Efficacy of a Final Lab Practicum and Lab Reports for Assessment in a Fundamentals Electric Circuits Laboratory

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Abstract

In a fundamental electrical engineering laboratory course, the traditional team based approach to laboratory structure with two or more members per lab team was not as effective for teaching basic laboratory skills and knowledge as a lab structure that allowed students to perform laboratory exercises individually throughout the semester. The laboratory report was insensitive and insufficient to measure the difference in the laboratory abilities and knowledge from these two groups. In order to assess the students' laboratory knowledge and abilities, it was necessary to develop a new assessment instrument that would be sufficient for this purpose. The students' performance on the final laboratory practicum exam provided an effective and verifiable objective metric with sufficient specificity to differentiate between the traditional team based and solo participation lab groups. Students who performed their laboratory exercises individually during the semester showed noticeable improvement in 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 five consecutive semesters with 160 students sub-divided into control (traditional lab teams) and solo groups. Students in the control group performed the weekly laboratory exercises in lab teams of two or more while students in the solo group worked independently. The solo group exhibited statistically significant higher scores on the final lab practicum as compared to the control group; however, the lab report was not sufficiently sensitive to distinguish these differences. The results of this study indicated that students must be fully engaged in all laboratory exercises to thoroughly and properly learn and retain the skills and knowledge required to perform basic fundamental circuit analysis. The employment of an adequate and verifiable assessment instrument with requisite sensitivity to measure these laboratory knowledge and skills was essential to corroborate adherence to these laboratory objectives.

Introduction

The engineering laboratory has traditionally been a hallmark of the engineering educational process[1]. The ABET/Sloan Foundation sponsored colloquy defined thirteen objectives for the "engineering instructional laboratory[2]." Electric circuits laboratories designed to teach basic skills and knowledge in undergraduate engineering programs typically utilized a team based laboratory approach with two or more member teams. The team based structure remains the recommended format to teach fundamental skills along with team work and communications[3]. In a recent study the laboratory structure designed to foster team work was found to be counterproductive to the students' abilities to retain and utilize basic laboratory instrumentation for routine laboratory measurements. This study evaluated the laboratory skills and knowledge acquired by students who worked in two member teams and contrasted those attributes for the students who worked individually on the weekly laboratory assignments during the semester. The results indicated a significant improvement in the ability to retain and apply laboratory skills and knowledge for the individual over the dual lab team member groups where a final laboratory practicum was utilized as an objective assessment instrument for this study[4,5]. The adequacy of an assessment metric applied to the laboratory learning objectives must meet both a validity and reliability threshold[6]. The lab report has been the traditional method for assessing student laboratory knowledge and has been recommended as the best assessment tool[3]. Although the laboratory report may be an adequate measure for certain laboratory goals such as communicative skills, assessment measures which are less subjective have been recommended to measure a broader spectrum of laboratory educational goals and benefits[7]. This study considered the efficacy and reliability of the lab practicum which was contrasted with lab report for evaluation of basic laboratory skills and knowledge.

Background

The study encompassed five consecutive semesters of circuits laboratory, and involved students enrolled in a one semester circuits lab coincident with their second semester of a two semester circuits lecture course. Ten or more labs were held on a weekly basis during the semester and were designed to reinforce the electric circuits principles presented in the lecture. 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.

Students were assigned to either two member lab teams or to work individually on the weekly lab assignments. A random assignment of students to work in pairs or solo each semester was neither practical or feasible. Therefore a longitudinal study design was implemented. The first and last semesters of the five semester study comprised the control group and included 30 students in the first and 44 students in the last semester. During these two semesters, laboratory assignments were performed by the traditional lab teams consisting of two or more students with a single lab report submitted by each team. In the second, third and fourth semesters, a total of 85 students performed each laboratory exercise individually and submitted their own lab reports. These three intervening semesters constituted the solo group. Students in both the control and solo 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 control and solo 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. Its composition and structure remained unchanged throughout the five semester study (except for modified circuit component values). The lab practicum circuits were constructed prior to the final exam with components selected to reduce the difference between their rated and actual values. The markings of several key components were covered to discourage a circuit analysis solution. Monte-Carlo simulations were performed with the rated component tolerances to obtain acceptable ranges for the measurements.

A comparison of the final lab practicum grades between the solo and control groups provided a measure of the effectiveness of solo versus team laboratory student organization. The final laboratory practicum served as an objective and direct measurement of the students' electric circuit laboratory knowledge and skills. This study was reviewed and approved by the Human Subject Committee.

Results

Lab Practicum Scores:

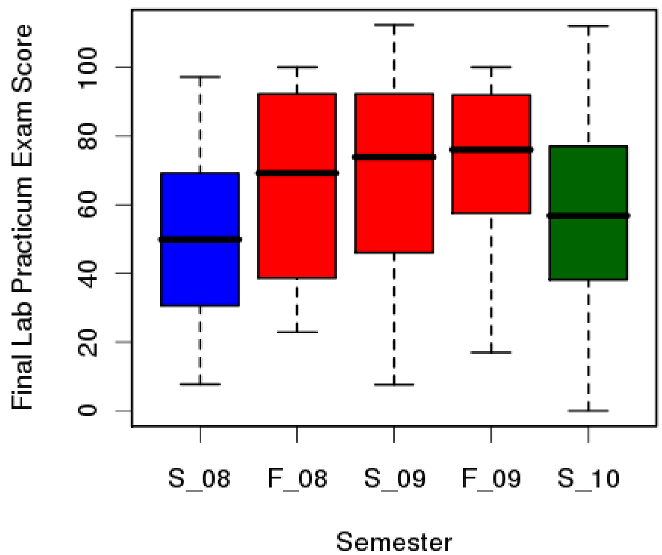

Figure 1: Final lab practicum grades for the five consecutive semester study. Students worked in two member teams for the spring 2008 (blue) and spring 2010 (green) semesters and individually in the fall 2008, spring and fall 2009 (red) semesters. The top and bottom of the rectangles represent the upper and lower quartiles, the horizontal line near the center is the median score and the top and bottom whiskers represent the maximum and minimum scores. The combined control group (Spring 2008 & Spring 2010) lab practicum scores (blue and green) are statistically different than the combined solo group (Fall 2008 – Fall 2009) (red) scores, $p<0.005$.

The final laboratory practicum scores are summarized in Figure 1 for each of the five consecutive semesters in the study. Statistical analysis was performed to compare lab practicum scores between the two control semesters (Spring 2008 and Spring 2010) and between the three semesters comprising the solo group. In each comparison, the distributions were first checked for normality with the Shapiro-Wilk test[8] utilizing the statistical package R[9]. The two control semesters were not statistically different from normal distributions ($p > 0.05$) and hence were compared with the student t-test exhibiting the following results: $t = -0.8$; $p > 0.05$. Since the final lab practicum score distributions were not statistically different between the first and last control semesters, they were combined into a single control group.

The lab practicum scores in the second two solo semesters (Spring & Fall 2009) were normally distributed; however, the score from the first solo semester (Fall 2008) were not as determined by the Shapiro-Wilk test ($p < 0.01$). Therefore, a non-parametric Kruskal-Wallis rank sum test[10] was utilized. It was unable to distinguish a statistical difference between the lab practicum scores for these three solo semesters (chi-squared = 0.33; $p > 0.05$). In order to further uncover a potential difference between the lab practicum scores in the three solo semesters, a student t-test was performed between the two normally distributed scores in Spring & Fall 2009 semesters revealing that these distributions were not statistically different ($t = -0.32$; $p > 0.05$). Then the scores from these last two semesters in the solo group were combined and compared with the scores in the first solo semester (Fall 2008) utilizing the non-parametric Kolmogorov-Smirnov (K-S) two-sample test[10] with no statistically different detected (D=0.15 with p=0.8). This result confirmed the original Kruskal-Wallis analysis on all three solo semester scores. Since the lab practicum score for the three solo semesters were not statistically different, they were combined into a single distribution of lab practicum scores for the solo group. The statistical parameters for the lab practicum scores from the combined control semesters and combined solo semesters are summarized in Table 1.

Group	Minimum	1st Quartile	median	mean	3rd Quartile	Maximum	n
Control	0.0	32.5	53.5	53.9	75.5	112.0	74
Solo	7.6	46.1	72.0	68.7	92.3	112.3	85

Table 1: Final lab practicum score statistics for the control and solo groups. The practicum included a bonus problem resulting in a score greater than 100 for one student in each of the control and solo groups.

The cumulative distribution functions for the lab practicum scores from the control and solo groups are show in Figure 2. Since the combined lab practicum scores for the solo group were not normally distributed, the distributions were compared with a non-parametric K-S two-sample test and found to be statistically different (D=0.30 and $p<0.005$). D is the maximum absolute vertical separation between these distributions. A passing grade for the lab practicum was achieved with a score of 60 or greater, and, as indicated by the horizontal lines in Figure 2, 57% of the students in the control group failed the exam as compared to 34% in the solo group.

In order to determine the impact of the students basic knowledge of circuit theory on the lab practicum scores, the students' final grades in the companion circuits lecture course (CircuitsII) were evaluated. The GPA scores (on a 0 to 4 point scale) were not normally distributed. Therefore a non-parametric statistical analyses were performed. No statistical difference between the GPA scores within or between semesters for both the control and study groups was detected. Although there was no statistical difference in the GPA distributions between the control and solo groups, the control group had a slightly larger mean GPA score compared with the solo group, 3.12 and 2.89 respectively.

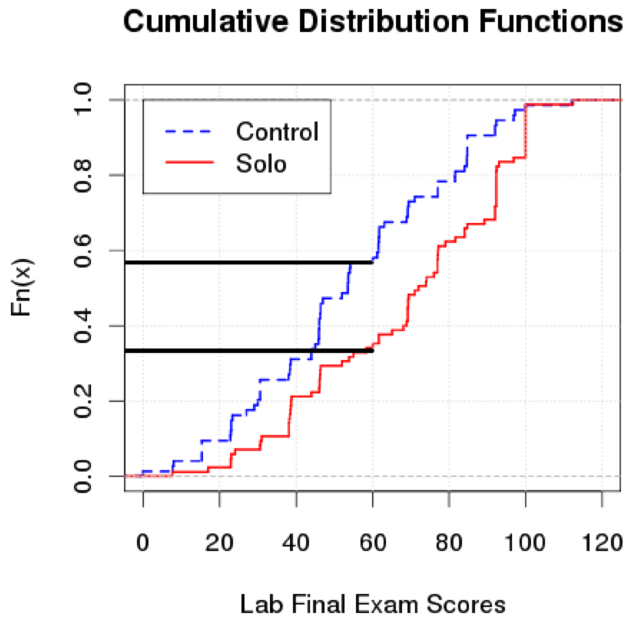

Figure 2: Lab practicum score cdf's for the control and solo groups. The K-S test revealed a significant difference between these two distributions. With a passing score of 60, 57% of the control group failed compared to 34% of the solo group (as indicated by the horizontal lines).

In order to assess the contribution of basic circuit knowledge on the lab practicum results, the control and solo groups were sub-divided into two partitions based on the students' grades in the companion circuits lecture course (CircuitsII). Students who earned an A or B in CircuitsII were segregated from those earned a C or less. The A-B partitions included 80% and 60% in the control and solo groups, respectively. A comparison between the lab practicum grades between these two partitions for the control group yielded no significant difference. However, in the solo group there was a statistical difference between the A-B and C or less partitions ($D=0.33$ and $p<0.05$). The cumulative distribution functions for the combined control group and the two solo group partitions are shown in Figure 3. The A-B solo group partition was found to be significantly different from the combined control group with the K-S two-sample test ($D=0.43$ and $p<0.001$). However, the solo group partition with grades C or less in CircuitsII was not statistically different from the combined control group partition or from the control group with a C or less partition.

The solo lab participation had significant impact on the lab practicum pass rate with 66% for the combined solo group as shown in Figure 2. The solo group pass rate increase to 77% for the A-B partition, Figure 3. These results imply that the solo lab experience had a greater beneficial affect on the student with an A or B in the CircuitsII lecture than it did for the students that earned a C or less.

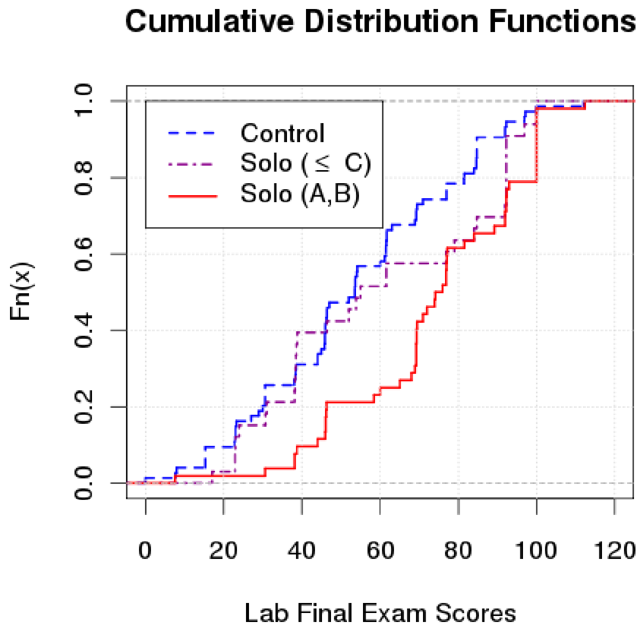

Figure 3: Lab practicum score cdf's for solo group students that achieved an A or B in the companion circuits lecture course (red solid curve), solo group student that earned a C or less in the circuits course (magenta dash-dot curve), and the combined control group (blue dashed curve). The solo A-B cdf was statistically different from the control cdf; however the solo C or less and control cdf's were not. The solo A-B cdf was significantly different from the solo C or less cdf. The lab practicum pass rate was 77% for the solo group A-B partition.

Laboratory Report Scores:

Students who worked individually on each laboratory assignment during the semester demonstrated a statistically significant improvement in the final laboratory practicum score as compared to the students who worked in two member lab teams; however, the lab report scores did not demonstrate a similar improvement. Students from the solo group submitted individual lab reports, and the students in the control group submitted a lab report for each team. Grades on the lab practicum provided an objective metric of the students' laboratory knowledge and abilities. Each question was evaluated as a correct or incorrect answer. The assigned lab report grades were dependent on the individual grader and were therefore more subjective than the lab practicum grades. The same instructor graded the lab (and pre-lab) reports in the first four semesters of the study (Spring 2008 – Fall 2009); however, in the final semester, the reports were graded by two separate instructors. The cumulative distribution functions for the lab report scores were not statistically different within the three solo semester sequence (Kruskal-Wallis rank sum test, chi-squared=1.17; $p>0.05$) nor between the combined solo and first semester control (K-S two-sample test, $D=0.21$; $p>0.05$) with the same grader; however, lab report scores were statistically different in the final control semester as compared to the first control semester (D=0.41; p<0.005) and the combined solo semester scores (D=0.46; p<0.0001) as shown in Figure 4. Since presumably the lab report scores in the control semesters represented the combined effort, knowledge and skills for both members of the lab team while the lab report scores from the solo teams reflected their individual knowledge, a comparison of these cdf's between groups may be neither helpful nor necessarily meaningful. In the absence of supporting data to the contrary, the increased lab report scores in the second control semester most likely reflected a difference in grading scales between instructors and was not indicative of the students laboratory knowledge nor abilities.

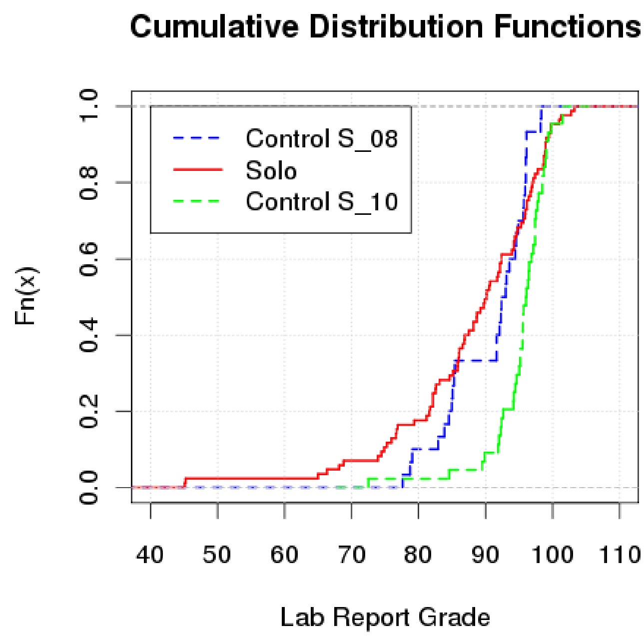

Figure 4: Lab report cdf's for the first and last control semesters (Spring 08 and Spring 10) and combined solo groups. There was no statistical difference in the the first control semester scores and the solo group distributions; however there was a statistical difference between the last control semester lab report grades and the first control and the solo grades.

Lab report grades were also not statistically different between the first control semester and the combined solo group if the student population was restricted to those who made an A or B in the companion circuits lecture course (D=0.3 p>0.05).

Students performed a pre-laboratory report typically involving a circuit simulation with Pspice/OrCAD. Each student individually submitted their own pre-lab report in both the control and solo semesters. The pre-lab score results were similar to the lab report scores: no statistical difference within the solo group between semesters and no difference between the first control semester and the combined solo group. As with the lab report grades, there was a significant difference between the solo and second control semester pre-lab score distributions which was attributable to the difference in grading scales between instructors.

Relationship Between Assessment Indicators:

A measure of concordance between the lab report and final lab practicum scores was obtained utilizing the Kendall's tau coefficient applicable to non-normal bivariate distributions[10]. There was no statistically significance concordance (correlation) found between the lab report and lab practicum grades for either of the two control semesters or the combined solo semester group. A biplot[11] provide a visual representation between these assessment indicators. A correlation between the LabReport and LabFinal variables represented by the vectors in the biplots in Figures 5, 6 and 7 was proportional to the cosine of the angle between these vectors. The approximate 90º separation between the lab report grades and final lab practicum score vectors in all three figures was indicative of the independent nature of these indicators and confirms the previous analyses based on Kendall's tau. Notice that this 90º relationship existed not only for the control semesters where each two-member team submitted lab report but also for the solo group where each individual student performed the laboratory exercises and submitted their own lab report.

These biplots[11] provide a visual representation of the relationship between the four laboratory assessment indicators (final laboratory practicum scores, lab report grades, PSpice final exam scores, pre-laboratory report grades) and the CircuitsII lecture grades. The latter was included as an indicator of the students' basic understanding of circuit theory. Biplots were constructed from principal component analyses of the correlation matrix for the laboratory assessment indicators and CircuitsII lecture grades. The first two principal components (PC 1 and PC 2 on the graph) were associated with the two largest eigenvalues or variances. These first two principal components represented 70%, 68% and 68% of the total variance of the five indicator PCs for the first and second control semesters and the solo group respectively.

The angle between the pre-lab report and lab report vectors were similar for the two control semesters; however, it was nearly zero for the solo group. Recall that each individual student submitted a pre-lab report for both the control and solo groups whereas the solo group submitted individual lab reports. Hence a close correlation between the pre-lab and lab report grades was consistent with the submission requirement in the solo group.

Conclusions

These results indicated that individual participation in the weekly laboratory exercises enhanced the students' laboratory skills and knowledge as assessed by their performance on a final laboratory practicum. The laboratory practicum results were consistent across a five semester study within the control and solo groups. The pass rate for students for the solo group with a thorough understanding of basic circuit theory as indicated by their grades in a companion circuits lecture course was 77%; however, only 46% for the students who participated in two member lab teams. The laboratory report was unable to distinguish a difference in the control and solo groups for all students or for the students that made an A or B in the companion circuits lecture course. The laboratory practicum proved to be a reliable and consistent metric for laboratory skills and knowledge.

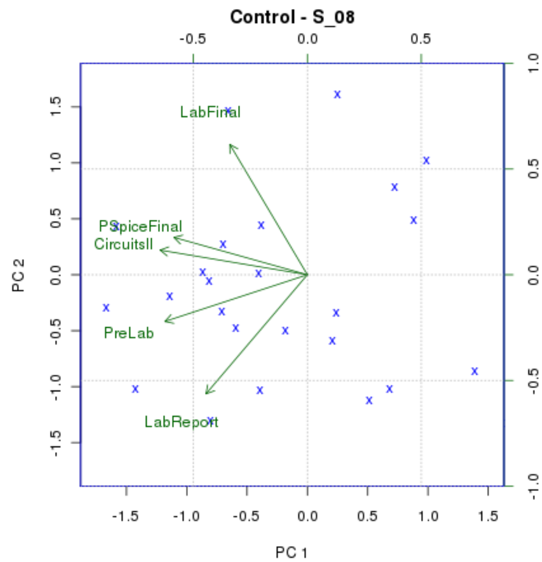

Figure 5: Biplot for first control semester representing the data points (x) and variables (vectors) projected onto the first two principal components from the original five dimensional space.

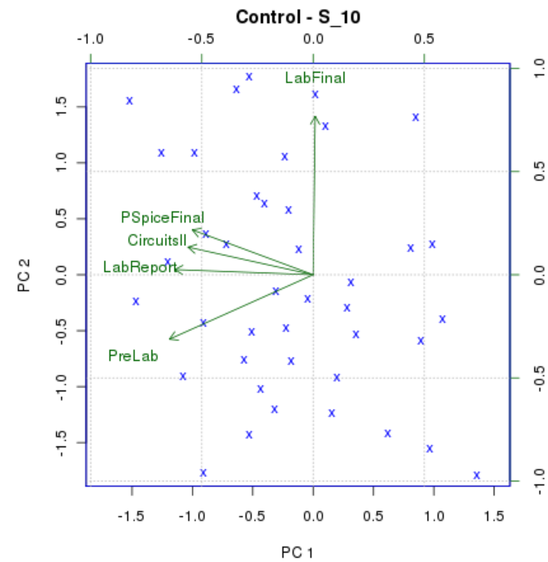

Figure 6: Biplot for the second control semester. The data scales are represented by the left-hand and bottom axes and the right-hand and top are the variable axes.

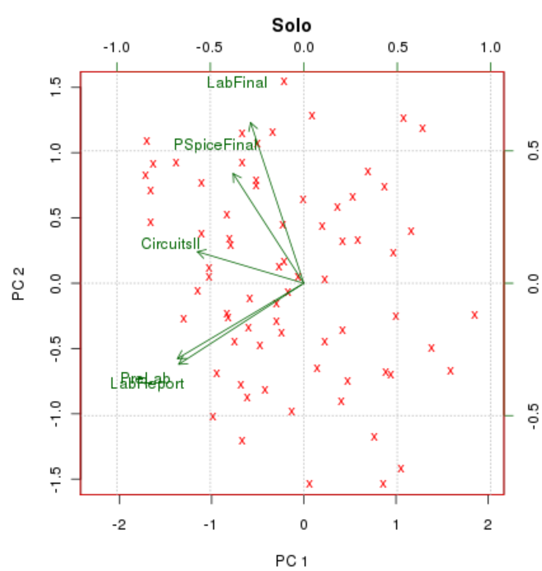

Figure 7: Biplot for the solo group. The vectors for the pre-lab report and lab report grade are nearly coincident.

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 solo 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. The lack of concordance between the laboratory report and final lab practicum grades in both the control or the solo groups as determined by the Kendall tau, and their ~90º orientation in the biplots implies that these two assessment metrics should not be considered equivalent.

Although individual laboratory exercises resulted in a significant and meaningful improvement in the students' abilities and knowledge, the implementation of the solo laboratory organization will 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 increased utilization of resources must be considered.

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 well established as 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 these results do imply that 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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