AC 2010-1503: STUDENT LABORATORY SKILLS AND KNOWLEDGE IMPROVED THROUGH INDIVIDUAL LAB PARTICIPATION

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Student Laboratory Skills and Knowledge Improved Through Individual Lab Participation

Abstract

The traditional laboratory team based teaching paradigm did not as effectively inculcate basic laboratory skills and knowledge as did solo lab participation. In a fundamental electrical engineering laboratory course, the acquired knowledge and skills of students who performed laboratory experiments individually throughout the semester were contrasted with those who performed the lab exercises in traditional two member teams. The students' performance on the final laboratory practicum exam provided an effective and verifiable objective metric with sufficient specificity to differentiate between the dual and solo participation lab groups. Students who performed their laboratory exercises individually during the semester showed noticeable improvement in the their ability to apply rudimentary laboratory skills and knowledge to basic circuits analysis applications in their final lab practicum scores. The study was performed over three consecutive semesters with 96 students sub-divided into a control and study group. Students in the control group performed the weekly laboratory exercises in lab teams of two or more while students in the study group worked independently. The study group exhibited statistically significant higher scores on the final lab practicum as compared to the control group. An extensive verification analysis was performed to investigate additional inter-group factors which may have contributed to the observed inter-group differences in student performance on the final laboratory practicum exam. The only factor that significantly and independently contributed to the students' laboratory skills and knowledge base proved to be the 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 and retain the skills and knowledge required for application to basic circuit analysis.

Introduction

The engineering laboratory (or “shopwork”) has been a hallmark of the engineering educational process from its very beginning[1]. Traditionally, electric circuits laboratories designed to teach basic skills and knowledge in undergraduate engineering programs have utilized a team based laboratory approach which remains the recommended format to teach fundamental skills along with team work and communications[2]. A laboratory team of two or more students was reported to be the best method to achieve the laboratory objectives based on student surveys[3], and the lab report was recommended as the best assessment tool[2]. Other authors have stated that objective assessment tools are required to evaluate the laboratory education benefits[4]. This study will established that there was 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 by a final laboratory practicum.

Background

The study encompassed three consecutive semesters of circuits laboratory, and involved students who were enrolled in the second semester of a two semester circuits lecture course. Ten or more labs were held on a weekly basis during the semester which were designed 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. Laboratory exercises involved rudimentary design and analysis of linear (resistive, first and second order) networks, operational amplifiers and diodes and utilized basic electronic laboratory test equipment such as protoboards, function generators, power supplies, oscilloscopes, multimeters and frequency counters.

In the control group, the laboratory assignments were performed by teams consisting of two or more students with a single lab report submitted by each team. Students in the study group performed each laboratory exercise individually and submitted their own lab report. Students in both the control and study groups individually completed the pre-laboratory circuit simulation assignment and submitted a weekly pre-lab report.

A final examination was administered to each student in both groups during the final week of the semester and consisted of a laboratory practicum and a separate PSpice circuit simulation component. The laboratory practicum was straight forward, laboratory skill based, and covered only material presented in the weekly lab exercises. In the control group, each student's active participation level in the laboratory exercises was determined by the laboratory instructor. If each member of the team participated equally in the laboratory exercises, they were each assigned a 50% level of participation. Observation reveled that several teams in the control group segregated individual responsibilities and maintained those duties throughout the semester. A team member was assigned a 10% or less for participation if their duties routinely involved data recording and report writing with little or no active participation in the laboratory exercise, and their partner was assigned a concomitant 90% or greater participation level.

The final lab 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 in the control group. A statistically significant correlation was found between lab time spent building and testing circuits and the the final lab practicum grade (Spearman's rank correlation $\rho = 0.61$, p-value = 0.00031), Figure 1. The correlation between the lab practicum grade and the time spent as a builder-tester was even more apparent below the 50% participation level. However, the PSpice final grade did not reveal a significant correlation between lab time spent as a builder-tester and the PSpice final grades ($\rho = 0.24$, p-value = 0.2), Figure 2.

These results imply that the students' active participation in the weekly laboratory exercises directly contributed to their laboratory skills and knowledge; however, a statistically significant correlation does not imply causality. In order to further investigate these findings, the student participation in the basic circuits laboratory exercises was altered from teams composed of multiple students (dual student participation) to individual-student (solo) lab participation. Each student in the study group individually preform the pre-lab portion of the lab assignments.

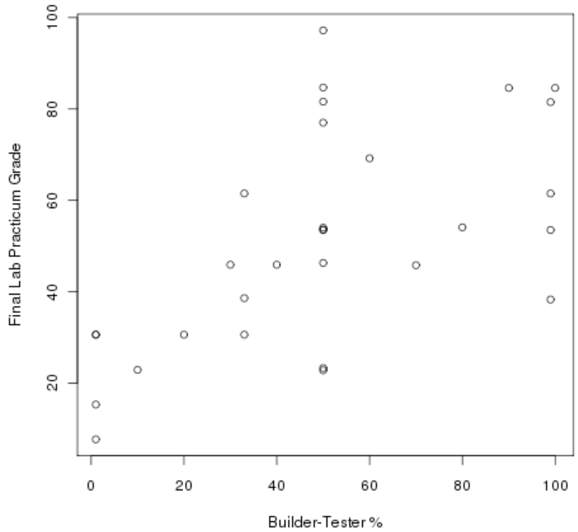

Figure 1: Laboratory final practicum grade for the dual partner (control) group.

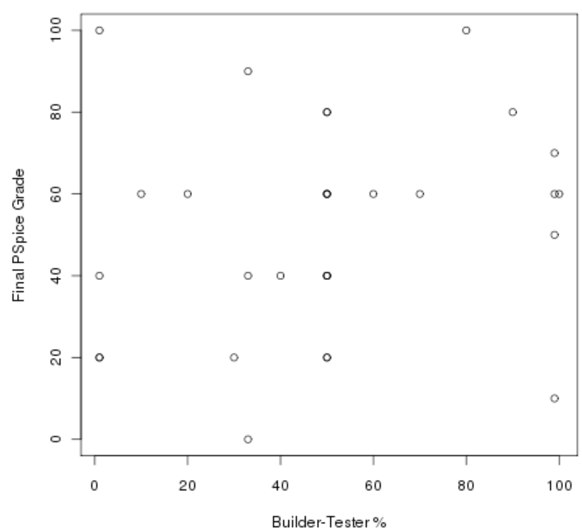

Figure 2: PSpice final grade for the dual partner (control) group.

The effectiveness of solo versus team laboratory student organization was then evaluated by contrasting the data between the study and control group. The control group consisted of one semester (two sections) of dual lab participation with 30 students, and the study group encompassed two semesters (a total of seven sections) of solo lab participation with a total of 66 students. Since the composition and structure of the final laboratory practicum remained unchanged throughout the control and study group evaluations (except for modified circuit component values), it served as the laboratory course effectiveness metric. This study was approved by the Human Subject Committee.

Results

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

The histograms of the lab practicum grades for the two groups are shown in Figures 3 and 4, with Table 1 providing associated statistics for these groups. The histogram bins represent the distribution of the lab practicum exam grades in increments of 20 points. The upper bin extends to 120 points due to a bonus question provided on the lab practicum exam for both the control and study groups. The vertical axes in Figures 3 and 4 represent the frequency of grade occurrences per bin. The vertical axes were normalized in order for each distribution to represent a density function with a total area equal to 1.

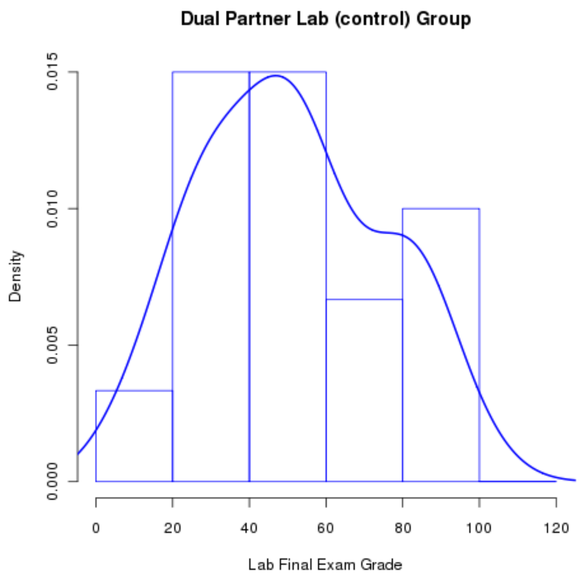

Figure 3: Histogram of final lab exam grades for the control group (two student lab teams).

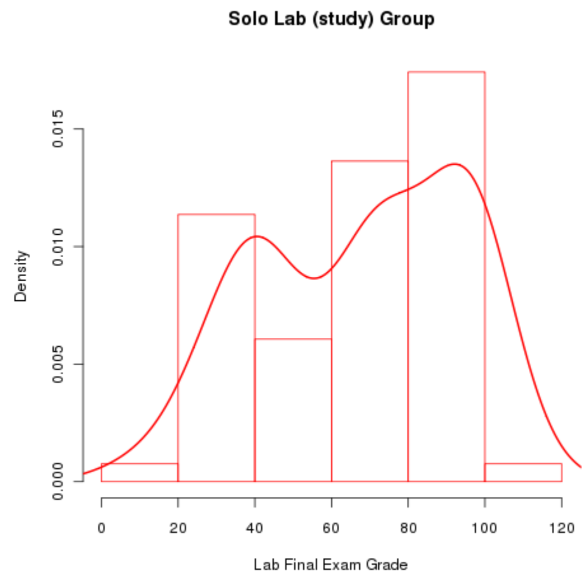

Figure 4: Histogram of final lab exam grades for the study group (solo lab teams).

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. Each practicum included a bonus problem. One student was able to correctly answer the question resulting in a score greater than 100.

The students' grade on the final laboratory practicum provided a measurement of laboratory knowledge and procedures 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 not normally distributed (Shapiro-Wilk test, p-value = 0.0015). Therefore, nonparametric tests were used to compare these two distributions[5].

The Kolmogorov-Smirnov (K-S) two-sample test[5] was applied to the Cumulative Distribution Functions (CDF) of the two data sets as shown in Figure 5 utilizing the statistical package R[6] 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[5], or the maximum vertical difference between the two CDF curves in Figure 5. The CDF represents the cumulative sums of the grade density functions, shown in Figure 3 and 4, 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[6] which yielded the results (W = 618.5, p-value = 0.0033) further confirming a statistically 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[7] such that the U statistic from the Mann-Whitney U test is linearly related to the W statistic[5].

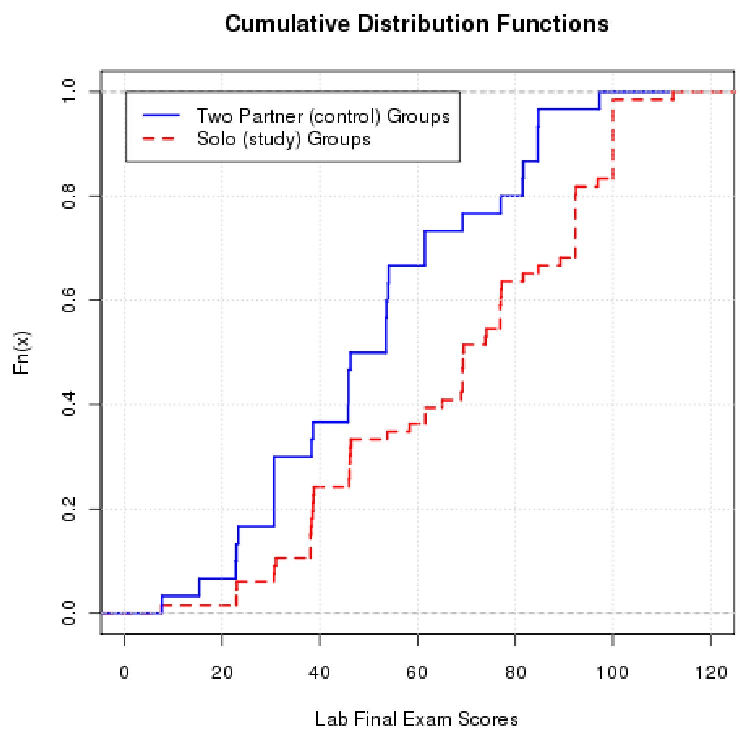

Figure 5: Lab final exam grade cumulative distribution functions for the control group (solid blue) and the study group (dashed red), p<0.01 (K-S test).

Lab Practicum Results by Level of Laboratory Participation

The control group included all students regardless of 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 then subdivided into three sub-groups based on their level of active participation in the laboratory exercises during the semester – less than 50% (N=11), equal to 50% (N=10), and greater than 50% (N=9). Two additional control sub-group partitions were also consider: participation ≤50% (N=21) and ≥50% (N=19). Since each student in the study group individually performed every laboratory exercise, their level of participation was 100%.

As shown in Figure 5, there was a statistically significant improvement in the lab practicum performance between the study and combined control groups.

The percentage of students that passed the final lab practicum (a score of 60 points on the lab practicum was considered passing) is shown in Table 2 by groups. The median scores along with K-S test CDF comparison results are also shown in Table 2. There was a statistically significant difference between the lab practicum grade CDF distribution between the study group and the control group at <50% participation as well as between the study group and the control group at ≤50%, but not between the study group and the control group at ≥50% participation. The lab practicum score CDF comparison within the control group between the partitions <50% and >50% participation was also significantly different, $p<0.05$. Table 2 shows a progressive increase in the pass rate and lab practicum median scores with level of active participation.

Students' participation in the weekly laboratory exercises of <50% significantly limited their performances on the final laboratory practicum. As the level of participation increased so did the pass rate and median lab practicum test scores. These results imply the students' performances on the final lab practicum were directly related to their level of participation in the weekly laboratory exercises.

<table>
<tr><th></th><th colspan="3">Control</th><th>Study</th></tr>
<tr><td>Level of Participation</td><td><50%</td><td>50%</td><td>>50%</td><td>100%</td></tr>
<tr><td>Pass Rate</td><td>9% (1 of 11)</td><td>40% (4 of 10)</td><td>56% (5 of 9)</td><td>64% (42 of 66)</td></tr>
<tr><td rowspan="4">Lab Practicum Median Score</td><td>30.6
p<0.0005</td><td>50.8
n.s.</td><td>61.5
n.s.</td><td rowspan="4">69.4</td></tr>
<tr><td colspan="2">45.9 (participation ≤50%)
p<0.005</td><td></td></tr>
<tr><td></td><td colspan="2">54.1 (participation ≥50%)
n.s.</td></tr>
<tr><td colspan="3">49.4
p<0.01</td></tr>
</table>

Table 2: Lab practicum pass rate (score ≥60 points) and lab practicum median scores for the study group and partitions of the control group by level of active participation in the laboratory exercises. The two-sample K-S test CDF comparison results between the study group and each partition of the control group are given. Although not shown in the table, there was also a statistically significant difference in the lab practicum score CDFs between the control group <50% and control group >50% participation, $p<0.05$.

Control and study group populations differences may have influenced the laboratory practicum results. In the following sections, the factors which were independent of the group composition were investigated to assess their impact on the final laboratory practicum grades.

PSpice Results

The PSpice final examination results were analyzed to rule out a difference in the student population between the control and study groups as a potential cause for the improvement in the lab practicum grade distribution. In both the control and study groups all students were required to individually perform the PSpice pre-laboratory exercises. 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. A difference in the PSpice final exam scores between the two groups would potentially imply a difference in the basic level of circuit knowledge between the the two groups. The CDFs 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, PSpice exam score on the final exam was not in itself able to reject the homogeneity of the control and study group student populations. The lack of statistical significance in the PSpice exam scores between the control and study groups was still not sufficient to state that the two groups were the same; however, other factors may have contributed to a difference in these two groups of students.

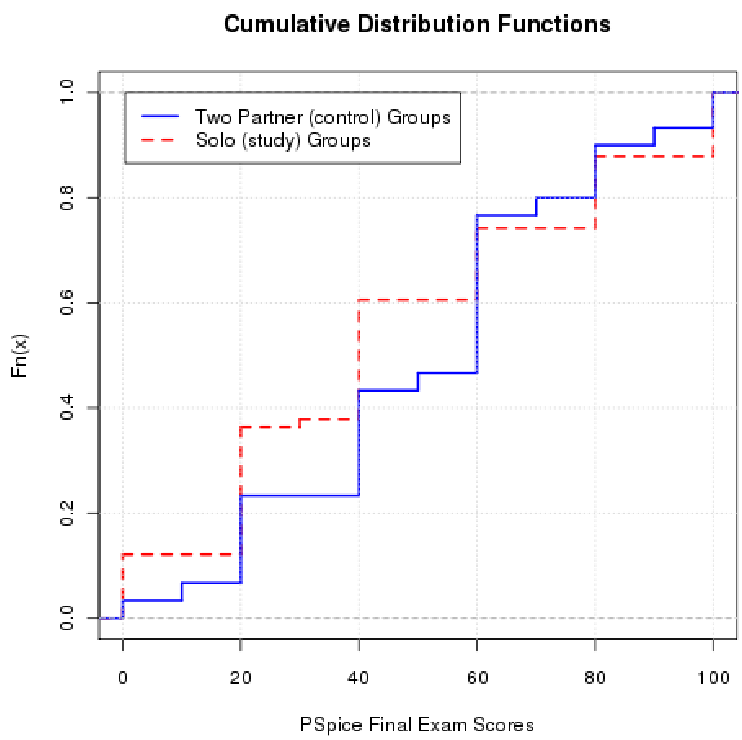

Figure 6: PSpice final exam grade cumulative distribution functions for the control group (solid blue) and the study group (dashed red).

Other Factors That May Contribute to Student Population Differences

Three academic programs utilized the electric circuits lab in their respective curricula. The control and study group compositions were investigated to discover any statistically significant differences in the group demographics; 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 3 (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 3: 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 there were no physics majors 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 were typically enrolled in the circuits II lecture coincident with circuits lab. A shift in the lecture grades distribution between was observed 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 have reflected 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 the circuit lecture grade distribution shift on the lab practicum results, only the students that made an A or B in both the study and control groups were compared. There were 24 students in this partitioned control group and 41 in the corresponding study group. The resultant statistical analysis of the CDFs 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.

As a result of these analyses, it can be assumed that the compositions of each group were not a contributing factor to the differences observed in the lab practicum grades between the control and study groups and therefore these groups were considered homogeneous based on the following:

- the distribution of student majors were 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 distributions in circuits II lecture were slightly different between the control and study groups; however, lab practicum grade results were not significantly altered by the lecture grade distributions.

Relationship Between Lab Report Grades and Lab Practicum

The lab report has been proposed as an assessment tool for laboratory exercises[2]; therefore, a close correlation between the final lab practicum and the laboratory report grade would be expected if both tools were equally adequate and sufficient measures of the students' knowledge and skills obtained in the laboratory. The results from two separate non-parametric correlation tests are shown in Table 4 for both the control and study groups. A statistically significant correlation was obtained in one of the two tests for the study group; however, neither test reached a level of statistical significance in the control group. In the control group, the laboratory exercises were performed by the two member lab teams with a common lab report submitted by each team. Student in the study group performed the laboratory exercises independently and submitted a lab report individually. Since it is impractical to independently determine the contribution of each team member in the control group to the creation of their common group lab report, the lack of a correlation between team lab report grades and individual lab practicum scores for the control group was non-conclusive.

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 4: Correlation between the lab practicum and average lab report grades. Statistical significance was achieved only for the study group data with the Spearman's rank correlation test.

Each student in the study group individually performed the laboratory exercises and submitted their own weekly lab report. The study group lab practicum grades versus the average lab report scores are also displayed in Figure 7. If the weekly laboratory report grades were an indicator of a level of the students comprehension and retention of their skills and knowledge during the semester, a correlation between the weekly lab report grades and the final lab practicum scores could be expected. However, only the Spearman's rank correlation test reached a level of significance. The data in the lower right-hand quadrant in Figure 7 (90 and above average weekly lab report grade and 60 or below lab practicum grade) represent students (13 of 66) who appeared to have an above average understanding of the material on a weekly basis (based on lab report grades) but were unsuccessful retaining and applying it on the final practicum exam.

There was no correlation between the lab report and lab practicum grades for the control group and at best, a weak correlation for the study group implying that the lab report and individually applied lab practicum did not provide an equivalent measurement of the same phenomena.

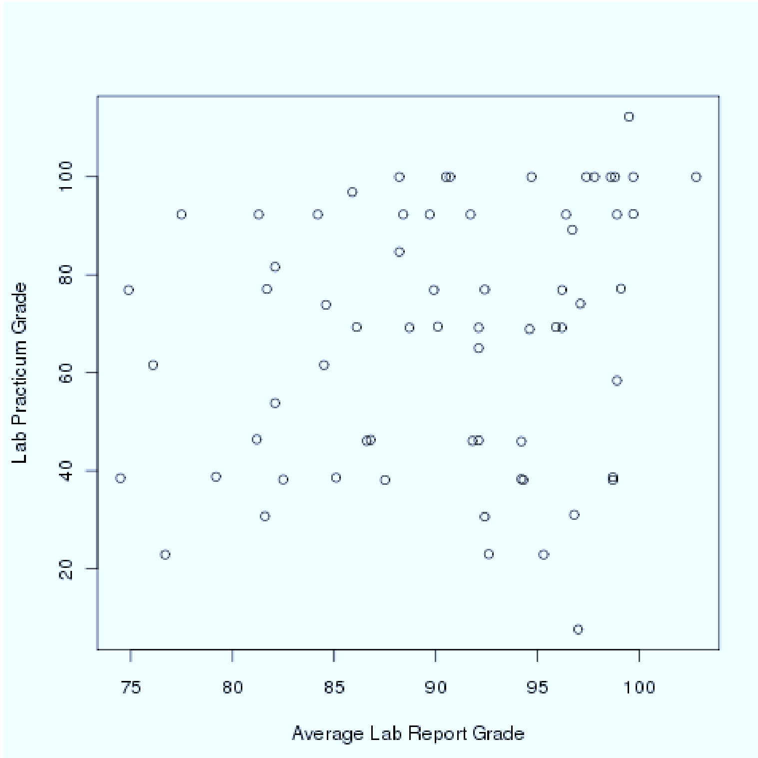

Figure 7: Study group lab practicum and average lab report grades.

Conclusions

These results indicate that the level of individual participation in the weekly laboratory exercises enhanced student acquired laboratory skills and knowledge as evaluated by the performance on the final lab practicum exam. The students' final lab practicum grades were directly related to their active participation levels in the lab: Figures 1, 3 - 5 and Tables 1 and 2. A contributing factor to this in a team structure can be attributed to a phenomenon observed during the study. In several of the teams in the control group students initially established a role within the team either as an active participant in the laboratory exercise or as a data recorder/report writer and maintained these roles throughout the semester resulting in a participation level of less than 50% for the data recorder/report writer. As shown in Table 2, the level of active participation in the weekly laboratory exercises increased within the control group which extended to the 100% participation in the study group, and there was a resultant statistically significant increase in the students' scores on the final laboratory practicum corresponding to the increase in active participation. Although the control and study groups were slightly dissimilar in composition, these small differences in their demographics did not appreciably alter the results.

A final laboratory practicum was administered uniformly to each student at the end of the semester, and weekly laboratory reports were submitted by each lab team. For both the control and study groups, the practicum served as an objective assessment of each student's retention and application of the basic electric circuits laboratory knowledge and skills obtained during the semester. However, the weekly laboratory report grades did not correlated with the final lab practicum grades in the control group and only weakly correlated for the study group. Although a lack of correlation between the lab report grades and the final lab practicum does not imply statistical independence, the results indicate that these two assessment metrics may not be considered equivalent. The relationship between individual lab practicum questions and the related weekly lab reports requires further investigation.

Many engineering laboratories routinely perform laboratory exercises with groups of two or more students. Although individual laboratory exercises resulted in a significant and meaningful improvement in the students' abilities and knowledge, the implementation of the solo laboratory organization would require additional personnel and physical resources which would potentially require a corresponding increase in the number of laboratory sections per semester. The cost to benefit ratio for the concomitant utilization of resources requires additional investigation.

The solo lab structure emphasized the acquisition and retention of basic laboratory skills and knowledge over team work. The ability to function effectively in an interdisciplinary team has been shown to be critical to the engineering discipline. The results from this study should not be interpreted to imply that all engineering laboratories should be restructured to the solo participation model; however, engineering laboratories designed to teach basic skills and knowledge should consider a structure where each student is required to be actively and fully engaged in every laboratory exercise.

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