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Enhancing Student Learning via Hardware in Homework

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I. Introduction:

An important problem that has come up over the years in some engineering programs is the loss of laboratory experiences in favor of more theoretical emphasis in upper division courses. In Electrical Engineering (EE) curriculums, the majority of programs now include laboratory work only in introductory courses such as circuits and logic design [1]-[3]. Advanced courses such as Electronics II, Communications, and others have lost their labs due to the curriculum changes and the tendency becoming more towards the theoretical from the practical. Many faculty over the years have regretted the loss of the "hands on" experience of lab work. Theory courses most often lack the hands-on experience that is given traditional lab courses and do not resonate well with the students without the lab component [4].

In order to rectify the problem, software simulations have been proposed to replace the lab component. While simulations can be used to reinforce concepts, they could not adequately present problems that students could encounter in a real laboratory, nor would they provide the appropriate hands-on experience necessary for effective learning [5], [6]. Despite the fact that the courses can greatly be supported by simulation tools, having hands on experience is still invaluable, especially to the ones that are "experiential learners".

We have successfully integrated laboratory experiences into purely theoretical courses via Hardware-in-Homework (HiH) concept without requiring any change on course credits.
In HiH, students are given lab work that they would complete using their portable lab kit or using their own lab using the lab-in-a-box approach. This would allow courses that either never had a lab experience or lost the lab experience to increasing amounts of material to be covered under restricted lecture time to result in a value added lab experience.

Our lab-in-a-box approach at Lamar University (LU) uses Analog Discovery Kit with its unique measurement features. Analog Discovery is a low-cost, portable test and measurement kit (see Fig.1) that includes a range of instruments that can be operated or observed using a USB port on any computer [3], [7]-[9]. This is a real hands-on lab where students create simple circuits, test them with waveforms and switch closures, collect analog and digital data, monitor outputs, and analyze the results in this real-world lab. They can do it at their own speed and at their leisure, without having to share lab space or equipment [9].

At Lamar University Electrical Engineering (LUEE), students purchase the Analog Discovery kit during their freshman year as part of their course enrollment requirement around $250 and they acquire the knowledge and know how to conduct the experiments using the module.
We consider this burden to be small since our students use it during their four years at LU, and its cost is comparable to that of an engineering textbook.

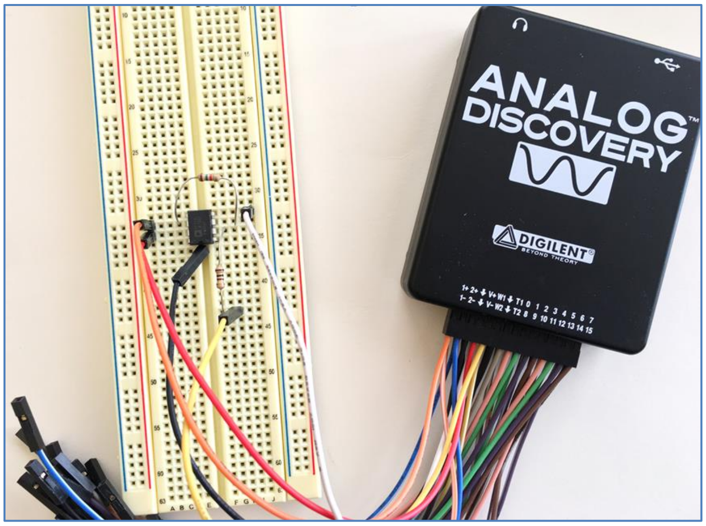

Figure 1. Lab-in-a-box using Analog Discovery

There are less expensive alternatives to the lab-in-a-box solution that can also be used for HiH assignments. The company that involved in the development of the original Analog Discovery unit now offers a similar hardware module "ADALM2000" at a lower price (currently $150) yet having similar capabilities. The Analog Discovery module was chosen over the ADALM2000 because of its software as it has more advanced features such as external triggers and a more user-friendly user interface.

II. Integration of the HiH Assignments into Junior Electronics II Course

Starting early spring 2018, the HiH concept has been integrated into the junior level ELEN 3322 Electronics II course via an online laboratory component without requiring any change on the course credits. The class enrollment for the ELEN3322 course was 42 students.

In order to examine the impact of HiH concept on student learning, the classroom has been divided into two groups: the simulation and the hardware-in-homework group. Half of the students (21 students) in Electronics II class have randomly been selected to participate in the trial. Since, students have previously purchased the Analog Discovery kit during their freshman year for their online laboratory courses; all students had the knowledge on how to conduct the experiments using the hardware module. For those needing assistance, the previous tutorial materials regarding Analog Discovery have been made available via Blackboard Learning Management Systems (LMS). The selected group was able to easily adopt the online laboratory and perform the HiH experiments using their kits. The remainder of students performed Multisim software simulations.

A total of twelve new experiments have been designed: six experiments for the simulation group, and another six for the hands-on laboratory group. The experiments designed for simulation and online labs were made almost identical to allow a better comparison of the skills gained. Both groups were assessed on the same deliverables during the semester: a written lab report summarizing the following characteristics, objective of the experiment, data acquisition, data analysis, discussion and error analysis, comparison with theory, calculations and derivations, conclusions drawn, overall technical understanding.

Below is the list of experiments designed for the hardware group:

- HiH Lab- 1: Passive RL filter
- HiH Lab- 2: Passive RC filter
- HiH Lab- 3: Band-pass filter
- HiH Lab- 4: Active High-pass filter
- HiH Lab- 5: Basic 2 transistor BJT current mirror
- HiH Lab- 6: Widlar Current Source

And the experiments for the simulation group were:

- Simulation Lab- 1: Passive RL filter
- Simulation Lab- 2: Passive RC filter
- Simulation Lab- 3: Band-pass filter
- Simulation Lab- 4: Active High-pass filter
- Simulation Lab- 5: Basic 2 transistor BJT current mirror
- Simulation Lab- 6: Widlar Current Source

As an example, Fig. 2 below shows Active High Pass Filter circuit (Lab 4) that is to be built by the simulation group. Students in simulation group first constructs the circuit using components in Multisim environment and then apply AC Analysis (AC Sweep) to generate the bode plots (gain and phase vs. frequency). Students own the Multisim SPICE software during their freshmen year in other courses and are familiar with the simulation environment.

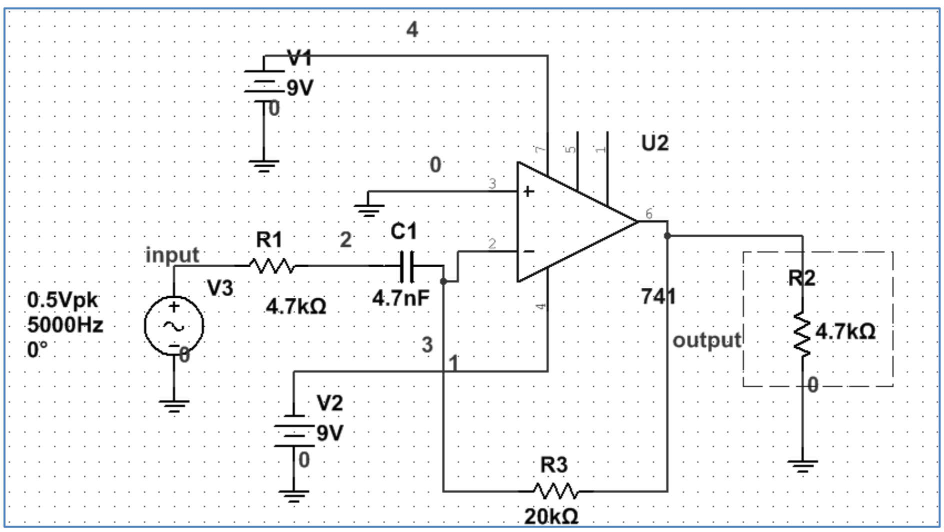

Figure 2. Simulation setup in Multisim for the Active HP Filter

Fig. 3 below indicates the values for the beginning and end frequencies and other details. These details are provided to the students in Simulation Lab manuals.

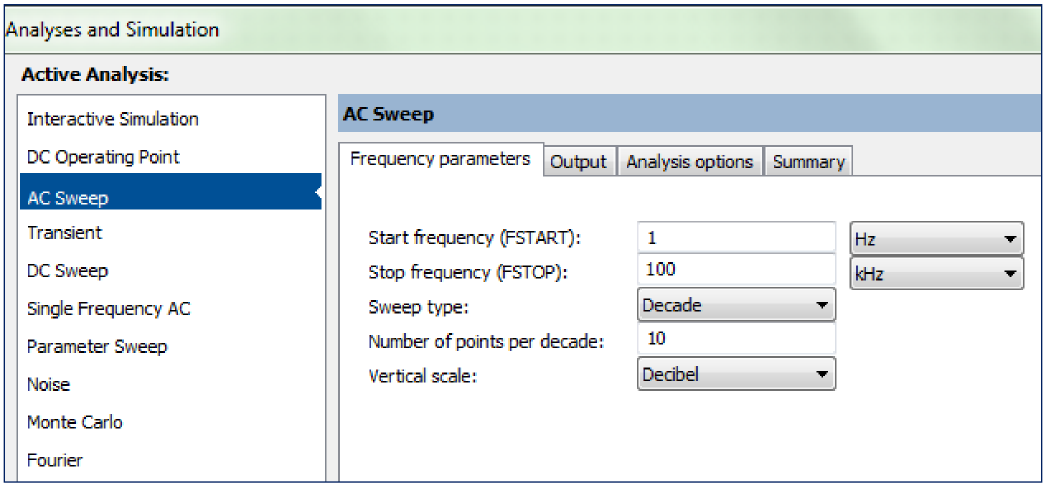

Figure 3. AC Sweep Analysis details in Multisim

The students in "HiH group" implement the same active high pass-filter using Analog Discovery Module. In this case, all circuit components (resistors, capacitors, and integrated circuit) are physically placed on the circuit board (Fig. 4). Students need to use "Network Analyzer instrument" in Analog Discovery user interface in order to automatically generate bode plots (gain and phase vs. frequency plots). Fig. 5 shows the beginning and end frequencies and other details for the "Network Analyzer". All experiment details are provided to the students in the HiH lab manuals.

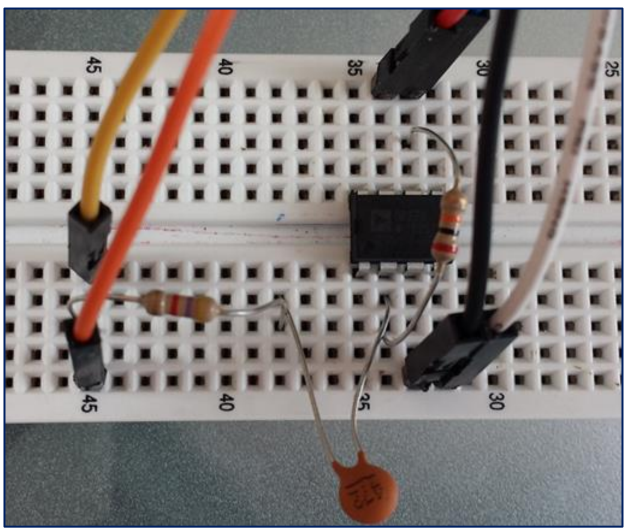

Figure 4. Active HP Filter implemented on a circuit board for the HiH version

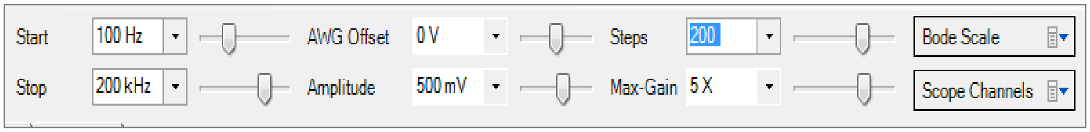

Figure 5. The "Network Analyzer" setup information

Figs. 6 and 7 above shows the output bode plots obtained from simulation and HiH versions, respectively. Both groups need to report on the corner frequencies and max gain of this High Pass filter.

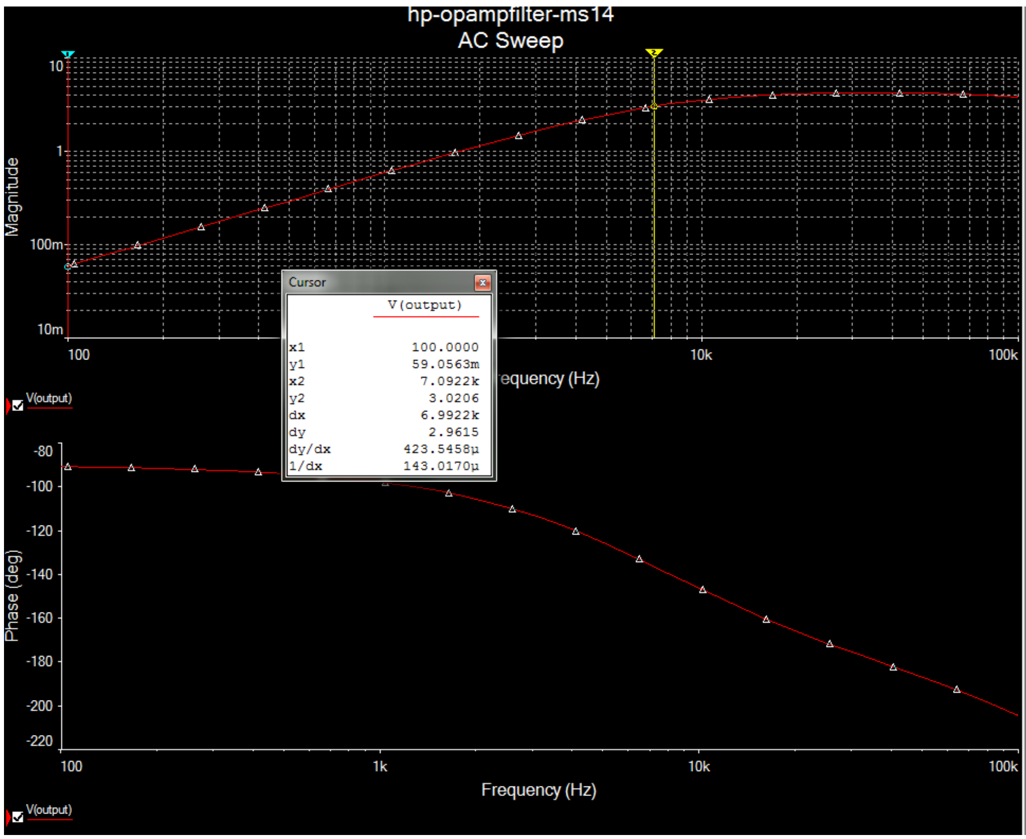

Figure 6. Output (Bode) plots obtained using Multisim Simulation

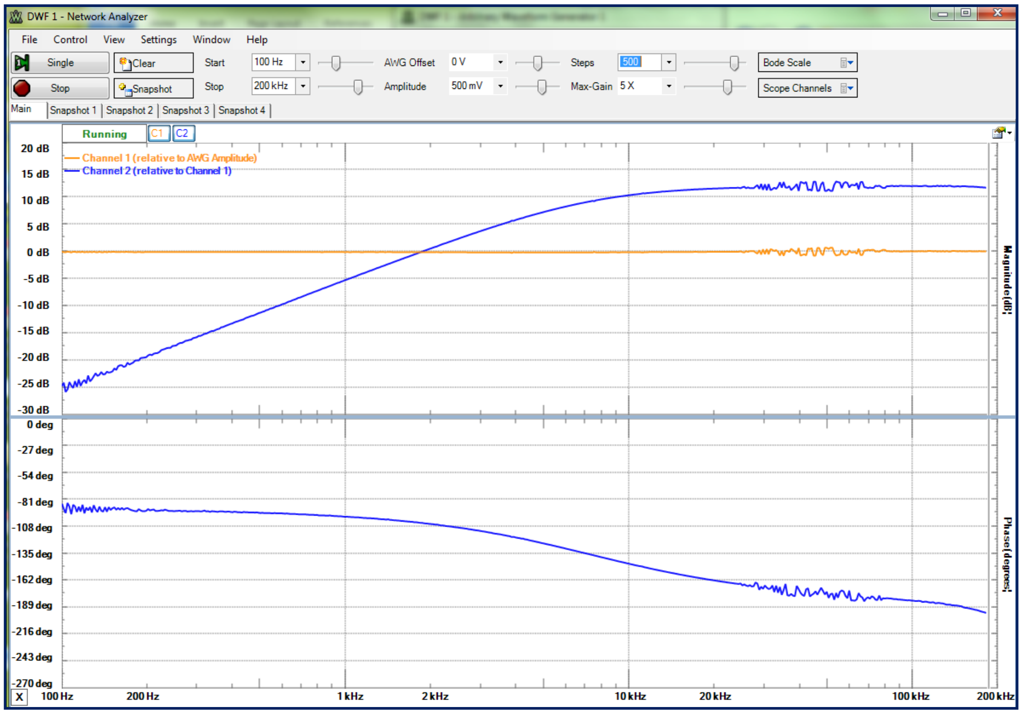

Figure 7. Output (Bode) plots obtained using Analog Discovery-Lab version

Another example is the Widlar Current Source experiment of Lab #6. Fig. 8 shows the Multisim setup for the simulation group. In this simulation experiment, two 2N3904 BJT Transistors are used to construct the Widlar circuit. Students use DC analysis in Multisim to plot the DC collector currents of transistors Q1 and Q2. Then, they perform a DC sweep analysis on the output to perform output resistance calculation.

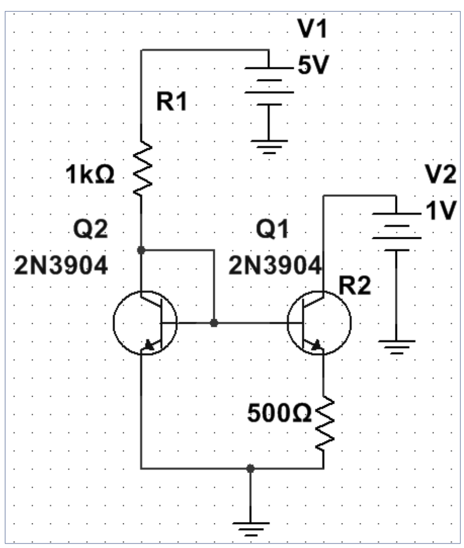

Figure 8. Widlar current source constructed in Multisim.

Fig. 9 illustrates the experimental setup for the HiH version. Due to characteristics of Analog discovery, there is no current measurement tool. This limitation can be overcome by referring to resistor voltage measurements since they are proportional to current.

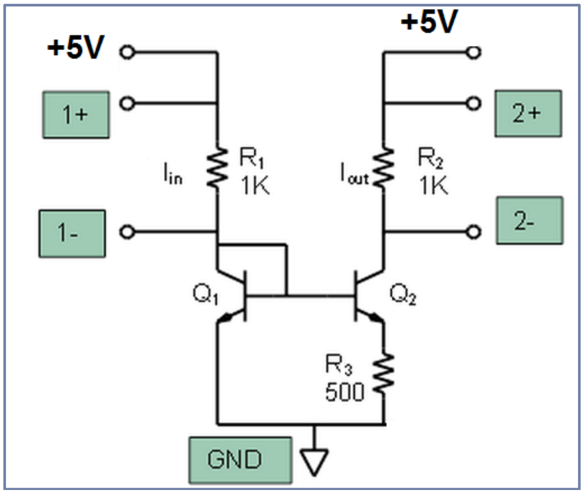

Figure 9. Widlar Source Experimental Setup for the HiH version.

The breadboard configuration of Fig. 9 somewhat may seem a little more complex for some students (Fig. 10). In order to ease their frustration, breadboard pictures have been provided to HiH group for all the labs.

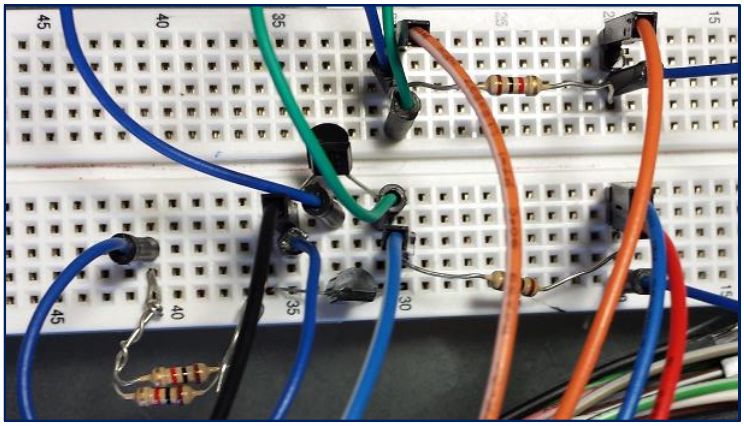

Figure 10. Breadboard configuration for the Widlar Source shown in Figure 8.

III. Results

In order to assess improvement in learning via HiH lab enhancement, two means of assessment have been used: the results obtained from the project using a survey and the comparison of learning outcomes between online laboratory and simulation groups.

LUEE began content delivery in Digital eLearning format effective Fall 2015. Our Content Delivery system relies heavily on Blackboard and includes closed-captioned videos, tutorials, lecture slides, discussion forums, assignments and most importantly our online labs. In our study, both groups have accessed to the same learning material via Blackboard Content Management System (CMS), only difference was in the laboratory and simulation assignments.

Various student learning (ABET) outcomes have been tested throughout the course for both groups. These outcomes are: an ability to (a) apply knowledge of mathematics, science, and engineering, (b) design and conduct experiments as well as analyze and interpret data, (c) design a system, component, or process to meet desired needs, and (k) use techniques, skills and modern engineering tools necessary for engineering practice.

A post-assessment has been administered at the end of the course via an online survey. Online surveys were used to ensure confidentiality of student responses. This also reduced data entry errors and costs. Using online surveys, students have been asked their opinions on the value and quality of the lab/simulation components and overall effect. We were especially interested in (a) the students' impressions on the accuracy of their experimental data and (b) the students' confidence in their ability to carry out the experiments. Some of the survey questions included were: "How easy it was to understand and perform the experiment?", "Was the outcome of the experiment same as predicted?" Last question on the survey inquired about the long-term usefulness and impacts of the lab experience. "Do you think the experience gained in experiments will help in your future career?"

All students in this study have answered the surveys. According to Table I, students in both student groups reported about the same level of difficulty when running the experiments. The striking difference appears if one looks at the question that says "I had accurate data available to me". About 90.5% of hardware group either "agreed" or "strongly agreed" that their data was accurate. This percentage was only 65% for the simulation group. Hardware group has also reported that they have obtained more predictable outcome compared to simulation group.

On the last question "The experience gained after completing the experiments is important for my future career", 80% of students in the high group have reported that the experiments will help in their future career. In the simulation group, only 57% of students either "agreed or "strongly agreed" on the same dimension. This may be due to the fact that they are gaining hands-on experience with hardware laboratories, which improve their confidence.

Learning outcomes for the two groups were also assessed and the samples of student work have been collected from both groups to measure learning outcomes. ABET outcomes (a) and (c) were assessed using midterms and final exam scores. Lab reports, on the other hand, have been used to assess ABET outcomes (b) and (k).

TABLE I. Students' Opinions Regarding the HiH Lab Component

ELEN 3322 Hardware (HiH) group	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
It was easy to understand and perform the experiments	33.3%	28.57%	38.1%	0%	0%
Upon completion of the experiment, I had accurate data available to me	23.8%	66.67%	0%	9.5%	0%
The outcome of the experiment was same as predicted	33.3%	47.6%	19.1%	0%	0%
Instructions given for experimental/simulation set-up (lab procedure) were clear	28.6%	57.1%	14.3%	0%	0%
The experience gained after completing the experiments is important for my future career.	50%	30%	15%	5%	0%

TABLE II. Students' Opinions Regarding the Simulation Lab Component

ELEN 3322 Simulation group	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
It was easy to understand and perform the experiments	30%	35%	15%	15%	0%
Upon completion of the experiment, I had accurate data available to me	15%	40%	35%	5%	5%
The outcome of the experiment was same as predicted	25%	35%	40%	0%	0%
Instructions given for experimental/simulation set-up (lab procedure) were clear	40%	40%	5%	15%	0%
The experience gained after completing the experiments is important for my future career.	38.1%	19%	33.3%	9.5%	0%

Both midterms and final exam were created using Blackboard tests. These tests consisted of many multiple choice, multiple answer and True/False questions. Some multiple choice and answer questions had partial credit. For both groups, the grading was done automatically by Blackboard CMS.

In grading lab reports, students' abilities were evaluated based on the following criteria: objective of the experiment, data acquisition, data analysis, discussion and error analysis, comparison with theory, calculations and derivations, presentation of information, conclusions drawn, overall technical understanding. The rubric was provided to students at the beginning of semester. A teaching assistant has graded the lab reports of both groups using the same rubric.

Fig. 11 shows the average score obtained for learning outcomes based on midterm and final exam scores and graded lab reports. The first bar (blue) indicates the score for the hardware group while the 2nd bar indicates the score for the simulation group. For outcomes (b) and (k), the average score was slightly higher for the hardware group. The hardware group had a 2.6 percent higher average score than the simulation group on these outcomes. Table III lists lab grades for both groups indicating that all lab scores were higher for the hardware group with the exception of Lab3- Band-pass filter.

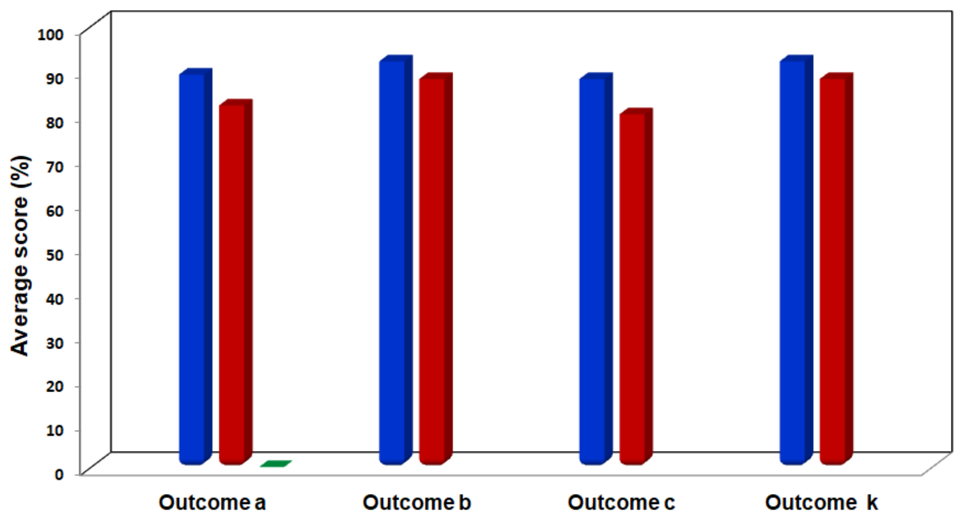

Figure 11. Assessment results for learning outcomes (ABET)

TABLE III. Lab Report Grades for Simulation and Hardware Groups

LABS	1	2	3	4	5	6
Simulation Group	84.86	92.95	82.40	88.91	92.85	76.35
Hardware Group	89.33	93.90	78.05	90.33	93.90	88.19

On the other hand, for outcomes (a) and (c), the average score was almost 10% higher than the simulation group showing a direct improvement in the corresponding learning outcomes.

More importantly, based on the surveys, we see that students in "the hardware group" believe they have more accurate data, feel more confident about their data and they also believe the experiments helped them more for their future careers.

Conclusion:

This paper presented the results of Hardware-in-Homework (HiH) integration into Electronics II theory course. The HiH integration provided students with laboratory experiences in a purely theoretical course, allowing them to gain the comprehensive hands-on skills required of engineers.

It is believed that active lab experiences such as these would increase student self-efficacy and student engagement and confidence. This would also enhance the feeling that students belong in the EE discipline and increase student retention. The results also show that the integration of HiH laboratory experiences contributes to the improvement of multiple ABET student learning outcomes. The method used to expand the laboratory experience should be applicable to other disciplines as well.

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