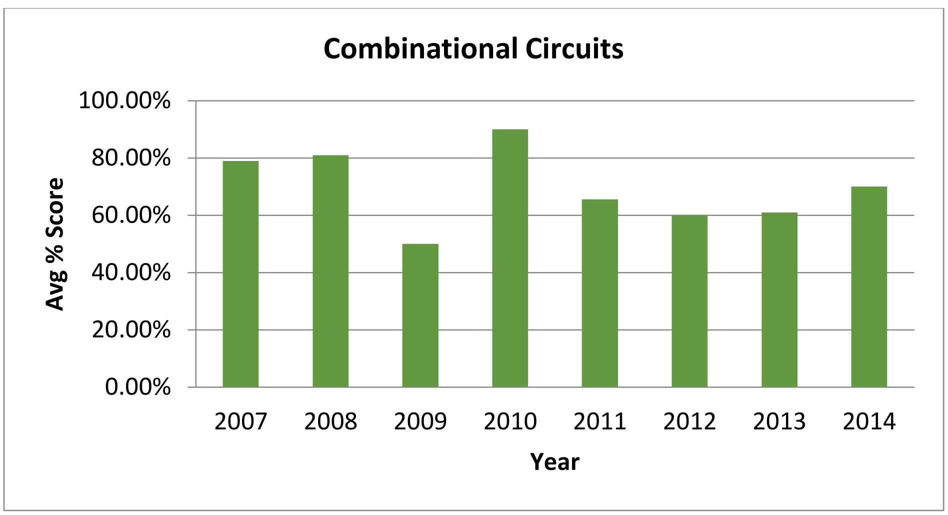

Figure 8: EE Students Scores on Combinational Circuits Questions

Application of Sequential Circuits

The understanding of sequential circuits building blocks are primarily tested in this question type along with basic applications such as registers and counters. Figure 8 shows that the EE students mainly gain basic understanding on this question type and only managed to meet at least the basic understanding level 5 out of 7 years. The same trend is true for all majors. Historically, it appears students have struggled with this question type on the comprehensive exams and there are multiple factors that have attributed to this issue. Since the topic is normally addressed towards the end of the semester, it could be speculated that students tend to engage in end of semester projects, as opposed to new class material. In 2012, this question type was not presented to students on the final exam. The use of ECP could offer opportunities for students to engage in learning the subject of sequential circuits to meet the expected level of proficiency.

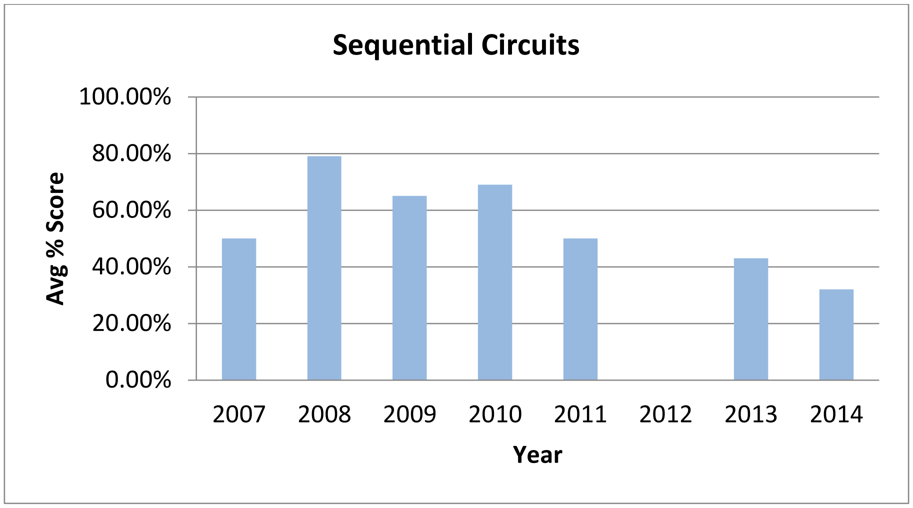

Figure 9: EE Students Scores on Sequential Circuits Questions

Experimental Centric Pedagogy Outlook and Conclusion

The goal of the ECP project is to create a sustainable network of engineering faculty at HBCUs to focus on the development, implementation, and expansion of an experiment-centric instructional pedagogy, based on Mobile Studio and other similar platforms like Analog Discovery. At Hampton University, the approach is currently in the first phase of implementation in 6 courses namely: Introduction to Engineering, Introduction to Digital Electronics, Electric Circuits I & II, and Engineering Electronics I & II primarily using the Digilent Digital Analog Discovery platform. Currently, the USB powered platform is loaned to students on a semester by semester basis. The platform allows the students to measure, visualize, analyze, record, and control mixed signal circuits from a computer through a free WaveForms software interface and a solderless breadboard. Students are now building and testing analog and digital circuits in virtually any environment. The capabilities of this platform include: 5V DC power supply, a 2-channel oscilloscope, 2 channel waveform generator, 16-channel logic analyzer, 16-channel digital pattern generator, spectrum analyzer, network analyzer, voltmeter, and digital I/O.

Based on the analysis of the past student performances, four student outcomes were below the desired proficiency levels for electrical engineering students as shown above. Outcome 8 (basic combinational circuits such as encoders, decoders, and multiplexers) and outcome 9 (basic sequential circuits such as flip flops, registers, and counters) can be directly addressed through the ECP approach.

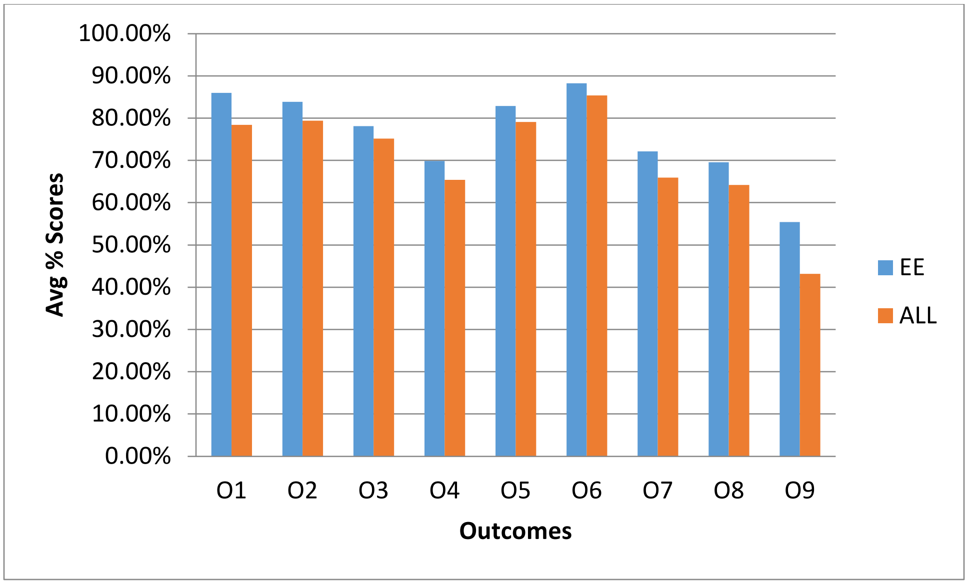

Figure 10: 2007-14 Average EE and Overall Student Outcome Proficiencies

As for outcome 4 and 7, both are centered in understanding Boolean algebra concepts. The challenges with these outcomes could be attributed to broader mathematics (algebra) problem that a few students tend to have. The same trend was also observed from non-EE students as shown in Figure 10. In review of all the comprehensive exams outcomes, all EE students are achieving the basic understanding of the 9 learning outcomes for the course; however, 4 of the outcomes do need improvements beyond basic understanding. When considering all students taking the class, one outcome (basic sequential circuits such as flip flops, registers, and counters) is below basic understanding (<50%) and 3 outcomes are in the basic understanding range. It should be noted that the comprehensive exam only contributes 20% of the course grade; therefore, this assessment is not a reflection of the student grades in the course. Additionally, the passing grade for EE students was a C or better, whereas Music Recording Technology students only required a D grade. This could be another explanation to the level of learning outcome differences in addition to the fact that most non-EE majors took the class to fulfill their graduation requirements during their senior year.

As a result of the assessment and beginning in the fall of 2015, 2-week project activities were assigned to address outcomes 8 and 9. As an example, an introduction module to combinational circuits focused on:

- Examining characteristics of a quad AND-gate chip.
- Verifying AND-gate logic through circuit construction.
- Examining characteristics of a quad OR-gate chip.
- Verifying OR-gate logic through circuit construction.
- Observing input/output waveforms for both AND and OR gates.

Another module on sequential circuits focused on:

- Examining internal schematic of an S-R Flip-Flop.
- Examining internal schematic of a Gated S-R Flip-Flop.
- Examining internal schematic of a J-K Flip-Flop.
- Examining internal schematic of a Master-Slave J-K Flip-Flop.

- Observing and verifying input/output waveforms of constructed Flip-Flops (constructed using basic logic gates).

The results of the student outcomes from this effort will be examined in the future after exposing the approach to the student multiple times.

Acknowledgements

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