Improvement in Laboratory Skills and Knowledge Achieved Through Individual Student Lab Participation

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Abstract

In a fundamental electrical engineering laboratory course, the performance of students in a solo laboratory team organization was contrasted with the performance of students utilizing a multiple student lab team model. The students' performance on the laboratory final practicum exam provided an indicator of their individually acquired knowledge and skills. The student's participation individually in lab resulted in marked improvement in the their ability to learn rudimentary laboratory skills and knowledge and their ability to apply them in basic circuits analysis applications. Several other factors were investigated that could have contributed to this increase in student performance on the final laboratory practicum exam; however, the only factor that significantly and independently contributed to the students' laboratory skills and knowledge base proved to be student level of participation in the laboratory exercises. The results of this study indicated that students must be fully engaged in the fundamental laboratory exercises to thoroughly and properly learn the skill and knowledge required for application to basic circuit analysis.

Introduction

Traditionally, to teach basic electric circuits skills and knowledge undergraduate engineering programs have utilized a group based laboratory organization consisting of multiple students per team. A laboratory team of two or more students was reported to be the best method to achieve the laboratory objectives based on student surveys[1]. Other authors have stated that objective assessment tools are required to evaluate the laboratory education benefits[2]. In a previous paper[3], the authors reported the results from a preliminary study showing a direct correlation between a student's participation as an active member of a laboratory team and his or her ability to perform basic electric circuit measurements and interpretations as evaluated in a final laboratory practicum.

Background

The circuits laboratory involved in the previous study was a one semester course presented coincident with the second semester of a two semester circuits lecture course. Ten or more labs were held 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. The students individually completed the pre-laboratory assignment and submitted a weekly pre-lab report. The laboratory assignment was then performed by teams consisting of two or more students, and a single lab report was submitted by each team. A final examination was administered to each student in the final week of the semester and consisted of a laboratory practicum and a separate PSpice circuit simulation component. The lab practicum was straight forward, laboratory skill based, and covered only material presented in the weekly lab exercises. An objective measure was established to determine a student's active participation level within a team. The lab final practicum and Pspice grades are shown in Figures 1 and 2 relative to the percentage of time each student spent as an active participant (builder-tester) during the laboratory exercise. A statistically significant correlation was found between the time spent during the the lab building and testing circuits and the grade on the final lab practicum (Spearman's rank correlation ρ = 0.61, p-value = 0.00031); however, a correlation was not seen between the builder-tester percent time and PSpice final (ρ = 0.24, p-value = 0.2). This correlation between the lab practicum grade and the time spent as a builder-tester was even more apparent below the 50% participation level.

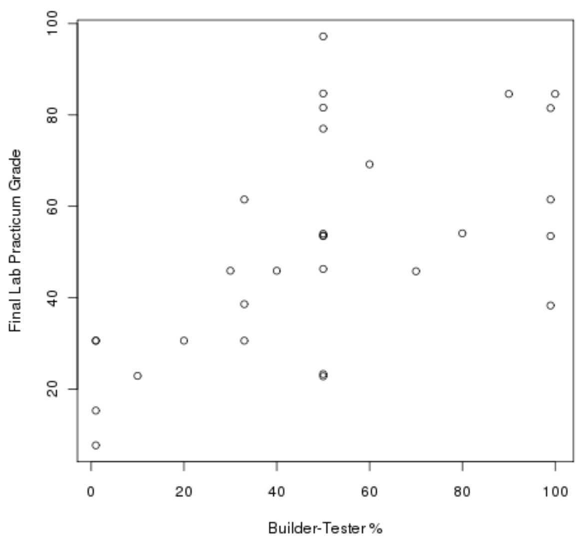

Figure 1: Laboratory final practicum grade for the dual partner (control) group.

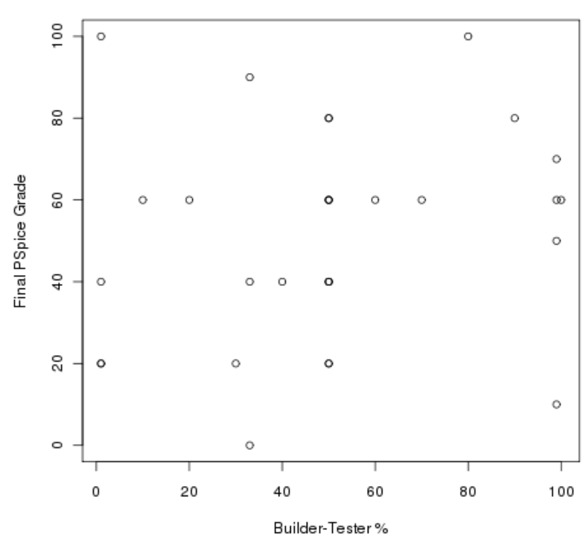

Figure 2: PSpice final grade for the dual partner (control) group.

Since correlation was observed between the lab practicum grade and the student's individual active participation level but not between the PSpice grade and their active participation level, it was held that the practicum test grade reflected the laboratory skills and knowledge acquired by the student. From the data presented, the performance of a student on the lab practicum was dependent on his or her degree of active participation in the laboratory exercise. As a result of these preliminary findings, the basic circuits laboratory organization was changed from teams composed of multiple students (dual student participation) to individual-student lab participation (solo student participation). There were no corresponding changes implemented in the pre-lab portion of the lab assignments.

A follow-up study was initiated to evaluate the effectiveness of the change in the laboratory student organization. The follow-up study utilized two groups: a study group and a control group. The study group was encompassed of two semesters of solo lab participation and included seven sections with 66 students. The control group consisted of the dual student teams utilized in the preliminary study. Since the composition of the lab practicum remained unchanged (except for modified circuit component values) from one study to another, it continued to serve as the lab course effectiveness metric. This study was approved by the Human Subject Committee of Arkansas Tech University.

Results

In order to evaluate the effectiveness of the change to solo participation in the electric circuits laboratory classes, both the lab practicum and PSpice final exam grades were compared between the control and study groups.

The histograms of the lab practicum grades for two groups are shown in Figures 3 and 4, and Table 1 provide associated statistics for these groups. The histogram bins represent the distribution of the lab practicum exam grades in increments of 20. The upper bin extends to 120 due to a bonus question provided on the exam for both the control and study groups. The frequency of grade occurrences was normalized by the number of students taking the exam and the bin width in order to represent a density function.

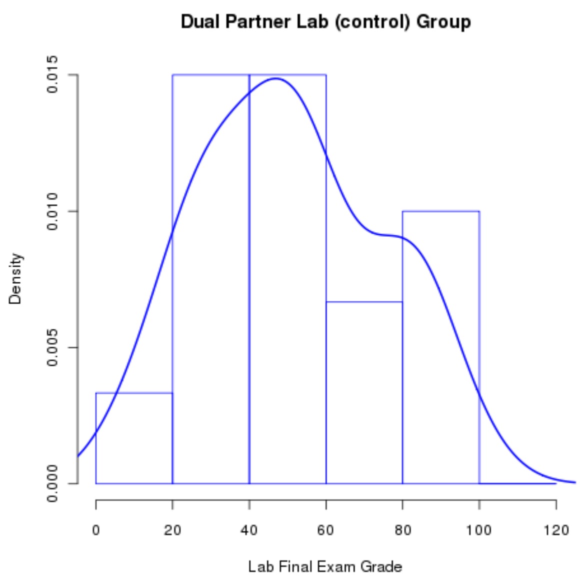

Figure 3: Histogram of final lab exam grades for the control group (two student lab teams).

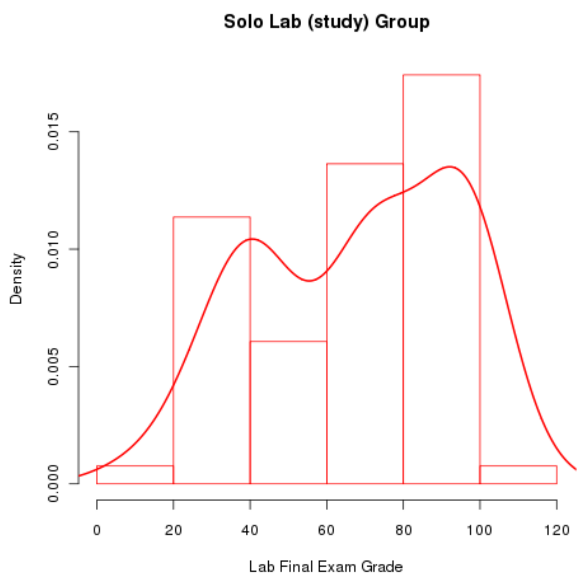

Figure 4: Histogram of final lab exam grades for the study group (solo lab teams).

Examination of Figures 3 and 4 reveals that for the study group (solo student laboratory organization) the frequency of failing grades (those below 60) was less than that of the control group (dual student laboratory teams) and conversely, for passing grades (those above 60), the study group exceeded the control group. This implies that individual student participation in the electric circuits laboratory experiments improved their ability to utilize their laboratory skills and electric circuit knowledge on the final lab practicum.

Groups	Minimum	1st Quartile	median	mean	3rd Quartile	Maximum	n
control	7.7	30.6	49.4	50.9	67.3	97.2	30
study	7.6	46	69.4	67.9	92.3	112.3	66

Table 1: Lab final practicum grade statistics for the control and study groups.

The students' grade on the laboratory practicum provided an optimal estimator to compare the performance of the study group with the control group. A statistical test of normality applied to the control and study groups revealed that the study group, shown in Figure 4, was non-normally distributed (Shapiro-Wilk test, p-value = 0.0015). Therefore, nonparametric tests were used to compare these two distributions[4].

The Kolmogorov-Smirnov (K-S) two-sample test[4] was applied to the Cumulative Distribution Functions (cdf) of the two data sets as shown in Figure 5 utilizing the statistical package R[5] resulting in D = 0.37, p-value = 0.0071 (two-sided). The two-sided K-S two-sample parameter D is the maximum absolute difference between the two empirical cdf curves[4], or the maximum vertical difference between the two cdf curves in Figure 5. The cdf is the cumulative sum of the grade density function and as such, an improvement in the grades for the study group causes its cdf to fall below that of the control group. The K-S test results allowed the rejection of the null hypothesis (that these two distributions were equivalent) at p-value<0.01. In addition, the data was also evaluated using the nonparametric Wilcoxon rank sum test with continuity correction[5] which yielded the results (W = 618.5, p-value = 0.0033) further confirming a statistical significant improvement in the grades of the study over those of the control group. The Wilcoxon rank sum statistic W represents the sum of the ranks of the sample test scores in the control group which have been combined with the study group scores and then sorted in increasing order of magnitude. The Wilcoxon rank-sum test is similar to the Mann-Whitney U test[6] such that the U statistic from the Mann-Whitney U test is linearly related to the W statistic[4].

The control group included all students regardless their level of laboratory participation as a Builder-Tester (Figure 1). In order to further investigate the effect of the weekly laboratory participation, the control group was subdivided into those students who participated in the laboratory exercises at < 50% (N=11), and those who participated at the 50% level or higher (N=19). The comparison of the cdf's for lab practicum performance for these two partitioned control groups with the study group, yielded the following results:

- Study group compared to the control group as Builder-Tester of < 50%. K-S test: D = 0.67, p-value = 0.00046 (two-sided), indicating a significant difference in the cdf's.
- Study group compared to the control group as Builder-Tester of 50% or greater. K-S test: D = 0.28, p-value = 0.20 (two-sided), indicating the equivalence of these cdf's can not be rejected.

Thus, a participation in the weekly laboratory exercises of < 50% significantly limited the students' performance on the final laboratory practicum.

These statistical results show that the change in the laboratory organizational structure enhanced student acquired laboratory skills and knowledge as indicated by the improved performance on the lab practicum exam thus validating and supporting the increased utilization of resources required for the new structure.

Differences in the control and study group populations could have influenced the laboratory practicum results. In the following sections, the factors which were independent of the group composition and thus could have resulted in a change to the laboratory practicum were investigated.

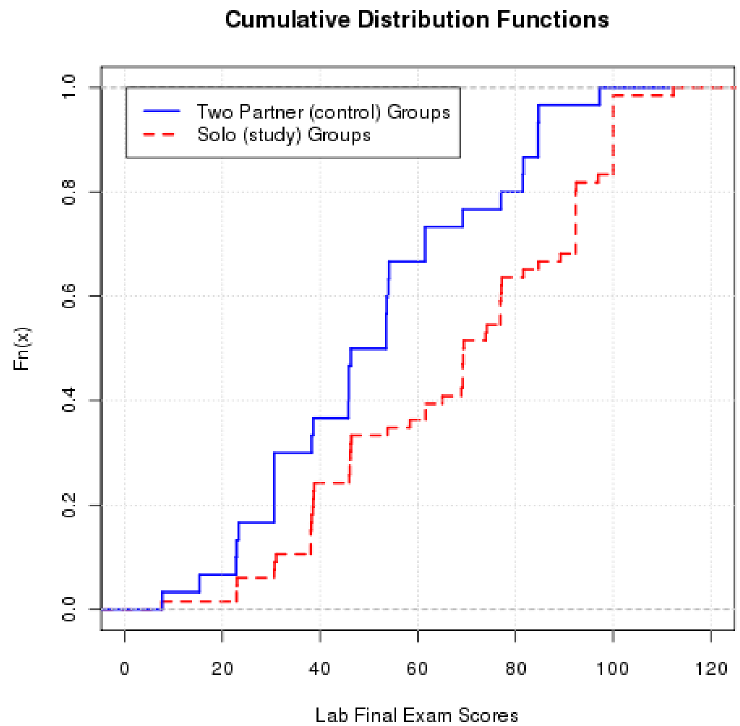

Figure 5: Lab final exam grade cumulative distribution functions for the control group (solid blue) and the study group (dashed red).

PSpice Results

The PSpice final examination results were also analyzed to rule out a difference in the student population between the control and study groups as a cause for the improvement in the lab practicum grade distribution. The change introduced in the laboratory organization between the control and the study groups did not appear to affect the PSpice component in the pre-laboratory exercises. All students were required individually to perform the PSpice pre-laboratory exercises for both the control and study groups. Since there were no differences between the PSpice exercises within the pre-lab components for the control and study groups, a difference in the student population between the these two groups may be reflected in their PSpice grades. The cdf's for the control and study groups for the PSpice final examination grades are depicted in Figure 6. Neither the K-S test ($D = 0.17$, p-value $= 0.57$) nor the Wilcoxon rank sum test with continuity correction ($W = 1119$, p-value $= 0.30$) reached a level of statistical significance. Therefore, the hypothesis that these two distributions are the same cannot be rejected implying that the PSpice exam score on the final exam is not able to reject homogeneity of the student populations between the control and study groups. The lack of statistical significance in the PSpice exam scores between the control and study groups is still not sufficient to state the the two groups are the same. There are several other factors which may indicate a difference in these two groups of students.

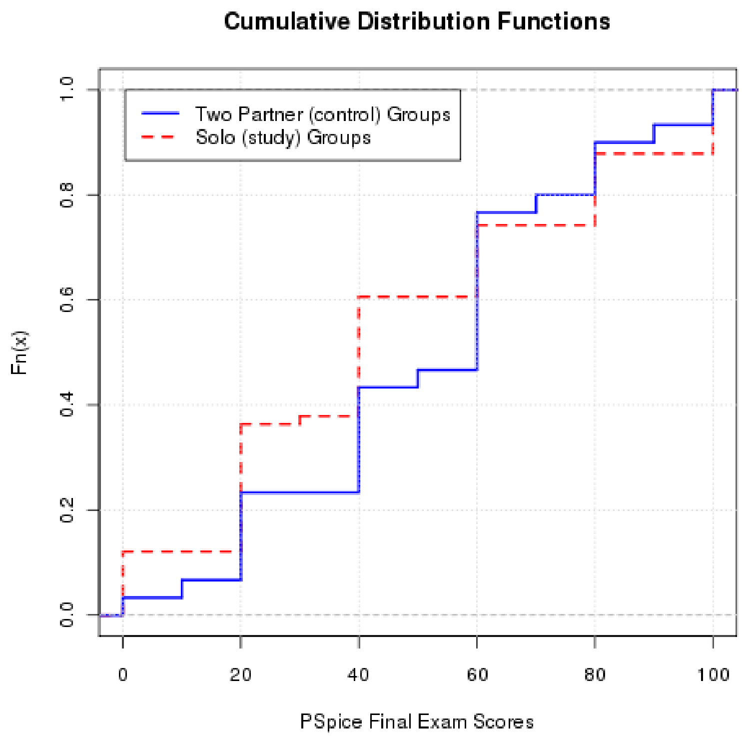

Figure 6: PSpice final exam grade cumulative distribution functions for the control group (solid blue) and the study group (dashed red).

Other Factors That May Contribute to Student Population Differences

Three academic programs utilize the electric circuits lab in their respective curricula. The control and study group compositions were investigated to discover any statistical significant differences in the group populations and if so how these differences might have influenced the results. The distribution of student majors between the control and study groups were similar as shown in Table 2 (e.g., 27% EE majors in the control group and 29% EE majors in the study group). Also, no statistical difference in the lab practicum grade distributions between majors within the control and study groups were found.

Groups	Overall			EE Majors			ME majors			Physics Majors		
	median	mean	n	median	mean	n	median	mean	n	median	mean	n
control	49.4	52.7	30	45.9	49.5	8	53.5	51.4	22			0
study	69.4	67.9	66	74.1	71.4	19	69.2	65.4	43	88.5	78.8	4

Table 2: Lab practicum grade medians (and means) and student numbers by majors in the control and study groups.

Although there was no statistical difference in the lab practicum grades between majors in the study group, the median (and mean) scores of the physics majors were higher than the corresponding EE and ME majors' scores. Since no physics majors were present in the control group, the physics majors were removed from the study group to form a modified study group and the lab practicum grade comparison between the control and this modified study group distribution was repeated with the following results: K-S test, D = 0.36, p-value = 0.01 (two-sided); and Wilcoxon rank sum test with continuity correction, W = 590.5, p-value = 0.0047. Thus, these small differences in the student populations between the control and the study groups did not appear to significantly impact the lab practicum results of the full study group.

Students typically enroll in the circuits II lecture coincident with circuits lab. There was a shift in the lecture grades distribution between the two groups: 83% earned an A or B in circuits II lecture from the control group as compare to 62% in the study group. The distribution of grades in the circuits lecture course may reflect the student's general knowledge and understanding of circuits which could affect his or her performance on the lab practicum. In order to evaluate the influence of this shift in performance in the lecture course on the lab practicum results, both the study and control groups were partitioned to include only those students that made an A or B in the circuits II lecture course. There were 24 students in this partitioned control group and 41 in the partitioned study group. The resultant statistical analysis of the cdf's of these lab practicum grade distributions yielded D = 0.40, p-value = 0.016 (two sided) for the K-S test. This was consistent with the results from the full populations of the control and study groups.

It can be assumed that the groups' composition was not a contributing factor on the difference observed in the lab practicum grades between the control and study groups and therefore these groups were considered homogeneous because:

- the distribution of student majors was similar between the control and study group,
- there was no statistical difference in the performance on the lab practicum between majors within the control and study groups,
    - and the removal of the Physics majors did not change the results,
- the grade distribution in circuits II lecture was slightly different between the control and study groups; however, it did not influence the results.

Relationship Between Lab Report Grades and Lab Practicum

Student participation in solo lab team organization resulted in a border-line statistically significant positive correlation between the the lab practicum grades and the average weekly lab report scores. This correlation was not present in the control group. Figure 7 shows the lab practicum grades versus the average lab report scores for the study group. Since both the lab practicum and lab report grades are not normally distributed, nonparametric correlation analysis was applied. The results are shown in Table 3 for both the control and study groups.

Groups	Spearman's rank correlation		Kendall's rank correlation	
	rho	p-value	tau	p-value
control	-0.100	0.600	-0.050	0.600
study	0.25*	0.045	0.170	0.051

Table 3: Correlation between the lab practicum and average lab report grades. There was a border-line significant positive correlation for the study group data.

This correlation between the weekly lab report grades and the final lab practicum scores for the study group implied that the level of laboratory skills and knowledge obtained during the semester influenced the performance on the final lab practicum examination. However, the spreading of data into the lower right-hand quadrant, indicated that those students represented by the lower right hand data were unable to successfully retain and apply their knowledge and skills on the final practicum exam.

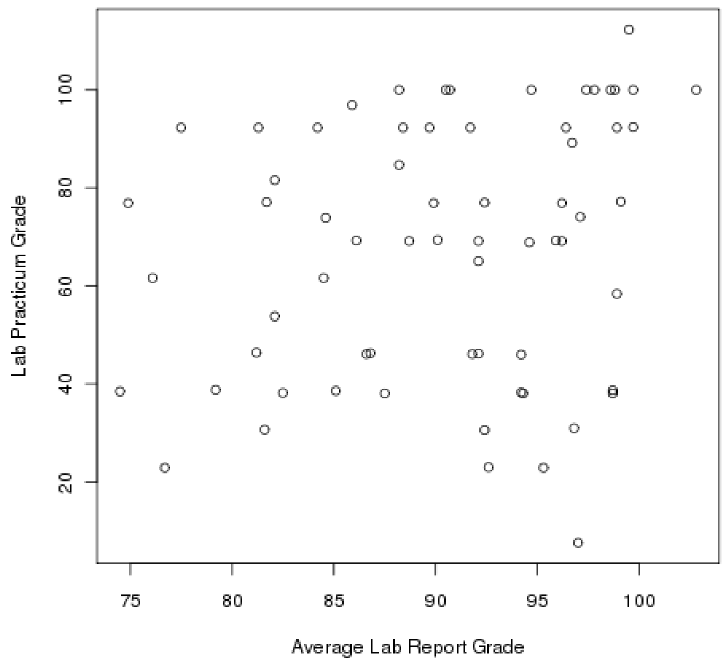

Figure 7: Study group lab practicum and average lab report grades.

Conclusions

Many university engineering laboratories are routinely performed with groups of two or more students. It was observed in the control group that several students immediately established a role within the team either as an active participant in the laboratory exercise or a data recorder and report writer. Although the lab syllabus clearly indicated that a final lab practicum would be administered, the students retained these roles throughout the semester. The students' activity scores (Builder-Tester percent in Figure 1) were directly related to their performance on the final lab practicum.

The final laboratory practicum administered uniformly to each student at the end of the semester for both the control and study groups served as an objective assessment of each student's knowledge and skill level for a basic electric circuits laboratory. Students performed better overall on a final lab practicum when student level of participation exceed 50%. Changing the laboratory structure into a solo laboratory organization further improved the overall performance on the final lab practicum as observed between the control and study groups by recruiting additional students at a higher level of participation on the laboratory exercises. Although, the control and study groups were slightly dissimilar in composition, these small differences in the groups did not appreciatively alter the results.

The implementation of the solo lab organization required additional personnel and physical resources which was achieved through a corresponding increase in the number of laboratory sections per semester. Although solo lab participation resulted in a significant and meaningful improvement in the students' abilities and knowledge, the cost to benefit ratio for the concomitant utilization of resources requires additional investigation.

Bibliography

1. Oakley BA, Hanna DM, Kuzmyn Z, Felder RM. Best Practices Involving Teamwork in the Classroom: Results From a Survey of 6435 Engineering Student Respondents. *IEEE Trans Education*. 2007;50(3):266-272.
2. Hofstein A, Lunetta VN. The laboratory in science education: Foundations for the twenty-first century. *Science Education*. 2004;88(1):28-54.
3. Greco EC, Reasoner JD, Nelson RE. Student Participation in EE Lab Teams as a Predictor of Acquired Skills and Knowledge. In: *Proceedings of the 2008 Midwest Section Conference of the American Society for Engineering Education*.; 2008.
4. Gibbons JD, Chakraborti S. *Nonparametric Statistical Inference*. 4th ed. Marcel Dekker; 2003.
5. R Development Core Team. *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing; 2009. Available at: http://www.R-project.org.
6. Wackerly DD, Mendenhall III W, Scheaffer RL. *Mathematical Statistics with Applications*. 6th ed. Duxbury: Thomson Learning; 2002.

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