

Efficacy of an Individualized, Self-Contained Instrumentation System in Electric Circuits Laboratory

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Abstract

A 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 three groups with academic matching between two of the 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 from Digilent to perform their weekly laboratory assignments individually at a time and location of their preference. A third group performed their weekly labs individually utilizing traditional laboratory equipment. 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. Students who participated in the EEBoard group performed at a higher level on the final lab practicum than did the control group. Results from this study indicated that an individualized laboratory system such as the Electronic Explorer™ Board 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 to deliver a comprehensive laboratory experience for the purpose of enhancing the students' electrical circuits knowledge and proficiency in an introductory circuits laboratory.

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 the current study, 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. These electric circuits laboratories convened weekly during the semester and were preceded by a preassigned laboratory exercise. Typically, the traditional electric circuits laboratory requires equipment such as oscilloscopes, function generators, power supplies, and multimeters which is expensive to maintain and update to the current level of technology. In addition, it requires a single-use laboratory facilities which occupies considerable dedicated space. Recent studies have shown that students benefit significantly from working individually on their laboratory assignments^[3]; however, availability of laboratory facilities and equipment limit the 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 for three consecutive semesters. Initial results from the pilot study from the first semester were reported previously and have been confirmed and extended.

Background and Methods

The EEBoard was evaluated in a regularly scheduled circuits laboratory which was held in conjunction with the second of a two semester circuits lecture course. Students were required to pass the prerequisite Circuits I lecture course prior to enrolling in the lab 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 performed the laboratory exercise either as two member teams in the Control/Partners group or individually in either the Singles or EEBoard groups. The Control/Partners and Singles groups utilized traditional laboratory equipment for their weekly labs, while Digilent's Electronics Explorer™ Board, Figures 1 and 2, was used by the EEBoard group members. All three groups were assigned the same weekly laboratory exercise.

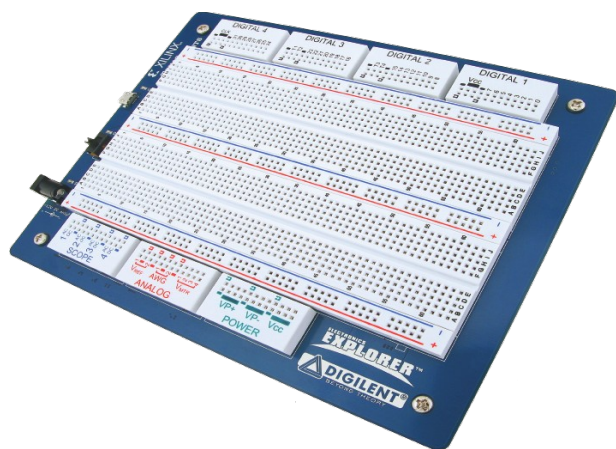


Figure 1: Digilent's Electronics Explorer™ board and the WaveForms™ application provides a 4-channel oscilloscope, voltmeters, voltage sources, waveform generator and logic analyzer.



Figure 2: Portable electronics self-contained lab components including the EEBoard.

Reports were then submitted for each lab to document the laboratory exercise. The Control/Partners group members submitted one lab report per team while the Singles and EEBoard group members submitted individual lab reports.

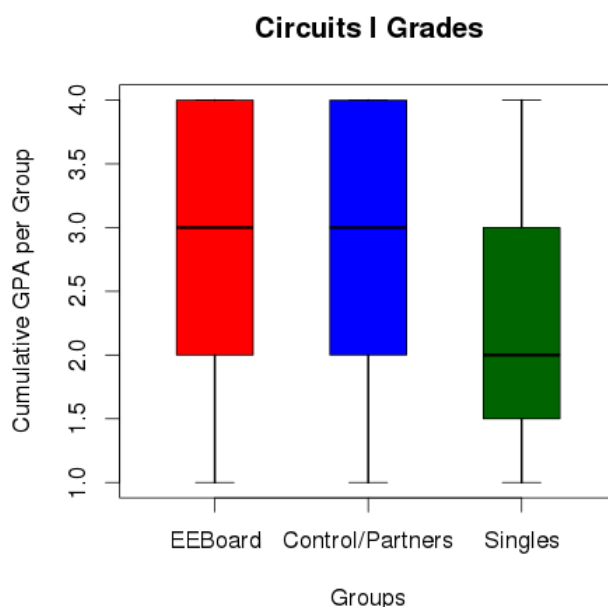


Figure 3: Circuit I grades for each group. EEBoard and Control/Partners groups were matched based on their prerequisite Circuits I grades. See Table 1.

A final assessment exam administered to each individual student included a component on circuit simulation and a laboratory practicum. Previous studies in our lab have shown a weak correlation between the students' Circuits I prerequisite lecture course grades and their performance on the circuits lab final lab practicum which was used as the primary metric of student laboratory performance^[6]. Students in the current study were voluntarily separated into the three groups: an EEBoard, a control/partners and a singles group. There were 30 students in the control group, 17 in the EEBoard group and 12 in the Singles Group. The prerequisite Circuits I grade distributions for all three groups are shown in Figure 3 and Table 1. There was no statistically significant difference between the EEBoard and Control/Partners groups. Although the Singles group had a lower median and mean than the other two groups there was no statistically significant differences between Singles group and the other two groups either individually or in combination.

Groups	1 st Quartile	Median	Mean	3 rd Quartile	Maximum	N
Control/Pairs	2.00	3.0	2.80	3.75	4.0	30
Singles	1.75	2.0	2.25	3.00	4.0	12
EEBoard	2.00	3.0	2.71	4.00	4.0	17

Table 1: Grades in the prerequisite Circuits I course for the three groups based on 4 point grading scale (A – F encoded as 4 – 0). Circuits I grades were matched in the EEBoard and Control/Pairs groups. See Figure 3.

The Control/Partners group worked in two member teams, and the interaction between team members has been shown to be beneficial^[7] and may have had a synergistic effect in the current study. The Singles and Control/Partners group members were required to perform their laboratory exercises on traditional laboratory equipment in an environment where immediate assistance was available from the laboratory instructor. The circuits laboratory course was the first opportunity in the curriculum for student to become extensively exposed to the laboratory equipment and environment. As such, the Control/Partners and Singles group background with this equipment was limited. However, a small number of students from these two groups may have had an advantage over their EEBoard group peers due to a potential experience with traditional laboratory equipment in a previous or current academic or employment environment. Since the Electronics Explorer™ Board has just recently become available, no one from the EEBoard group had any prior experience with its operation.

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, a 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 immediate assistance of a laboratory instructor to provide support and advice, 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 students from all three groups during 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. For the lab practicum, students utilized the same laboratory equipment from their weekly laboratory exercises. The PSpice® final exam component required the students to perform a set of simulations similar to the pre-lab exercises performed during the semester.

The circuits for the final lab practicum were the same for all three groups and were pre-assembled to eliminate circuit construction errors during the lab practicum. In addition, the circuit component values were altered between test stations to minimize the potential for shared answers. This study has been approved by the university's Human Subject Committee. Results from the first semester were presented as a pilot study^[8].

Results

Final Lab Practicum Results

Histograms for the final lab practicum grades and their associated cumulative distribution functions (cdf) for control/partners, singles and EEBoard groups are shown in Figure 4. The vertical axis of the cdf represents the fraction of students who obtained a lab practicum grade less than the grade value indicated at the corresponding intersection on the horizontal axis. For example, the fraction of students with a score < 60 on the exam in the EEBoard group was $F_n(x)=0.12$ (2 of 17) compared to 0.43 (13 of 30) for the Control/Partners group. (Or conversely, 88% of the EEBoard group scored 60 or higher whereas 57% of the Control/Partner group scored at that same level.)

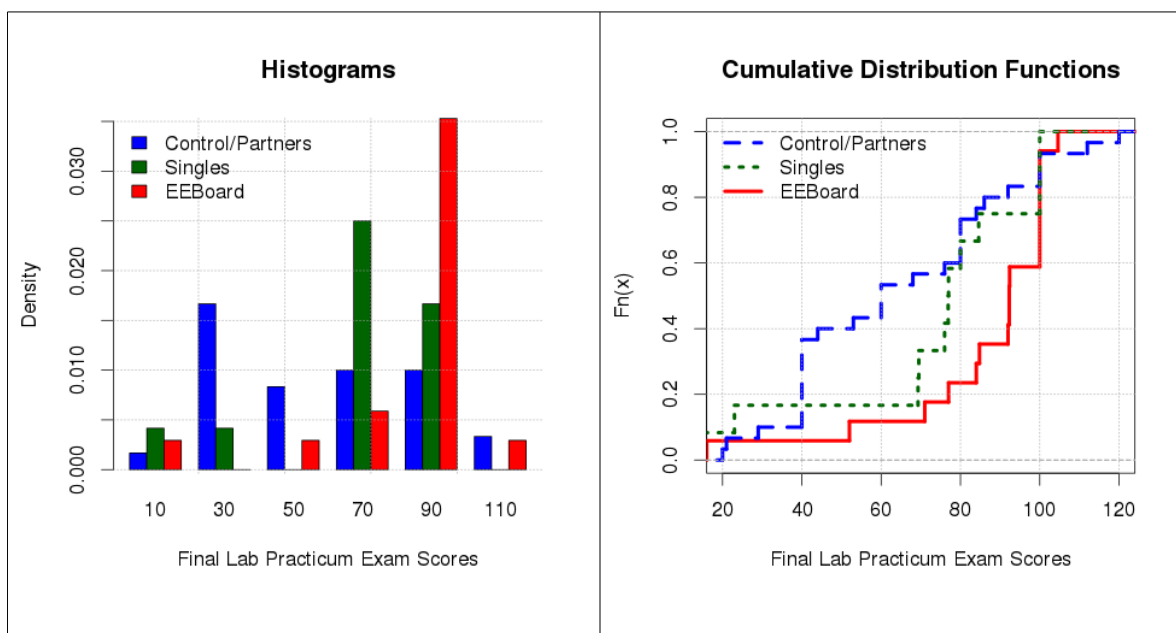


Figure 4: Lab final practicum exam grade histograms (left) and their cumulative distribution functions (right) for the Control/Partners group (blue), Singles group (green) with the EEBoard (Electronics Explorer™ board) group (red). The right shift in the EEBoard group cdf distribution represented a significantly enhanced performance ($p < 0.01$) on the lab practicum exam compared to the Control/Partners group distribution.

In order to compare the distributions of the lab practicum between the three group, it was first necessary to determine if these distributions were normally distributed since parametric statistical tests for comparison of means between distributions (i.e., student t-test) assume normal distributions. The Q-Q graphs for each of these groups are shown in Figure 5. Normally distributed data will occur along a straight line in these diagrams. Although the Control/Partners group appears to be normally distributed, the Singles and EEBoard groups deviate from normality. The Shapiro-Wilk test for normality confirmed that the Control/Partners distribution was not statistically different from normal; however, both the Singles and EEBoard distributions were indeed non-gaussian distributed ($p < 0.05$ & 0.001 respectively). Since the Singles and

EEBoard lab practicum final distributions were significantly non-normally distributed, nonparametric tests were mandated.

A comparison of the Control/Partners and EEBoard distributions using the nonparametric two-sample Kolmogorov-Smirnov test revealed a statistically significant difference with $p < 0.01$. This statistical difference was confirmed with the Wilcoxon sign rank (Wilcoxon-Mann-Whitney) test, $p < 0.01$. Although nonparametric statistical analyses are less sensitive for the detection of differences in distributions, they are more robust than a comparable parametric test.

In contrast to the statistical difference between the Control/Partners and EEBoard distributions, the final lab practicum scores for Singles group distribution did not differ statistically from the Control/Partners group based on evaluation by either the Kolmogorov-Smirnov or the Wilcoxon Signed Ranked tests. However, there was a statistically significant difference between the Singles and EEBoard groups distributions (Wilcoxon rank sum $W=141$, $p < 0.05$ one-tail). A statistical summary of these results for the final laboratory practicum examination is provided in Table 2 with the number of students in each group shown in the right hand column.

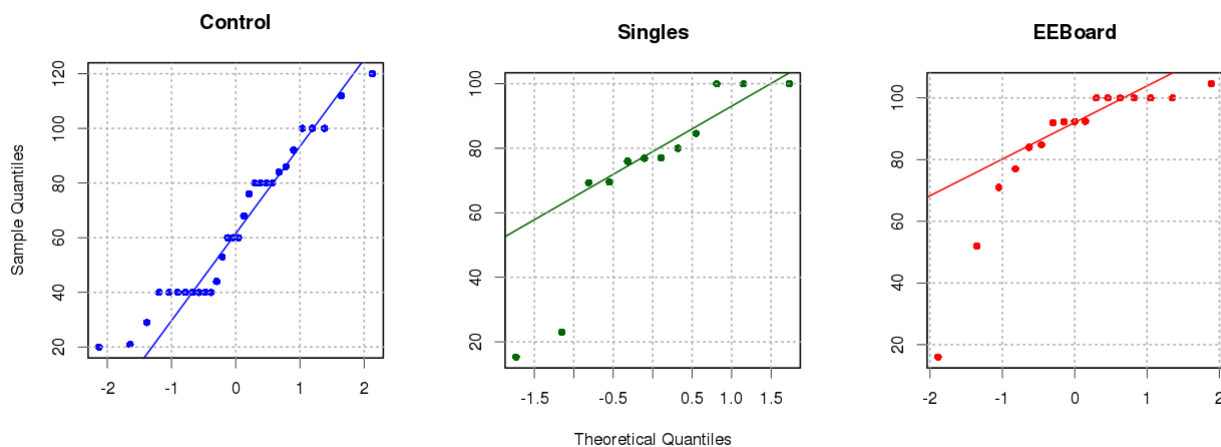


Figure 5: Final Lab Practicum Q-Q plots for the Control/Partners, Singles and EEBoard groups. Both the Singles and EEBoard groups tested positively for non-normal distributions.

Groups	1 st Quartile	Median	Mean	3 rd Quartile	Maximum	N
Control/Partners	40.0	60.0	64.2	83.0	120.0	30
α -Partner	72.0	80.0	80.9	100.0	120.0	15
Ω -Partner	40.0	40.0	47.4	60.0	84.0	15
Singles	69.5	77.0	72.6	88.5	100.0	12
EEBoard	84.0	92.3	85.8	100.0	104.6	17

Table 2: Lab final practicum grade statistics for the Control/Partners, Singles and EEBoard groups. The control group was split into the α and Ω sub-groups based on the lab practicum score (see text). The EEBoard group final lab practicum grade distribution was significantly higher than the Control/Pairs ($p < 0.01$); however, the Singles group distribution did not differ significantly from the Control/Partners or the EEBoard groups. The Control/Partner α and Ω sub-groups were statistically different, $p < 0.01$; however, the α -Partner, EEBoard and Singles groups were not. An extra credit problem extended the maximum to 120.

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. In this current study, there were fifteen 2-person teams in the Control/Partners group. For analysis, partners within each control group team were partitioned into two subgroups based upon their lab practicum scores. The partner within each team with the higher score was designated as the α and lower scoring partner as the Ω partner. Table 2 contains the statistical summary for the partitioned control sub-groups which were determined to be statistically different, $p < 0.01$ (from the two-sample Kolmogorov-Smirnov and Wilcoxon sign rank tests). These nonparametric tests were used instead of the t-test since the $\alpha|\Omega$ partitioned sub-groups were no longer normally distributed.

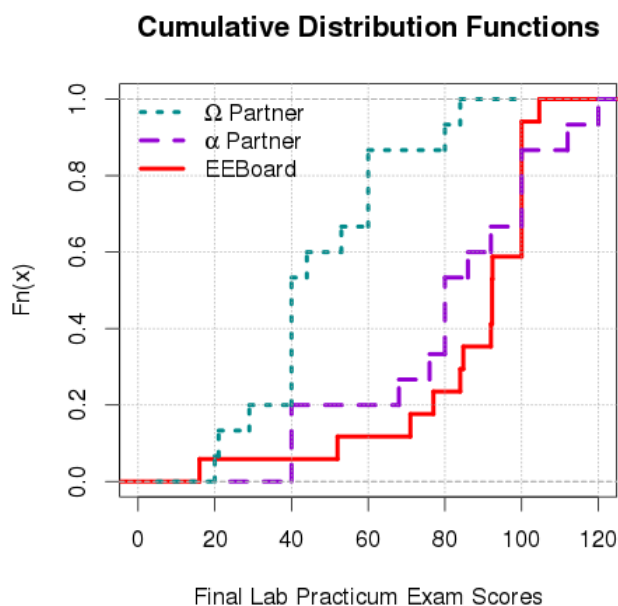


Figure 6: Lab final practicum exam grade distributions for the partitioned control group composed of the dominate α Partner (dashed violet) and their passive Ω Partner (dotted cyan) from the two person Control/Partner group teams along with the EEBoard students (solid red). The Ω Partner distribution differs significantly from both the α Partner and EEBoard distributions; however, the α Partner and EEBoard distributions were not statistically different.

Figure 6 includes the lab practicum score distributions for the α and Ω control partitions along with the EEBoard group's distribution. The EEBoard and Ω -Partner distribution were statistically different, $p < 0.001$ (Kolmogorov-Smirnov and Wilcoxon sign rank tests). The final lab practicum scores for the Singles group were not statistically different from either the EEBoard group or α -Partner control group distributions. These results imply that the level of laboratory proficiency on the final lab practicum for the α -Partner group was indistinguishable from the EEBoard students as well as those who worked individually on traditional laboratory equipment. Therefore, these findings show that the level of laboratory proficiency was unrelated

to the laboratory apparatus and directly related to the level of participation during the weekly laboratory assignments.

PSpice® Final Exam Results

The PSpice® final exam was administered on the same day as the final lab practicum exam and the summary statistics for the three groups are presented as cumulative distribution functions in Figure 7. The Kruskal-Wallis rank sum test revealed no statistically significant differences in these three distributions. The nonparametric Kruskal-Wallis test was employed since both the EEBoard and Singles group distributions failed the Shapiro-Wilk normality test.

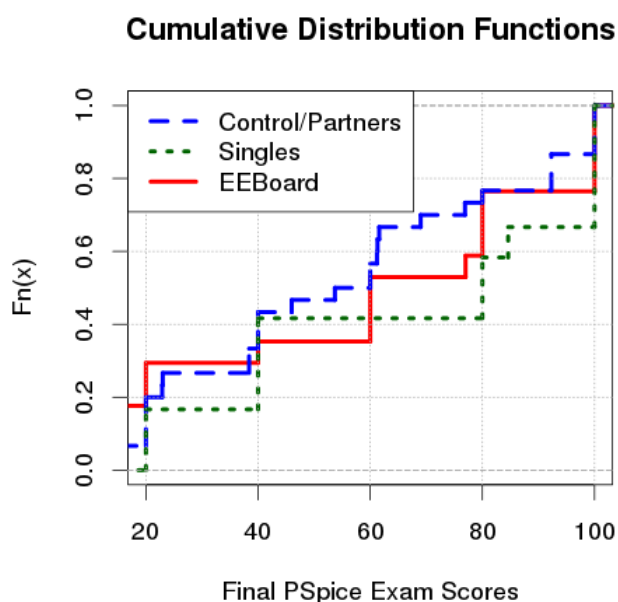


Figure 7: PSpice® final exam grade cumulative distribution functions for the Control/Partners group (dashed blue), Singles group (dotted green), and the EEBoard group (solid red). These group distributions were not statistically different.

In contrast to the final lab practicum, the PSpice final was unable to distinguish a difference between these three groups. Unlike the laboratory exercises, every student in each of the three groups was required to complete a pre-laboratory assignments which included a PSpice exercise. All students submitted their pre-laboratory results as an individual report. A similar analysis on the average pre-laboratory report scores disclosed no statistically significant differences between groups.

Similar to the prerequisite Circuits I course grades, the PSpice final may be considered an indicator of the students basic circuit knowledge. Both the Circuits I as well as the PSpice final grades did not differ between the Control/Partners and EEBoard groups yet there was a statistically significant improvement in the EEBoard group members final lab practicum grades as compared to the Control/Partners group's performance. Successful performance on the final lab practicum required both a basic knowledge of circuit theory as well as an ability to apply this knowledge to the construction and testing of the circuits. A similar level of the knowledge of circuit theory as measured by the grades in Circuits I and the PSpice final did not translate into a

comparable level of performance on the final lab practicum as with their cohorts in the EEBoard group. Partitioning the Control/Partners group into the α and Ω partners revealed that the aggregate performance of the Control/Partners group was statistically diminished by the differential performance of the partners.

Final Lab Practicum Relative to the Circuits I Grades

A weak correlation between the students' Circuits I grade and their performance on the final lab practicum had been observed in previous studies^[9]. The relationship between the final lab practicum grades and the Circuits I grades for the current study are shown in Figure 8. The lab practicum grades for students who earned an A or B in Circuits I ($n=32$) was statistically different from those who received a C or D ($n=27$) (Wilcoxon rank sum test, $W=292$, $p<0.05$). The Circuits I grade effect may have influenced the results for the Control/Partners and EEBoard groups final lab practicum grade distributions, in Figure 4, had there been a mismatch in their Circuits I grades. Since a matching existed between the Control/Partners and EEBoard groups Circuits I grade distributions (Figure 3), this potential differential bias was minimized in the current study between these two groups.

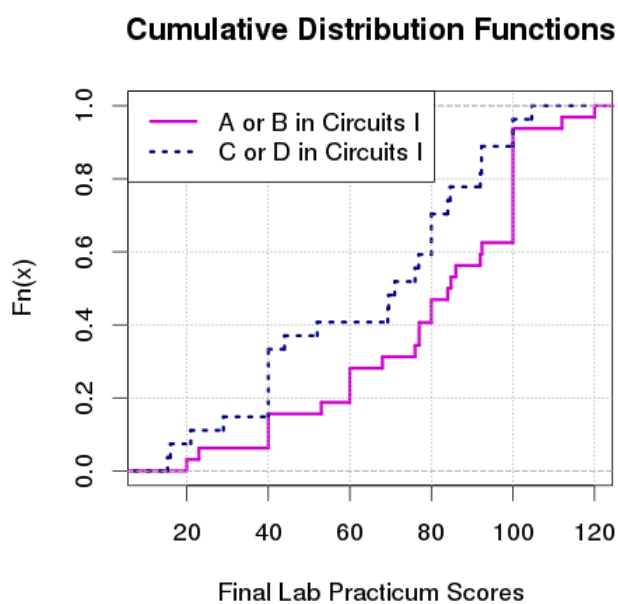


Figure 8: Final lab practicum grades cumulative distribution functions for students from a combination of all three groups in the study relative to the students' grades in Circuits I. There was a statistical significant difference between the A+B group distribution and the C+D curves where 40% (11/27) scored < 60 on the lab practicum.

Although previous studies found a statistically significant improvement in the final lab practicum score for Singles relative to the Control/Partners group, this was not the case for the current study. In the current study, the Singles group had a slightly lower Circuits I grade distribution as shown in Figure 3 which may have introduced a small left shift in the Singles group cdf curve as seen in Figure 4. Since the main objective of the current study was to compare and contrast the performance of the students who utilized the EEBoard with the students who performed their weekly lab assignments in a traditional environment with teams of two and with standard

laboratory equipment, the EEBoard and Control/Partners groups were matched at the expense of the Singles group.

Summary and Conclusions

The final laboratory practicum exam provided a direct assessment of the students' laboratory proficiency representing their circuits knowledge, laboratory skills and ability, and their ability to apply these to circuits analysis and applications. Students in the Control/Partners group performed their weekly lab assignments as two member teams and utilized traditional laboratory equipment while students in the EEBoard group performed their weekly labs individually on the Electronics Explorer board. Students in these two groups were matched based upon their prerequisite Circuits I lecture course grades, Figure 3. Students who performed their weekly laboratory exercises individually utilizing the EEBoard surpassed the Control/Partners group students on the final lab practicum exam, Figure 4.

A third group of students, Singles group, utilized traditional laboratory equipment and individually performed their weekly labs. Their performance on the final lab practicum was statistically significantly less than the EEBoard group's performance (Wilcoxon rank sum $W=141$, $p<0.05$ one-tail); however, not statistically different from the Control/Partners group, Figure 4. In previous studies, students who performed their weekly laboratory exercises individually out performed students who did their weekly labs in groups of two^[3]. The Singles group had a slightly lower average grade in the prerequisite Circuits I lecture course than did the students in both the Control/Partners and EEBoard groups, Figure 3. This may have compromised the separation between the Singles and Control/Partners groups. As observed in Figure 8, students with higher grades in the prerequisite circuits lecture course scored higher on the final laboratory practicum exam.

Students in each team within the Control/Partners group were separated into a dominate higher scorer (α) and lower scorer (Ω) partners on the lab practicum exam. The median score for the α sub-group was 80 while the Ω sub-group had a median of 40, Table 2. There was a statistically significant separation between these two sub-groups, Figure 6. The higher scoring α Partner sub-group distribution was similar to and not statistically different from the EEBoard or Singles groups' scores. As observed in this and previous studies^[3], one student in a team of two or more dominated the weekly lab performance and achieved a higher score on the final lab practicum relative to their partner.

It has been shown that students exhibit different learning styles which contribute to their comprehension and assimilation of instructional information especially in a classroom environment with a single dimensional presentation format^{[10][11]}. 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 preview the laboratory assignment and procedures. The instructor was available during the laboratory exercise to provide assistance in the mechanics of the lab procedures. Students progressively 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.

In the first semester of this three semester study, 5 of the 10 students participating in the 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 when 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. The students' cumulative grades for the course included their weekly lab reports in addition to the final lab practicum and PSpice final where the latter two components represented ~17% of their total. Four students in the EEBoard group and 5 in the combined Control/Partners and Singles groups failed to achieve a passing grade for the course. Since the students in the EEBoard 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. In order to palliate the drop out and failure rate, a policy was implemented requiring all student to attend a pre-lab briefing. In the remaining two semesters, 1 of 13 students enrolled in the EEBoard group dropped the course whereas 6 of 33 in the combined Control/Partners and Singles groups dropped.

The results from this study also imply that a full scale deployment of an individualized laboratory system would enhances the students' acquired laboratory proficiency. The resultant independent structure of the laboratory protocol requires periodic tracking of student progress. As observed in this study, a weekly pre-lab meeting and lab report should be required from each participant to monitor adherence to the laboratory schedule.

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