Assessment of an Individualized, Self-Contained System in Electrical Circuits Laboratory

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Abstract

A pilot study was performed to evaluate the efficacy of a teaching protocol employing an individualized, self-contained laboratory system for instruction in a fundamental electrical circuits laboratory. For purpose of evaluation, students were divided into two academically matched groups. The control group utilized traditional laboratory equipment and performed their weekly laboratory assignments as two member teams. The study group used the Electronics Explorer™ Board (EEBoard) from Digilent to perform their weekly laboratory assignments individually at a time and location of their preference. The students were evaluated based on their individual performance on a final laboratory practicum exam which provided a metric of their acquired and retained laboratory knowledge and proficiency. The students who participated in the study group performed at a higher level on the final lab practicum than did the control group. When the students in the control group were partitioned in order to select the dominant team member, their final lab practicum scores approached the EEBoard group scores. Results from this pilot study indicated that an individualized laboratory system such as the Electronic Explorer™ Board potentially enhanced the students laboratory knowledge and proficiency compared with students who worked in two member teams utilizing traditional laboratory equipment.

Introduction

The objective of this study was to evaluate the efficacy of an individualized laboratory system in order to deliver a comprehensive laboratory experience for the purpose of enhancing the students' electrical circuits knowledge and proficiency.

The engineering laboratory has traditionally been used to reinforce material presented in the classroom and to introduce students to basic engineering applications and concepts [1] [2]. In our university, electrical circuits laboratory students constructed basic electrical circuits and performed standard analyses utilizing current, voltage and power measurements in both AC and DC signal environments. Also, traditionally these electric circuits laboratories convened weekly during the semester with pre-assigned laboratory exercises being performed by students working in teams of two or more. In these traditional laboratories, the equipment included oscilloscopes, function generators, power supplies, and multimeters. This equipment has proven to be expensive to maintain and update to meet current technology advancement. In our university, the traditional single-use laboratory facilities occupy considerable dedicated space and have already experienced over crowding due to student population growth rates. Recent studies have shown that students benefit significantly from working individually on their laboratory assignments [3]; however, availability of laboratory facilities limit full implementation of this protocol.

Several self-contained laboratory systems have been developed which allow students to perform standard electronic laboratory exercises utilizing a portable device combined with a personal computer in a location of their choice. Two of the self-contained systems available are the Electronics Explorer™ Board (EEBoard) [4] from Digilent, Inc. as well as the National Instruments NI ELVIS system [5] which requires LabVIEW software. In this study, the EEBoard was selected for evaluation.

Background and Methods

The EEBoard was evaluated in a regularly scheduled circuits laboratory which was held in conjunction with the second semester of a two semester circuits lecture course. Ten labs were performed on a weekly basis during the semester to reinforce the electric circuits principles presented in the classroom. Each lab session contained a pre-laboratory assignment which included a PSpice®/OrCAD® circuit simulation followed by a laboratory exercise. Each student individually completed the pre-laboratory assignment and submitted a weekly pre-lab report. A laboratory assignment containing a detailed written description with diagrams and figures of the laboratory apparatus was provided prior to each laboratory exercise. In addition, the laboratory instructor presented an audio-visual pre-lab brief at the beginning of each lab. The students then preformed the laboratory exercise either as two member teams in the control group or individually in the study group. Reports were then submitted for each lab to document the laboratory exercise. The control group submitted one lab report per team while the study group members submitted individual lab reports.

Previous studies in our lab have shown a weak correlation between the students' Circuits I prerequisite lecture course grades and their performance on the final lab practicum which was used as the primary metric of student laboratory performance [6]. Students in the current study were voluntarily separated into two separate groups: a control and study group. There were initially 16 students in the control group and 10 in the study group. One student in the control group dropped the course shortly after the semester began. The remaining 15 control group student had a Circuits I average grade of 2.93 (on a 4.0 scale) while the 10 students in the study group (EEBoard) had a 2.90 average. The control group performed laboratory assignments utilizing traditional laboratory equipment in teams consisting of two students. Since there were an odd number in the control group, one student volunteered to work individually. Every student in the study group performed their weekly labs individually utilizing one of the university's 10 Digilent's Electronics Explorer™ Boards, Figures 1 and 2. Both the control and study groups were assigned the same circuits to construct and analyze.

The control group worked predominately as two member teams while the study group worked individually. The interaction between team members has been shown to be beneficial [7] and may have had a synergistic effect in the current study. The control group labs were required to performed their laboratory exercises in an environment where immediate assistance was available from the laboratory instructor. In addition, the control group students may have had an advantage over their study group peers due to their previous experience with traditional laboratory equipment.

For the study group, the Electronics Explorer™ Design Station (EEBoard) coupled with Digilent's WaveForms™ software essentially provided a complete system for the circuits laboratory exercises. The EEBoard's built in functions included a 4 channel oscilloscope, 4 channel DC voltmeter, 2 channel waveform generator, 2 programmable voltage references, and a programmable power supply. A handheld multimeter, set of tools and electronic components were added to complete the self-contained lab in a box, Figure 2.

Since the EEBoard provided a portable laboratory system, students were neither constrained by time nor place in performance of their lab assignments and were given the option to perform the laboratory exercises at a time and location of their choice. With fewer external distractions and without the crutch of a laboratory instructor to provide support and assistance, these students may have achieved an increased level of proficiency, understanding and retention for the basic electrical circuit laboratory procedures. Although the study group members may not have had immediate access to the lab instructor during their laboratory exercises, the laboratory instructor was available to both the study as well as control students throughout normal working hours to answer questions regarding the lab assignment or apparatus.

A final examination was administered to each student individually in the last week of the semester and consisted of a laboratory practicum and a separate PSpice® circuit simulation component. The lab practicum was a straight forward, laboratory skill based test, and covered only material presented in the weekly lab exercises. Students in the control group utilized the traditional lab equipment which they had used during the semester whereas the study group members used their Electronics Explorer™ boards. The PSpice® final exam component required the students to perform a set of simulations similar to their pre-lab exercises.

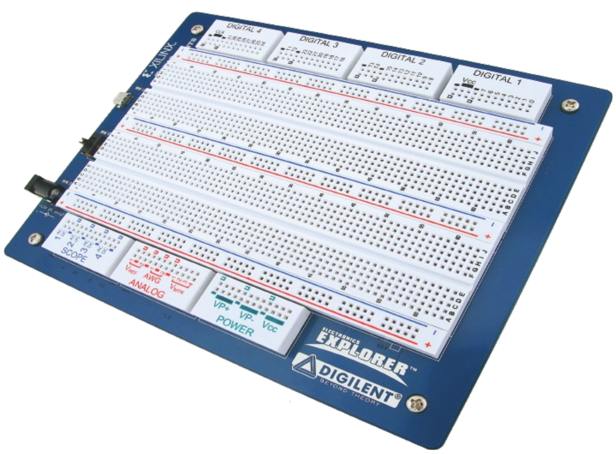

Figure 1: Digilent's Electronics Explorer™ with 4-channel oscilloscope, voltmeters, voltage sources, waveform generator and logic analyzer.

Figure 2: Portable electronics self-contained lab components utilizing the Electronics Explorer™ Board.

The circuits for the final lab practicum were the same for both the study and control group and were pre-assembled to eliminate circuit construction errors during the lab practicum which could have contributed to a diminution in the lab practicum scores. In addition, the circuit component values were altered between test stations to minimize the potential for shared answers. This study was approved by the university's Human Subject Committee.

Results

Final Lab Practicum Results

Table 1 summarizes the statistical results for the final laboratory practicum examination. The right hand column lists the number of students who completed the course, fourteen of the original 15 students in the control and 5 of 10 in the study (EEBoard) groups. Please see the Summary and Conclusions section for an explanation of the high attrition rate from the study group.

The change in the group population between the beginning and the end of the semester altered the balance in the Circuit I lecture grade distribution between groups. The initial balance in the Circuit I lecture grades between control and study groups was utilized to establish an equivalent circuits knowledge baseline between these two groups. Due to attrition during the semester the Circuits I grades for the students remaining in the control group changed from an average of 2.93 to 3.0, and the corresponding change in the study group went from an average of 2.90 to 3.4. Although the Circuits I grade distribution between the control and study group for the students who completed the lab course did not differ statistically, the control group was partitioned to more closely match study group's Circuit I lecture grades at the completion of the laboratory course. This new control group partition, designated Control_AB, contained 10 students, and their Circuits I lecture course average was 3.5 compared to a 3.4 in the study group. The associated lab final practicum grade statistical summaries for these three groups are given in Table 1.

Groups	Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum	N
Control	21.0	54.8	76.0	72.9	90.5	120.0	14
Control_AB	53.0	70.0	85.0	85.1	98.0	120.0	10
EEBoard	77.0	84.8	100.0	93.3*	100.0	104.6	5

*Table 1: Lab final practicum grade statistics for the control, Control_AB and EEBoard groups. An extra credit problem allowed students to score higher that 100. The Control_AB group was grade matched using Circuit I lecture grades to the EEBoard group. *The EEBoard group mean was significantly higher than the Control ($p \leq 0.05$) but not the Control_AB groups mean.*

A t-test analysis of the original control and EEBoard group lab final practicum score yielded a statistically significant difference between these two groups with $p < 0.05$. However, a similar analysis between the Control_AB and EEBoard group lab final practicum score was not statistically different. The cumulative distribution functions (cdf) for these three groups are shown in Figure 3. The cdf depicts the fraction of students who scored at or below a given level on the lab practicum. For example, none of the five students in the EEBoard group scored below a 77, while 2 of the 5 (40%) scored an 84.8 or below. As indicated in Figure 3, there was a shift in the EEBoard score cdf distribution to the right which was statistically different from the original control group but not from the Control_AB group's distribution.

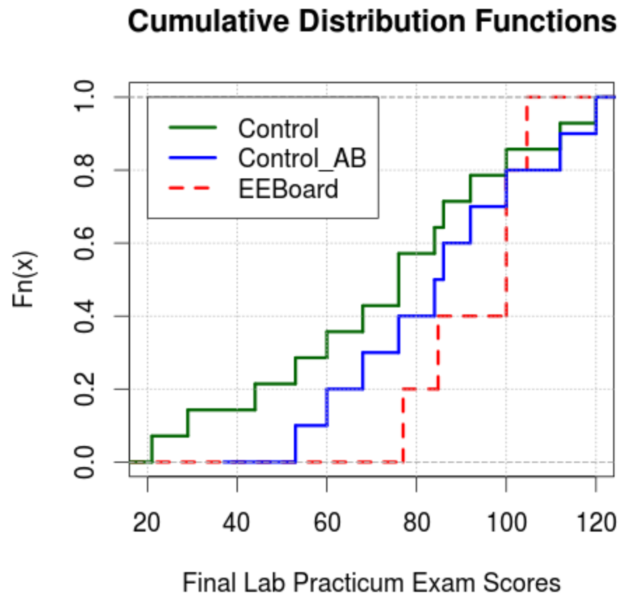

Figure 3: Lab final practicum exam grade cumulative distribution functions for the Control group (solid green), Control_AB group (solid blue) with Circuits I lecture grade matched to EEBoard group, and the EEBoard (Electronics Explorer™ board) group (dashed red). The EEBoard group mean was significantly higher than the Control but not the Control_AB groups mean.

As reported in a previous study, the percent of time that each student within a two person team spent actively engaged in the performance of the laboratory exercise was positively correlated with their final laboratory practicum scores [6]. It was not uncommon for one team member to become the dominate participant in their weekly laboratory exercises and to score significantly higher on the final lab practicum. It would follow that the performance on the final lab practicum of the dominate partner in a two person group should be comparable with that of the study group's scores. In this current study, there were six 2-person teams and two individual participants in the control group. The two partner control group teams were separated based on their lab practicum scores. This resulted in a 92 average for the higher scoring team member compared to 49 for the average for the lower team member. A paired t-test between these two groups resulted in a statistically significant difference, $p < 0.01$. The two students from the control group who performed their labs individually were now combined with the higher scoring members from the two person control teams. This newly partitioned control group was designated Control+.

Figure 4 includes the lab practicum score distributions for this new control partition, "Control+", along with the EEBoard group's cdf distribution. The mean score for the Control+ group was 91.3 compared to 93.3 for the EEBoard group, and these means were not statistically different. These results imply that students in the Control+ group performed at essentially the same level of proficiency on the final lab practicum as did the students who worked individually utilizing the EEBoard. Therefore, the Control+ group students who utilized traditional laboratory equipment and were either the dominate player in their respective lab team or worked individually during the semester achieved essentially the same level of electrical circuits laboratory proficiency as did the EEBoard students.

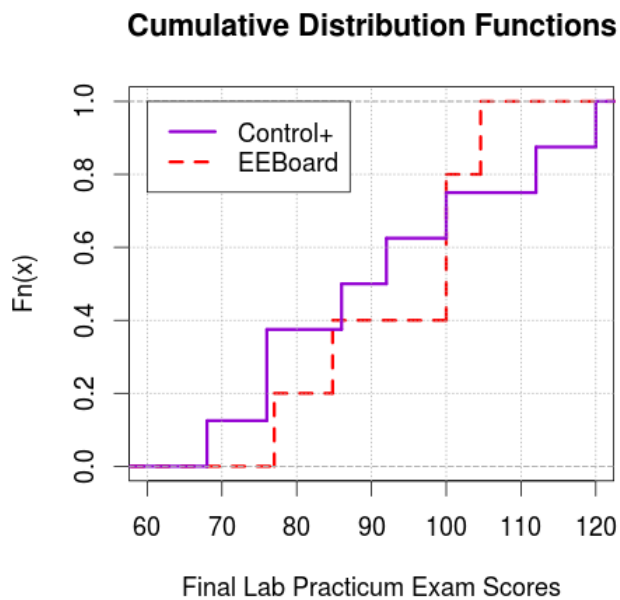

Figure 4: Lab final practicum exam grade distributions for the partitioned control (Control+) group (solid violet) composed of the dominate partner in the two person teams combined with the students who performed their weekly labs individually with traditional lab equipment. The EEBoard group distribution is represented with a dashed red line.

Relationship Between Final Lab Practicum Exam Scores and Lab Report Grades

Table 2 contains the laboratory report data summaries for the Control, Control_AB and EEBoard groups and shows no statistically significant difference between groups. Previous studies have indicated no correlation between lab report grades and performance on the final laboratory practicum exam [8]. In this study, as well as these previous studies, the average weekly lab report grades were uncorrelated to the students' final lab practicum scores. The relationship between the lab practicum score and the lab report grades are shown in Figure 5 for both the study (EEBoard) and Control_AB groups. Based on these and results in previous studies, the lab report grades were not utilized to assess the students' abilities and proficiencies in circuits laboratory.

Groups	Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum	N
Control	54.9	75.1	87.2	83.9	93.1	100.5	14
Control_AB	72.7	82.7	91.9	88.8	93.3	100.5	9
EEBoard	77.9	83.5	86.6	86.8	91.2	94.9	5

Table 2: Average lab report grades for the Control, Control_AB and EEBoard groups were not statistically different.

Since the two member lab teams submitted a common lab report but were tested individually on the final lab practicum, the lack of correlation between these two assessment methods was not unexpected. Similarly in previous studies where students utilized traditional laboratory equipment and performed and submitted their weekly labs and lab reports individually, this lack of correlation was also observed. Therefore, the students' lab report grades were not a sufficient indicator of their laboratory proficiency and knowledge.

PSpice® Final Exam Results

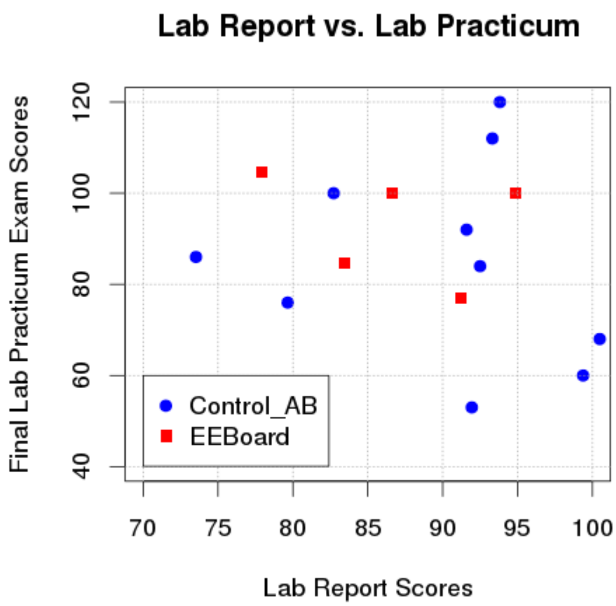

Figure 5: Final lab practicum exam scores and the average weekly lab report score distribution for the study (EEBoard) group (red squares) and the control group (blue dots) with Circuits I grades matched to the study group.

The PSpice® final exam summary statistics for the three groups are provided in Table 3, and their cumulative distribution functions are shown in Figure 6. Although the EEBoard distribution was shifted to the right of both the Control and Control_AB distributions, only the Control and EEBoard distributions were statistically different based of a t-test with $p < 0.05$.

Groups	Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum	N
Control	0.0	20.0	40.0	44.3	60.0	100.0	14
Control_AB	20.0	25.0	50.0	54.0	75.0	100.0	10
EEBoard	40.0	80.0	80.0	80.0*	100.0	100.0	5

*Table 3: PSpice® final examination statistics for the Control, Control_AB and EEBoard groups. The Control_AB group was grade matched using Circuit I lecture grades to the EEBoard group. *The means for the Control and EEBoard were statistically different ($p \leq 0.05$); however, the Control_AB and EEBoard means were not.*

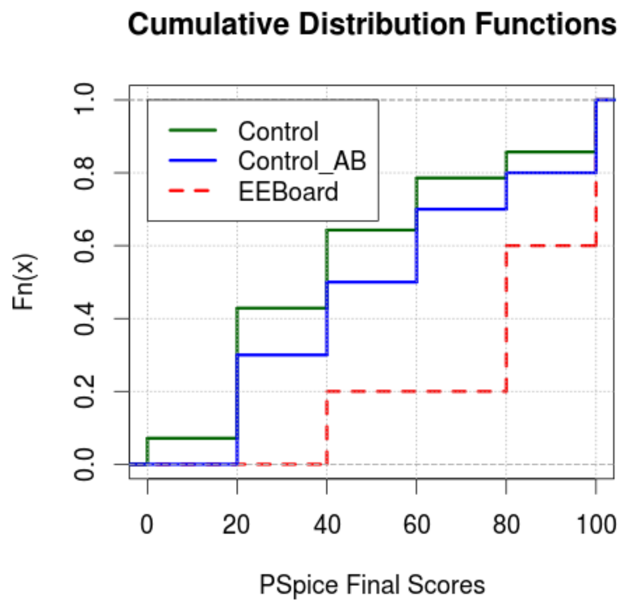

Figure 6: PSpice® final exam grade cumulative distribution functions for the Control group (solid blue), Control_AB group (solid green) with Circuits I lecture grade matched to EEBoard group, and the EEBoard (Electronics Explorer™ board) group (dashed red).

Summary and Conclusions

The final laboratory practicum exam served as a direct assessment metric for the students' laboratory proficiency which represents their circuits knowledge, laboratory skills and ability and to apply these to circuits analysis and applications. The students who used the EEBoard scored significantly higher on the final lab practicum than the students who utilized traditional laboratory apparatus and worked predominately in two member lab teams. However, due to attrition among the EEBoard student group, their Circuits I grade average increased, potentially altering the basic circuit knowledge equity between themselves and the control group. The control group was therefore partitioned to match their Circuits I grades with those of the members remaining in the EEBoard study group. This partitioned control, Control_AB, group's lab practicum score distribution shifted to the right from the original control group as observed in Figure 3 which represented an increase in the average lab practicum grade. Although the Control_AB lab practicum distribution did not equal or exceed the the EEBoard distribution, it was no longer statistically different based on either a one or two-tailed t-test with $p \leq 0.05$.

In previous studies, it has been reported that one of the individuals in a two member lab team assumed the lead in the weekly laboratory exercises and scored higher than their partner on the final lab practicum [6]. In order to compare and contrast the EEBoard students' performance on the final lab practicum with the dominate member in the traditional laboratory equipment group, a control group partition was established which consisted of the team member with the higher lab practicum score and the two students who worked individually for all or part of the semester. These results, presented in Figure 4, showed a marked improvement over the original combined control group and an extraordinary degree of similarity with the EEBoard lab practicum distribution. In previous studies with traditional laboratory equipment, a similar level of improvement was observed between students who worked individually and those who worked in groups [3]. The similarity in the lab practicum scores achieved between this partitioned control group (Control+) and EEBoard group, Figure 4, along with the results from our previous studies implies that had all the students in the control group performed their weekly labs individually they would have very likely achieved the same level of proficiency as the EEBoard group. Therefore, the level of laboratory knowledge and proficiency achievement was apparently not driven by the laboratory equipment itself but instead by the level of student laboratory participation.

Fifty percent of the students participating in the study (EEBoard) group dropped the course compared to 2 in 16 from the control group. Although the study group dropout rate seemed excessive, there were mitigating circumstances in several of the cases. Three of the five study group students dropped due to curriculum changes where circuits lab was no longer required for their major. The remaining two students in the study group as well as one of the student who withdrew from the control group indicated that they were not able to maintain the work load commensurate with the weekly assignments. Since the students in the study group were given a great deal of latitude as to when and where they performed their weekly laboratory exercises, students who had excessive demands on their time outside of their academic pursuits or who lacked self discipline, organizational and time management skills would very quickly find themselves hopelessly behind. It is interesting to note that four of the five students in the study group who completed the semester elected to perform the majority of their weekly assignments in the lab during the normally assigned lab period. Since the objective of this study was to verify that students who utilized the Electronics Explorer™ board achieved the same or greater level of laboratory proficiency as students with traditional laboratory equipment, the higher attrition rate for the study group did not appear to be equipment related and therefore did not circumvent the study protocol nor invalidate the results for this pilot study.

It has been shown that students exhibit differential learning styles which contribute to their comprehension and assimilation of instructional information especially in a classroom environment with a single dimensional presentation format [9] [10]. In order to mitigate a learning style bias on the dissemination of the laboratory procedures, the laboratory assignments were provided prior to the laboratory exercise and contained both explanatory figures and diagrams. Students had time to study and reflect on the assignment and to ask questions prior to the scheduled laboratory period. An audio-visual pre-lab brief accompanied each lab to previewed the laboratory assignment and procedures. The instructor was available during the laboratory exercise to provide assistance in the mechanics of the lab procedures. Students developed their laboratory skills and refined their circuit knowledge which they then applied to circuit analysis in the laboratory assignments throughout the semester. The final lab practicum allowed them to demonstrate their laboratory proficiency which they had acquired during the course of the semester.

Although the results from this study implies that an individualized laboratory system such as the EEBoard enhanced the students' laboratory knowledge and proficiency compared to a traditional team approach, additional data must be obtained to validate the results from this pilot study. Based on the data from the current current pilot study, it was projected that additional data from approximately 60 students would be required to yield an $\alpha = 0.05$ and power = 0.75 for statistical significance.

The results from this study also imply that a full scale deployment of an individualized laboratory system potentially enhances the students' acquired laboratory proficiency. However, due to the independent structure of the laboratory protocol, the lab syllabus should employ a process for the periodic tracking of student progress. At a very minimum, a weekly report should be required from each participant as was the case in this study.

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