Cooperative Learning in DC Circuits Laboratory for Improved Student Success and Equipment Proficiency

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Abstract

Undergraduate engineering and engineering technology laboratory assignments are often performed as ready-made, step-by-step experiments allowing for little collaboration in their execution, with the instructor acting as the content expert and dispenser of facts. In contrast, a constructivist approach involves the instructor taking less of an authoritarian role and serving as a facilitator, guiding students to understanding the material by promoting inquiry and discourse among peers.

This study explores two vastly different "cooperative learning" approaches to a first semester engineering technology laboratory. The aim was to investigate student performance, including laboratory equipment proficiency, during the first half of the semester on a series of DC circuit assignments. The control group was taught in a predominantly positivist fashion that allowed for no more than two students per equipment setup while the participant group was taught using the same instructional materials but from a more constructivist perspective. In this approach, teams of four students per equipment setup worked together to achieve understanding using predefined roles directly related to ABET student outcomes.

Data for the study included pre-and post-lab assessments, laboratory observations and an individually administered laboratory competency exam. Descriptive and inferential statistics indicate that, on average, the treatment group outperformed the control group on laboratory assignments and the competency exam. Implications for teaching engineering and engineering technology laboratories as well as future research are discussed.

Keywords

engineering, freshmen, laboratory, cooperative learning

Introduction

As an educator that leans toward a constructivist view of teaching and learning, I believe that personal understanding is socially constructed and subject to change as our understanding of the world around us changes. This is in contradiction to the traditional view of knowledge or positivism which holds that "objective reality exists and is knowable through scientific examination of evidence of the senses" [1]. While many engineering faculty value constructivist pedagogical approaches, the traditional view dominates the engineering education field[2] , and students are often viewed as independent vessels that need to be filled with appropriate facts and figures.

A constructivist educator does not take an authoritarian role in the classroom, as a traditional teacher might. Instead the constructivist educator assumes the role of a facilitator who guides students' questions towards understanding the material in the context of their own lives and promotes inquiry and discourse to that end[1]. Cooperative learning, as applied in this study, allows for the social construction of facts within teams. It places the instructor in more of a facilitating or guiding role. Instead of spending valuable laboratory time reviewing individual pre-laboratory work and describing lab activities in great detail, the instructor's time is spent answering questions posed by teams of students and helping these teams make meaning of the material being studied.

The laboratory plays an important role in the professional life of practicing electrical engineers[3]. Design and development engineers use the lab to test, enhance and perfect new designs. Mathematical and computer models of complex systems and circuits are improved and adjusted by incorporating empirical data, and circuit designs are proven over extreme operating conditions using laboratory equipment. Applications engineers use the laboratory to reproduce problems observed in the field and to determine viable solutions. The laboratory environment also plays an important role in research and development with experimental results informing the engineering field, often in new and exciting ways. Since this environment of discovery and exploration is so important to electrical engineers, it is no surprise that it is just as important to undergraduate engineering education.

Applied engineering programs, also referred to as engineering technology programs, place an even higher value on the laboratory experience than their traditional engineering counterparts. These programs require students to complete a great deal of laboratory work during their education. Students often begin such experiences as freshmen while traditional engineering programs frequently begin incorporating labs into the educational experience a year or two later. Common objectives for such labs are to demonstrate and reinforce the theoretical concepts being taught in the classroom using empirical means and to give students experience using equipment similar to what they are likely to encounter in their careers as engineering professionals[3].

In first semester electrical engineering technology laboratories, freshmen students build and test circuits, verify operation, record and present data and interpret lab results. The Accreditation Board for Engineering and Technology (ABET) requires undergraduate electrical engineering technology program student outcomes including several specific to laboratory experiences be met[4]. Collaboration within the laboratory setting, including technical team membership and communication, can be used to demonstrate ABET criteria directed at the ability to build and test circuits, function effectively in a team environment and apply various modes of communication in a technical environment[5]. The most recent guidelines for accreditation require that baccalaureate degree programs in engineering technology demonstrate several student outcomes, including the following:

> 3 c. an ability to conduct standard tests and measurements; to conduct, analyze, and interpret experiments; and to apply experimental results to improve processes;
>
> 3 e. an ability to function effectively as a member or leader on a technical team;
>
> 3 g. an ability to apply written, oral, and graphical communication in both technical and non-technical environments; and an ability to identify and use appropriate technical literature

These outcomes must be documented and demonstrated in order for a program to achieve ABET accreditation. Outcome 3c relates directly to experimentation; however outcomes 3e and 3g can also be demonstrated using data and artifacts from student laboratory experiences.

Collaboration is well documented as having a positive impact on student learning, both across age ranges and disciplines[6, 7]. In a study investigating problem solving in engineering, Jonassen et al. (2006) interviewed 97 professional engineers and determined that solving most engineering problems requires extensive collaboration among team members[8]; this collection of professional engineers recommended more communication skills be taught in undergraduate engineering classes. Another key recommendation of this study was that team-related activities should encourage a sense of ownership among team members and the roles played by individuals should be diverse and authentic.

In the context of undergraduate engineering education, collaboration has been cited as a significant predictor of students' academic performance[7]. Practicing engineers report that collaboration is essential to solving real-world problems as knowledge is often distributed across multiple individuals[8]. However in contrast to this, conventional early undergraduate engineering and engineering technology laboratory assignments are often written as ready-made, recipe-like experiments that allow for minimal collaboration in their implementation, usually between a student and a single lab partner[9, 10] and often only to build a circuit and record the pertinent data.

According to research performed by Johnson, Johnson and Smith[11] that aligns with social interdependence theory, cooperative learning is a specific type of collaboration that occurs between two or more individuals when the following five conditions are met: positive interdependence, individual accountability, promotive interaction, social skills, and group processing. *Positive interdependence* requires group members to share ideas and resources in order to maximize the learning of all in the group. *Individual accountability* requires that each member is individually assessed and held accountable for their contribution to the groups' success. *Promotive interaction* requires that group members encourage and support the success of their fellow members to achieve the goals of the group. *Social skills*, such as verbal communications, conflict resolution, group decision making and leadership, require group members have certain abilities that are enacted so as to allow the group members to communicate and work with each other. Finally, *group processing* requires periodic reflection by group members to consider how the group is functioning and the entire learning process. Johnson and colleagues contend that these five basic characteristics are essential elements of cooperative learning.

Several studies describe the benefits of cooperative learning including: more positive student attitudes about the learning process and subject matter compared to alternate learning modes[11], improved academic achievement[7, 12, 13], improved self-esteem and interpersonal relationships[7, 13], and improved design, problem solving and group skills[14]. Unfortunately, the first engineering and engineering technology labs that students encounter often limit student interaction or "cooperation" to groups of two students. They also allow for little more than sharing of data collection responsibilities. In such circumstances, the five conditions required for true cooperative learning are rarely met and hence the potential educational benefits of this limited interaction are diminished or not realized at all.

There is a great deal of discipline-based research describing various pedagogical approaches to the teaching of specific laboratory topics or active learning strategies within the field of electrical engineering. These approaches and techniques often require extensive rework to current laboratory assignments and policies. Pedagogical approaches requiring significant changes to current practice are less likely to be adopted than those requiring minimal or moderate changes[15] due partially to the large investment of time and effort required by faculty members. In addition, many of these investigations can be interpreted as promotion pieces that encourage a specific style of student engagement, teaching technique or set of tools to use, but they frequently lack research questions and statistical backing for more generalized implementation of the approach discussed, for examples see: Dahu, et al. [16], Panaitescu, et al. [17], Jurado, et al. [18]. There is a gap in the literature concerning the implementation of cooperative learning in introductory freshmen electrical engineering technology laboratories to promote student success as well as proficiency with laboratory equipment.

Research Questions

As an educator that teaches undergraduate electrical engineering technology students, I am interested in constructing an environment that allows them to learn through experimentation and collaboration. I take on the role of facilitator or guide, answering student questions and posing additional questions back to them to help each achieve meaning instead of trying only to fill their heads with facts that they may or may not see the relevance of. Cooperative learning is one teaching technique that allows me to comfortably wear this role, working with groups of students in the laboratory in a way that has been shown to support student success in other engineering venues. The overarching research question that serves as the foundation for this paper is: Is a cooperative learning approach to teaching an introductory freshmen electrical engineering technology laboratory in DC Circuits more effective than a conventional approach?

The research questions addressed in this study are:

1) How is student success in DC Circuits laboratory impacted by cooperative learning?

2) How is individual student equipment proficiency in DC Circuits laboratory impacted by cooperative learning?

Student success is defined by grades achieved on multiple summative assessments throughout the study including multiple-choice pre-lab quizzes (preparedness) and post-lab quizzes (content understanding and reflection) and individual laboratory assignment results (successful completion of in-lab exercises submission of analysis). Equipment proficiency in the context of this study is the student's ability to use common electrical engineering laboratory equipment such as direct current (DC) power supplies and digital multi-meters (DMMs) to collect data and troubleshoot circuits that they construct in the lab using a protoboard. To consider the second research question, the student results on a one-hour lab competency exam, which is administered at the end of the study to each student individually, is considered.

Methodology

Conventional freshmen electrical engineering technology laboratory experiments require students to follow a rather rigid sequence of events to: 1) individually complete a pre-lab problem or investigation before coming to lab, 2) work in teams of (at most) two students in the lab to build a circuit and record data to confirm prelab results and then 3) submit individualized documentation for summative assessment and confirmation that learning has taken place. The primary elements of the in-laboratory experience include: following procedures, building a circuit and taking measurements, interpreting the results and communicating these results to the professor. In these labs collaboration occurs primarily during the data collection phase, leaving students on their own to interpret and communicate their results in a report or graphical format to their professor. Given the nature of this limited collaboration, one would be hard-pressed to call it cooperative learning as the five basic essential characteristics of cooperative learning are not likely present.

In this half-semester study, the treatment group was placed into teams of four and encouraged to work together, outside of lab time, on the prelab assignment. An individual summative assessment was given at the beginning of each lab assignment to verify the prelab has been completed correctly. Students then worked in their teams in the laboratory, each having a specific assigned role related to ABET outcomes 3c, 3e and 3g of either: 1) ensuring their team understands and is following procedures, 2) building a circuit, taking measurements and reviewing these within their group, 3) interpreting the results and discussing these within their group or 4) communicating the results by answering questions or preparing documentation required by the lab handout and verifying these within their group. These roles were rotated each week so that each student was placed into each of the four roles at least once within the study; the team composition did not change during the study. After each lab assignment, an individual summative assessment was given that tests each student's understanding of the lab's results. Specific documentation was submitted for each laboratory the week following its completion, at the beginning of that week's lab period. An individual lab competency exam was administered at the end of the study to gauge equipment proficiency.

Since each of the four treatment group members was assigned a specific role and each of these roles was required in order to successfully complete each lab experience, the concept of *positive interdependence* was present. Group members had to share ideas and resources in order to complete the weekly assignments. Each treatment group member was also held *individually accountable* for their contribution and for performing their assigned role each week. It was in the best interest of those in the treatment group to work closely together, supporting each other's success interactively and to build understanding together in order to interpret and communicate the results of each assignment, thus *promotive interaction* and *social skills* were also utilized. With the roles rotating each week, *group processing* was fairly natural as the treatment group members discussed the roles that were new to each of them that week with the members that held their role the previous week.

The control group followed a more traditional approach to the same laboratory assignments. This included students working only in pairs during the lab to follow procedures that including building circuits and taking measurements. The students maintained the same lab partner throughout the study. This minimal collaboration was unstructured, and no roles were assigned. Working together outside of lab was neither encouraged nor discouraged. The control group used the same laboratory handouts and was subject to the same assessments as the participant group throughout the study. It is important to note that the laboratory assignments and assessments were not developed for this study or modified in a significant way for this study from the previous offering of this laboratory. Only the method of learning was changed, and only for about half of the study's participants as detailed below. This minimally invasive change was designed to be duplicated with little to moderate effort on the part of interested instructors.

A convenience sample of 82 undergraduate students was used for this study. These students were enrolled in six sections of an introductory laboratory course in DC circuits, which is intended primarily for freshmen undergraduate engineering technology majors. This lab course was taught by the author with the support of a lab assistant during the fall semester of 2015 at a mid-sized, private university in the northeastern United States. Three sections were chosen at random to be the participant group (n=43) while the remaining three sections were designated as the control group (n=39). Data from students that withdrew during the course of the semester or that had taken a previous circuit or electronics course at the university was not considered in the analysis that follows.

All six sections of lab met once a week for 1 hour and 50 minutes in a well-equipped engineering technology laboratory on the following schedule:

Table 1- Laboratory Schedule (Control and Treatment)

Week	Activity	Topic
1	Lab 1	Resistor Color Code, Protoboard and Digital Multimeter
2	Lab 2	Series Circuits and Kirchhoff's Voltage Law
3	Lab 3	Ohm's Law, Parallel Circuits and Kirchhoff's Current Law
4	Project (week 1)	Series-Parallel Circuits
5	Project (week 2)	Circuit Characteristic Curve and Equivalent Resistance
6	Lab Competency Exam	Series-Parallel Circuit Construction, Voltage and Current Measurements
7	Lab Competency Exam	Second Attempt (if necessary, maximum grade of 70%)

The laboratories were designed to build on one another with material from the first being used in the second and so on. Labs 1, 2 and 3 were each completed in one week's time while the project was a two-week experience requiring more time on task to complete. This project contained content similar to that covered in previous lab assignments and introduced a new component, the light-emitting diode. Circuit characterization via the current-voltage characteristic curve was also introduced. Each of these experiences required all students to individually complete a multiple-choice quiz during the first 10 minutes of laboratory (pre-lab quiz) and a 15-minute, multiple-choice quiz after the completion of the laboratory (post-lab quiz). The pre-lab quiz was developed to assess the student's understanding of that week's material and readiness to engage in laboratory work. The post-lab quiz was designed as a measure of understanding the content and interpretation, to allow each student to reflect on their finished work that week. The laboratory results (lab results) were the third, additional measures collected for each laboratory assignment. The lab results component included instructor signatures, data, and any analysis required by that week's assignment and was submitted at the beginning of the following lab period. This measure was designed to measure successful completion of the lab activities, the accuracy of the data collected, and the student's interpretation and communication of that data. This measure was more subjective than the pre- and post-lab quizzes, since it did not contain multiple-choice questions; however, the instructor used the same rubric to grade all of the assignments. See Appendix A for examples of the pre-lab and post-lab quizzes, Appendix B for an example of a complete lab handout and Appendix C for a grading rubric for the lab results component. The following diagram details the three lab assignment components.

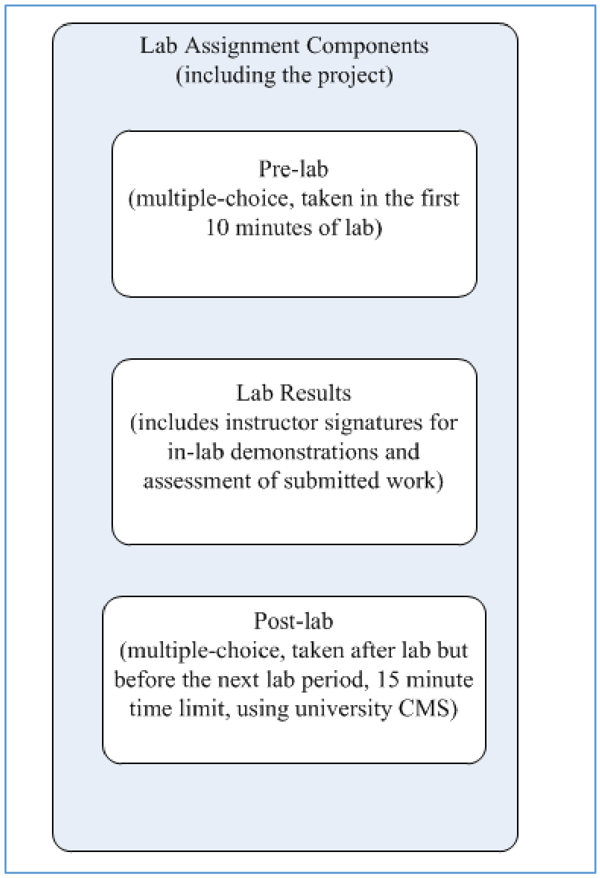

Figure 1- Lab Assignment Components

The dependent variable *Prelab #1* was used to check for pre-treatment differences in the two groups. Each of the aforementioned evaluation instruments were used to address the first research question regarding the effect of cooperative learning on student success in the laboratory. Dependent variables *Prelab #2, Prelab #3, and Project Prelab* served as measures of pre-lab performance. Dependent variables *Postlab #1, Postlab #2, Postlab #3, and Project Postlab* served as measures of post-lab performance. Dependent variables *Results #1, Results #2, Results #3, and Project Results* served to measure lab results performance.

The laboratory competency exam (lab competency exam) was administered individually for one hour during the week following completion of the previous laboratory assignments. During this exam, each student followed an instructional handout to construct a relatively complex DC circuit containing an unknown component, measured specified voltages and currents and presented the collected data for evaluation. Students scoring 60% or below on their first attempt at the exam were allowed to retake this assessment after participating in a one-hour seminar designed to address common problems encountered on the exam. In these cases, the student's second-attempt grade was multiplied by 0.70 before recording their final grade. The dependent variables *Initial Lab Competency Exam* and *Final Lab Competency Exam* were assigned for each student based on the initial attempt and, if applicable, the second attempt on the lab competency exam. These variables were used to address the second research question on the effect of cooperative learning on student equipment proficiency. The following diagram details the components of the lab competency exam how it was graded.

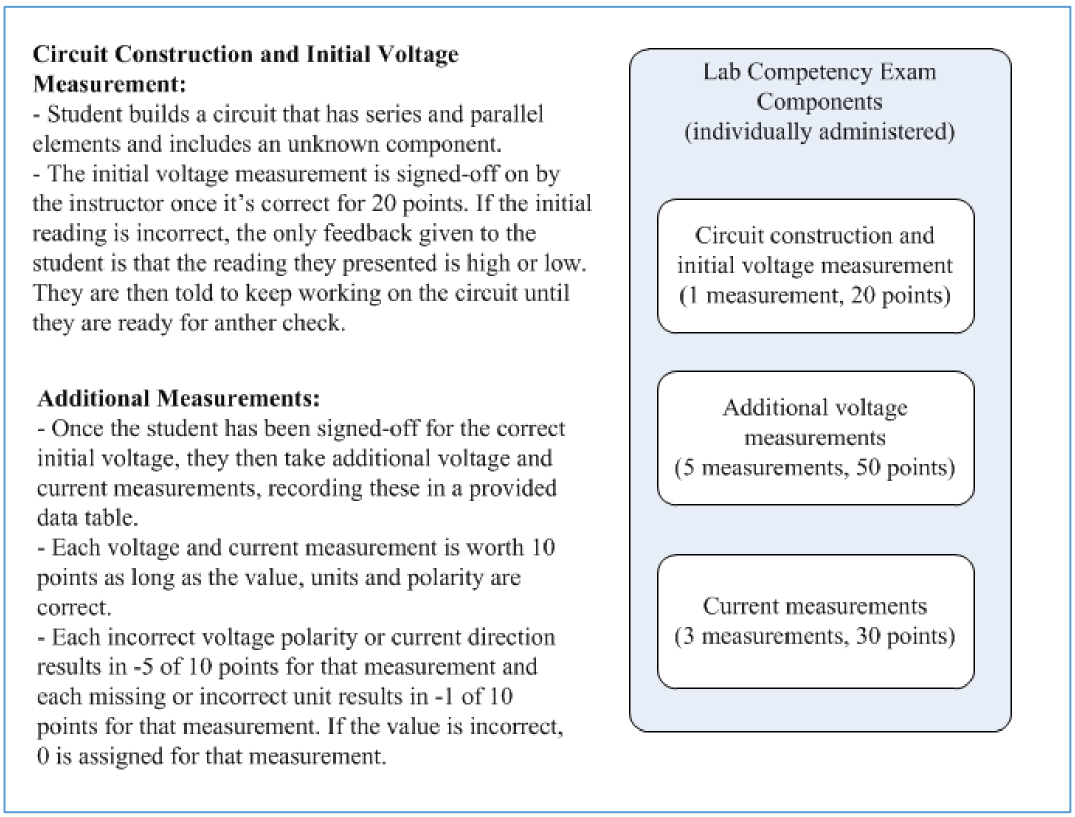

Figure 2- Lab Competency Exam Components

The following diagram summarizes the study design and participants.

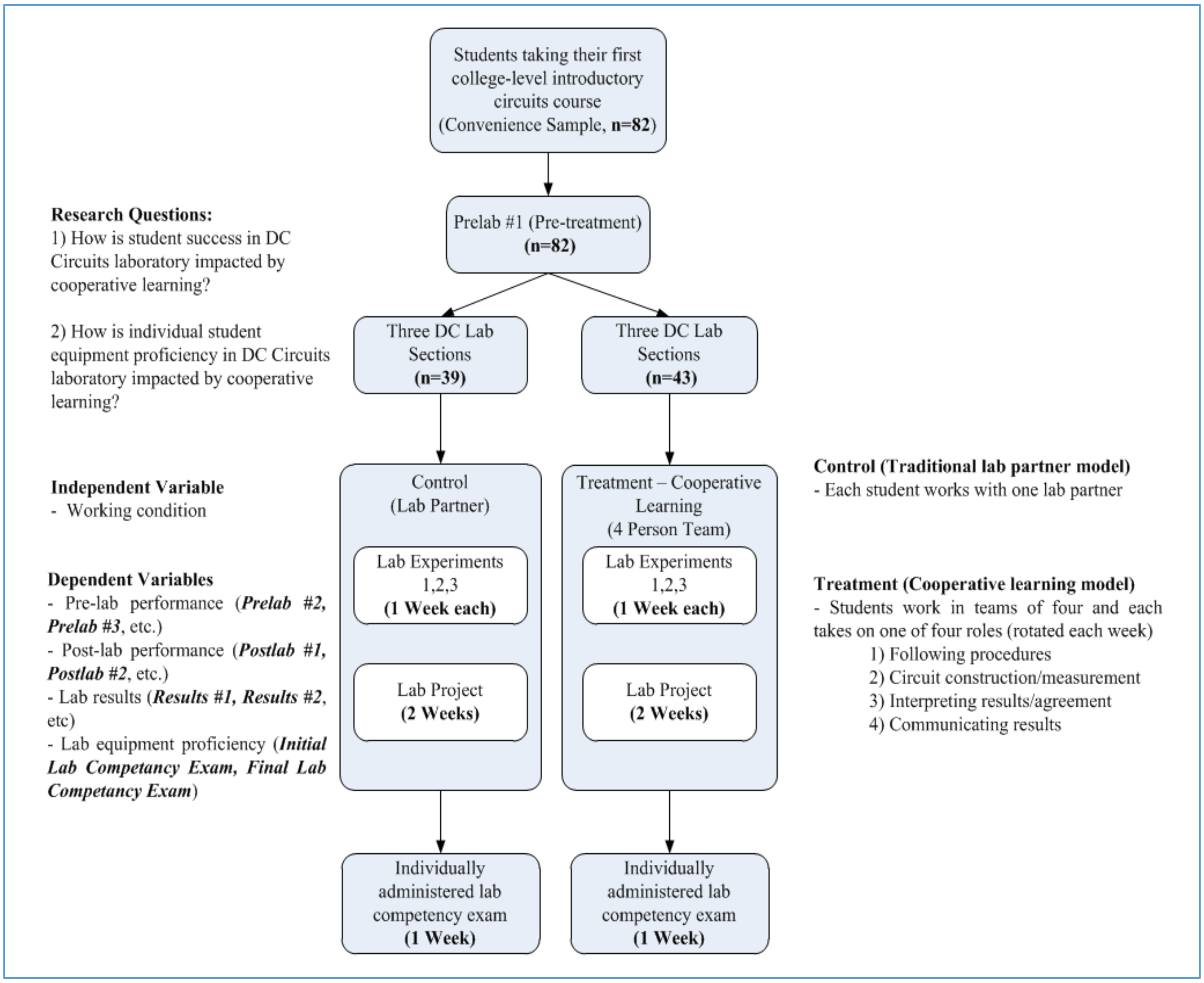

Figure 3 - Study Overview

Results

A Mann-Whitney U test was conducted to determine if there were significant differences in students' answers to the first pre-lab quiz (*Prelab #1*), taken at the start of the semester and before the two groups were subjected to two different instructional methods. The *prelab #1* grades were not significantly different, $U = 957.5$, $z = 1.23$, $p = .225$. In addition, the study participants in both groups were enrolled in this course as their first laboratory course in DC Circuits with the vast majority of them being freshmen students enrolled in engineering technology programs at the university and as such, no significant differences were expected.

Table 2 indicates that the mean scores for the cooperative learning group (treatment) were higher than the traditional learning group (control) for *Prelab #2* (7 points) and for *Project Prelab* (6 points) with a small effect size in each case. For *Prelab #3*, the mean score for the cooperative learning group (treatment) was lower than the traditional learning group (2 points) with minute effect size.

Table 2 - Means, Standard Deviations and Cohen's d for Prelab Grades

Measure	Mean (control)	Mean (treatment)	SD (control)	SD (treatment)	Effect Size (Cohen's d)
Prelab #2	70.1	77.6	29.4	21.5	0.29
Prelab #3	71.2	69.2	24.7	33.1	-0.07
Project Prelab	44.6	50.7	24.5	30.0	0.22

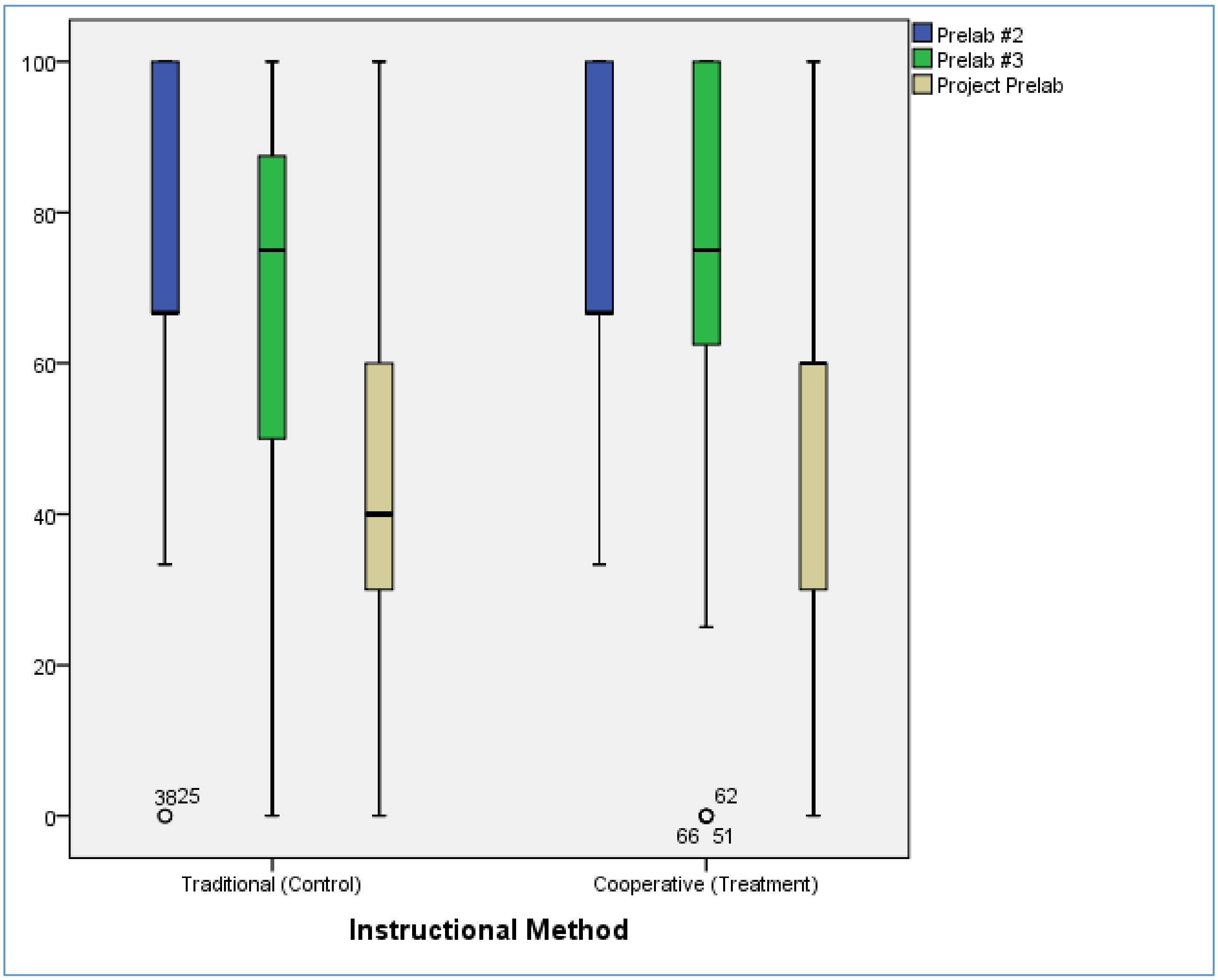

Figure 4- Boxplot Comparison of Prelab Grades as a function of Instructional Method

Mann-Whitney U tests were conducted to determine if there were significant differences in students' scores on the pre-lab quizzes (*Prelab #2*, *Prelab #3* and *Project Prelab*). In all three cases, the results were not statistically different (*Prelab #2*: U = 935.5, z = 0.978, p = 0.328 , *Prelab #3*: U = 871.5, z = 0.325, p = 0.745, *Project Prelab*: U = 935.5, z = 0.926, p=0.354).

Table 3 indicates that the mean scores for the cooperative learning group (treatment) were higher than the traditional learning group (control) for *Results #1* (6 points), *Results #2* (4 points), *Results #3* (8 points) and *Project Results* (6 points) with a small to medium effect size in each case.

Table 3 - Means, Standard Deviations and Cohen's d for Results Grades

Measure	Mean (control)	Mean (treatment)	SD (control)	SD (treatment)	Effect Size (Cohen's d)
Results #1	90.5	96.5	16.8	3.6	0.49
Results #2	90.7	94.5	17.0	15.4	0.23
Results #3	74.7	82.6	16.8	18.8	0.44
Project Results	62.2	68.3	20.0	24.1	0.28

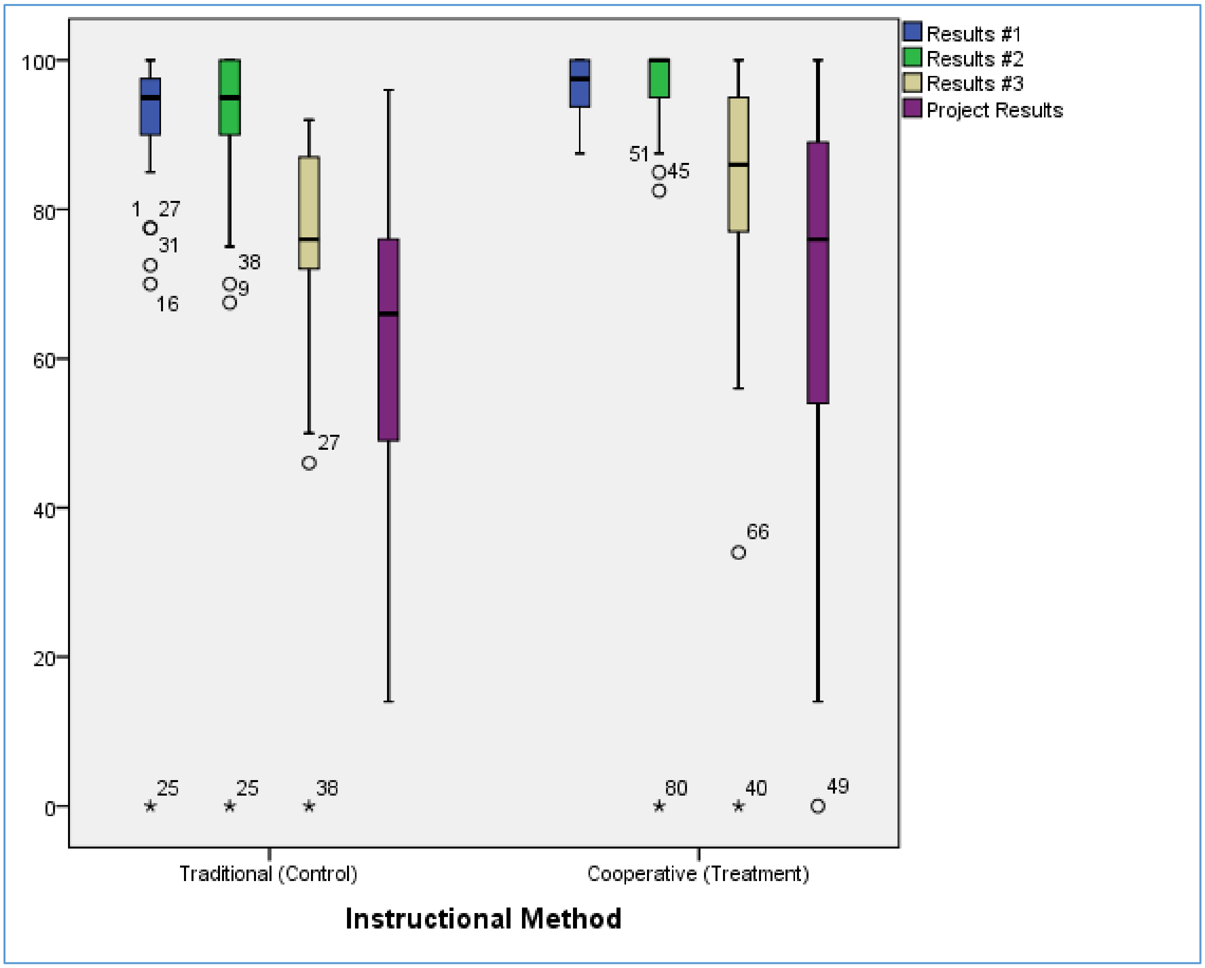

Figure 5 - Boxplot Comparison of Results Grades as a function of Instructional Method

Mann-Whitney U tests were conducted to determine if there were significant differences in students' scores on the results component of the laboratories (*Results #1*, *Results #2*, *Results #3*, and *Project Results*). In three out of the four cases, the results were statistically different: *Results #1;* U = 1071.5, z = 2.21, p = 0.027, *Results #2*: U = 1060.5, z = 2.15, p = 0.032, *Results #3*; U = 1154.5, z=2.94, p = .003. The differences in scores for *Project Results* were not significantly different (U = 1030.0, z = 1.78, p=0.075).

Table 4 indicates that the mean scores for the cooperative learning group (treatment) were higher than the traditional learning group (control) for *Postlab #1* (< 1 point), *Postlab #2* (8 points), *Postlab #3* (17 points) and *Project Postlab* (4 points) with a small to medium effect size for *Postlab #2* and *Postlab #3* and minute effect size for *Postlab #1* and *Project Postlab*.

Table 4 - Means, Standard Deviations and Cohen's d for Postlab Grades

Measure	Mean (control)	Mean (treatment)	SD (control)	SD (treatment)	Effect Size (Cohen's d)
Postlab #1	80.3	80.6	34.8	38.0	0.01
Postlab #2	85.5	93.0	31.3	18.6	0.29
Postlab #3	62.8	79.7	32.9	33.7	0.50
Project Postlab	53.2	57.6	35.0	38.0	0.12

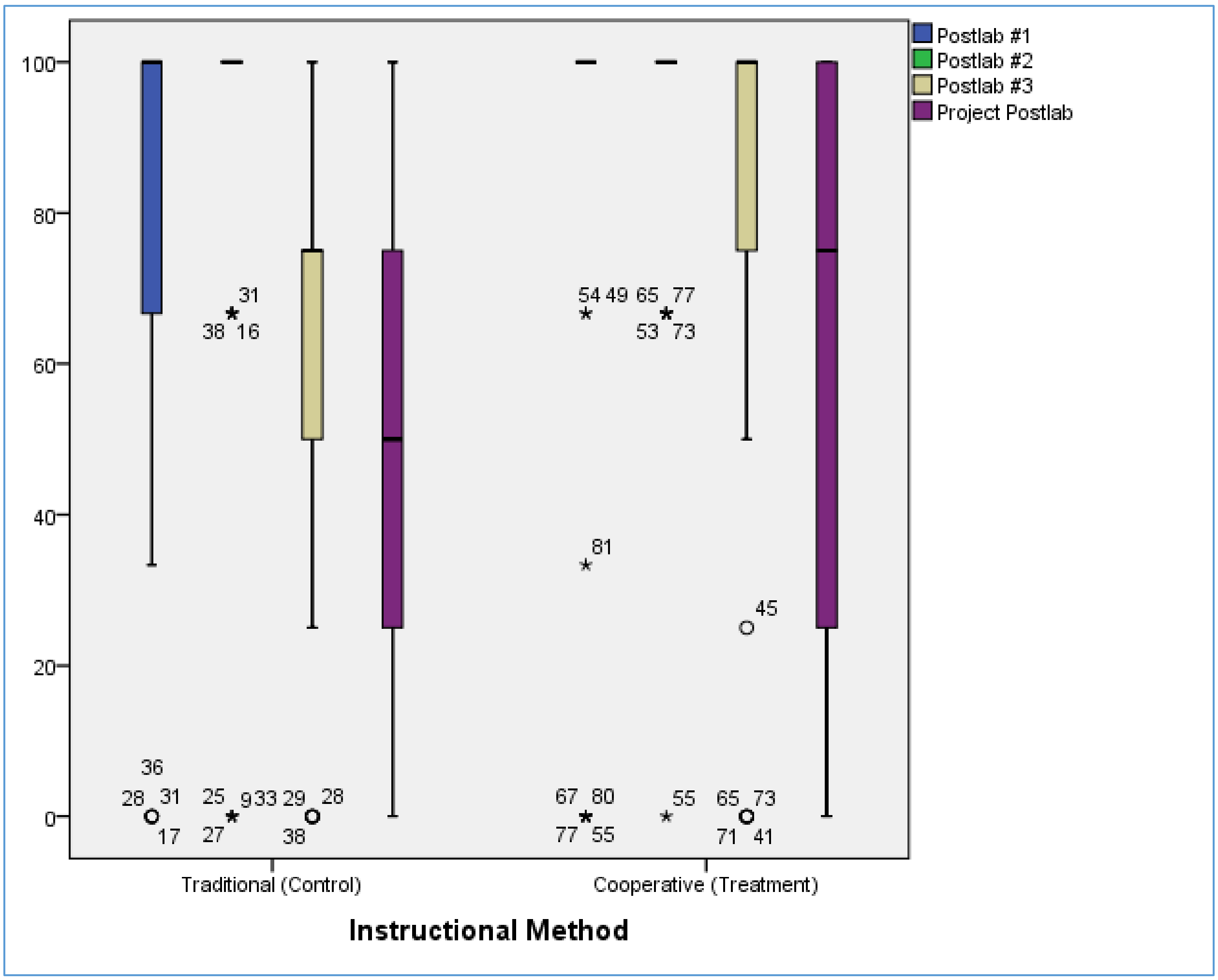

Figure 6 - Boxplot Comparison of Postlab Grades as a function of Instructional Method

Mann-Whitney U tests were conducted to determine if there were significant differences in students' scores on the post-lab component of the laboratories (*Postlab #1*, *Postlab #2*, *Postlab #3*, and *Project Postlab*). In three out of the four cases, the results were statistically insignificant: *Postlab #1;* U = 882.5, z = .53, p = 0.599, *Postlab #2*: U = 905.0, z = .895, p = 0.371, *Project Postlab*; U = 906.5, z = .647, p = .518. Only the differences in scores for *Postlab #3* were statistically different (U = 1150.0, z = 3.07, p=.002).

Table 5 indicates that the mean scores for the cooperative learning group (treatment) were higher than the traditional learning group (control) for *Initial Lab Competency Exam* (11 points) and *Final Lab Competency Exam* (4 points) with a small effect size in each case.

Table 5 - Means, Standard Deviations and Cohen's d for Lab Competency Grades

Measure	Mean (control)	Mean (treatment)	SD (control)	SD (treatment)	Effect Size (Cohen's d)
Initial Lab Competency Exam	60.1	71.1	38.8	38.2	0.29
Final Lab Competency Exam	74.8	78.8	23.4	28.0	0.16

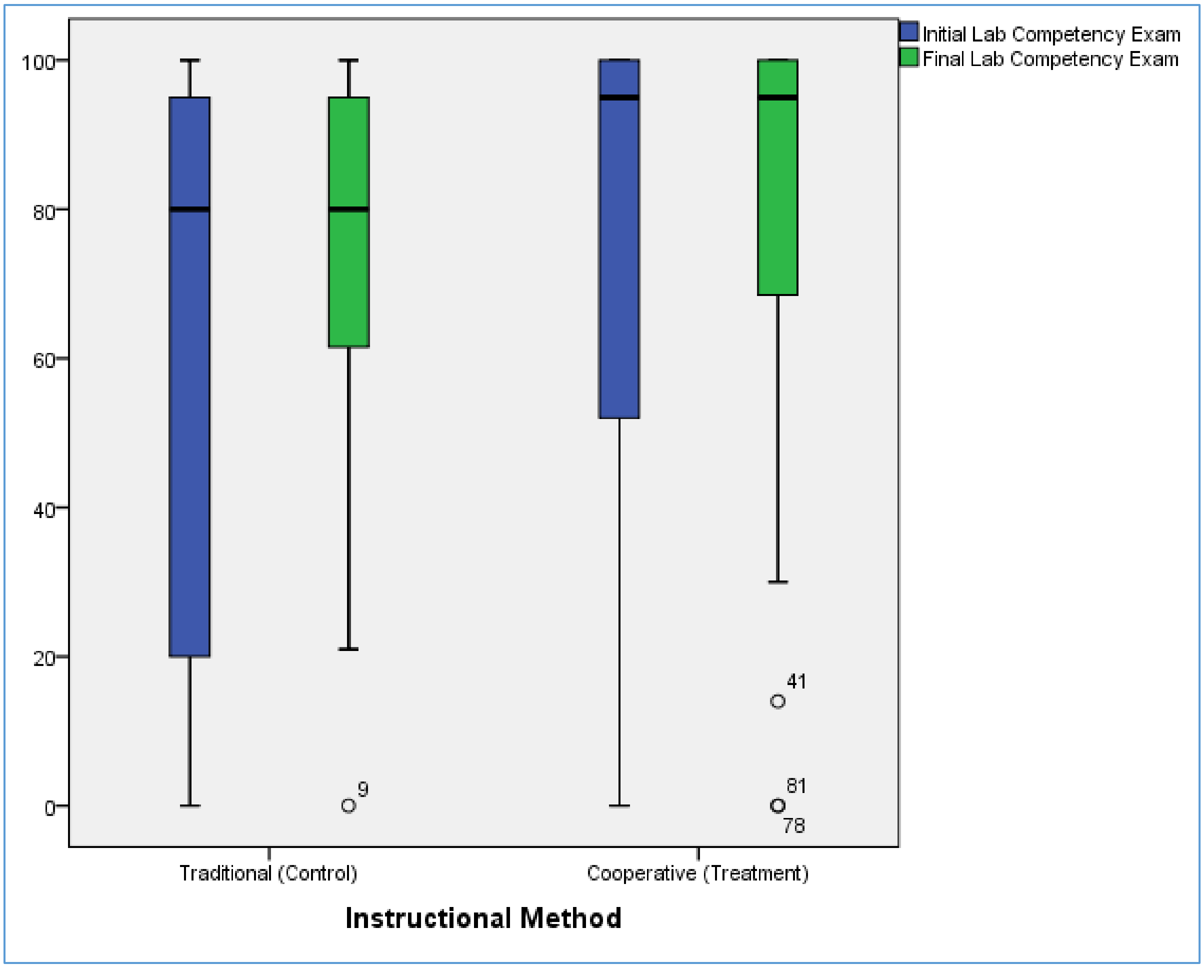

Figure 7 - Boxplot Comparison of Lab Competency Grades as a function of Instructional Method

Mann-Whitney U tests were conducted to determine if there were significant differences in students' scores on the lab competency exam (*Initial Lab Competency Exam* and *Final Lab Competency Exam*). In both cases, the differences were statistically insignificant: *Initial Lab Competency Exam;* U = 994.0, z = 1.46, p = .144, *Final Lab Competency Exam*: U = 986.5, z = 1.39, p = .165.

Discussion

Results of this study were promising and show that a relatively small change to instructional method in the laboratory setting can yield positive results for the students. While previous work has shown that cooperative learning can improve academic achievement in various settings, this study demonstrates the benefits of cooperative learning for improving student success in a first-semester engineering technology laboratory and indicates that this approach is at least as effective as a conventional approach and potentially more effective.

To address the first research question regarding the impact of cooperative learning on student success in DC Circuits laboratory, three separate components of the laboratory experience were analyzed for multiple laboratory assignments. For the pre-lab component, the mean scores for the cooperative learning group (treatment) were higher than the traditional learning group (control) for *Prelab #2* (7 points) and for *Project Prelab* (6 points) with a small effect size in each case. This indicates that cooperative learning had a positive impact on this component of student success although statistical significance was not reached for the pre-lab component analysis. For the results component, the mean scores for the cooperative learning group were higher than the traditional learning group for *Results #1* (6 points), *Results #2* (4 points), *Results #3* (8 points) and *Project Results* (6 points) with a small to medium effect size in each case. Statistical significance was reached for three of these four measures. In addition, one can see in Figure 5 that the medians were higher for the cooperative learning group and the distribution of scores indicates that a higher percentage of the cooperative learning students scored closer to the high end of the grading scale than the traditional learners. For the post-lab component, the mean scores for the cooperative learning group were considerably higher than the traditional learning group for *Postlab #2* (8 points), *Postlab #3* (17 points) and *Project Postlab* (4 points) with a small to medium effect size in each case. Statistical significance was reached for one of these four measures and one can see in Figure 6 that the medians were higher for the cooperative learning group in two of the four cases. The distribution of scores indicates that a higher percentage of the cooperative learning students scored closer to the high end of the grading scale than the traditional learners in all four cases.

Overall, considering the three measures of success considered in this study, the cooperative learning group (treatment) outperformed the traditional learning group (control).

To address the second research question regarding the impact of cooperative learning on student equipment proficiency in DC Circuits laboratory, two measures related to the laboratory competency exam were analyzed. The mean scores for the cooperative learning group (treatment) were higher than the traditional learning group (control) for *Initial Lab Competency Exam* (11 points) and *Final Lab Competency Exam* (4 points) with a small effect size in each case. This indicates that cooperative learning had a positive impact on student equipment proficiency although statistical significance was not reached for these measures. In addition, Figure 7 shows that the medians were higher for the cooperative learning group for both measures and that the distribution of scores indicates a higher percentage of the cooperative learning students scored closer to the high end of the grading scale than the traditional learners for both measures. Furthermore, for the cooperative learning group, only 21% (9 or 43) re-took the exam (11 of 43 were eligible) while for the traditional learning group, 36% (14 of 39) re-took the exam (16 of 39 were eligible). This also indicates that a larger percentage of students in the cooperative learning group developed individual proficiency with the laboratory equipment than those in the standard learning group.

Overall, considering the two measures of student equipment proficiency considered in this study, the cooperative learning group (treatment) outperformed the traditional learning group (control).

The sample used was one of convenience and limited in size. A larger sample taken from a larger population would yield more generalizable results.

The main implication of this study is that cooperative learning can be used in a first DC Circuits laboratory course to improve student success and equipment proficiency with only a small investment of time and effort on the part of the instructor. For this specific study, identical instructional materials were used for both the standard learning and cooperative learning groups. In addition, only a small portion of the first laboratory session of the cooperative learning group was taken up by having the students place themselves in teams and explaining the different roles. Rotating these roles within the student teams and reinforcing the value of each role each week took only a handful of minutes at the start of each laboratory session.

The next logical step towards creating a more constructivist experience in DC Circuits laboratory would be to modify each lab experience to be less prescriptive and more exploratory in nature.

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Appendix A

Pre-lab and Post-lab quiz examples from Lab #3

Prelab Questions (20 pts)

Question 1 (5 points)

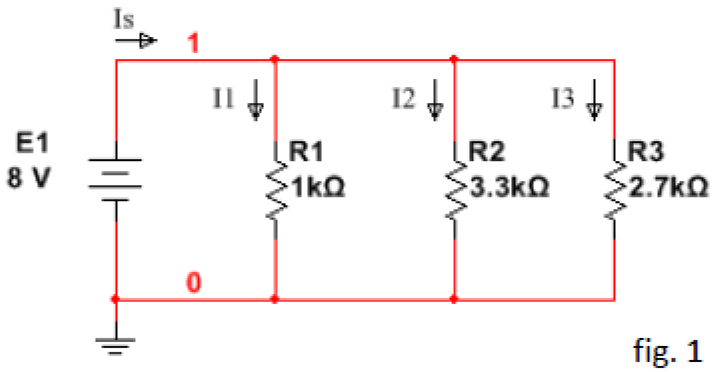

fig. 1

For the circuit of Fig. 1,I1 is:

Question 1 options:

- (•) 8.0 mA
- ( ) 16 mA
- ( ) 2.4 mA
- ( ) 3.9 mA

Question 2 (5 points)

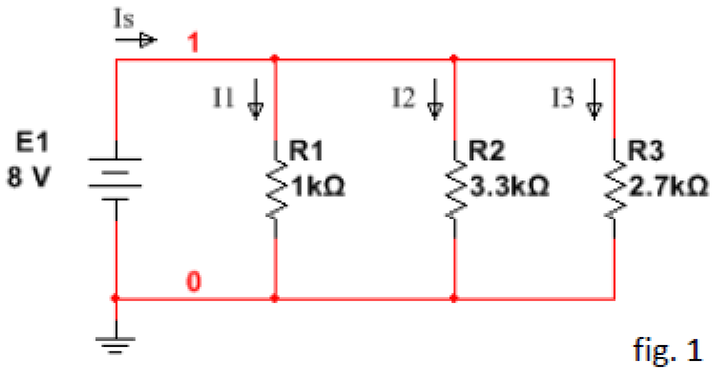

fig. 1

For the circuit shown in Fig. 1, the current Is is equal to:
Question 2 options:

- 21.4 mA
- (selected) 13.4 mA
- 19.26 mA
- 8.0 mA

Question 3 (5 points)

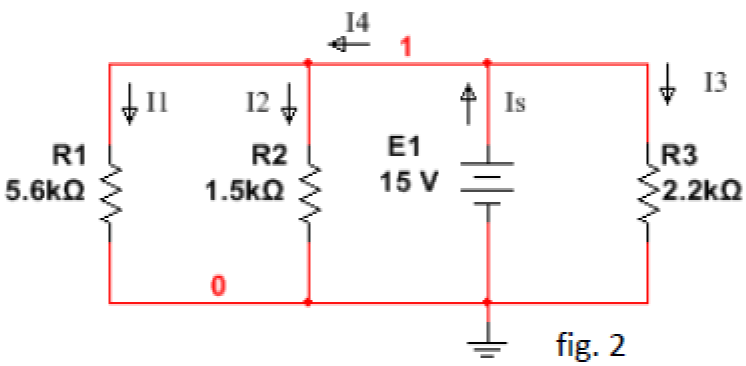

fig. 2

For the circuit shown in Fig 2, the voltage across R1 is:
Question 3 options:

- (selected) 15 V
- 7.5 V
- 30 V
- 5.0 V

Question 4 (5 points)

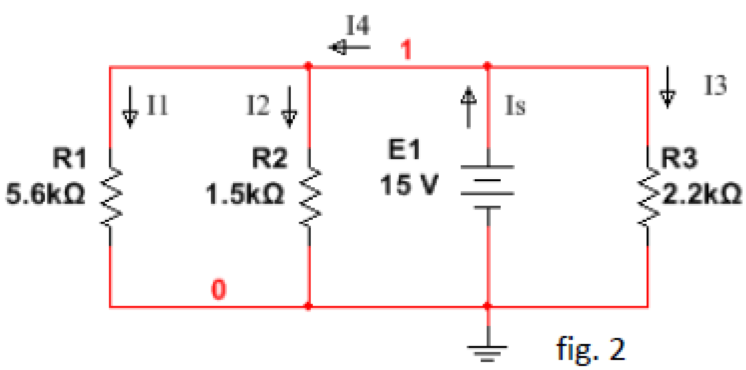

fig. 2

For the circuit shown in Fig 2, the current I4 is equal to:
Question 4 options:

- ◯ 6.82 mA
- ◯ 10.0 mA
- ◉ 12.7 mA
- ◯ 19.5 mA

Postlab Questions (20 points)

Question 1 (5 points)

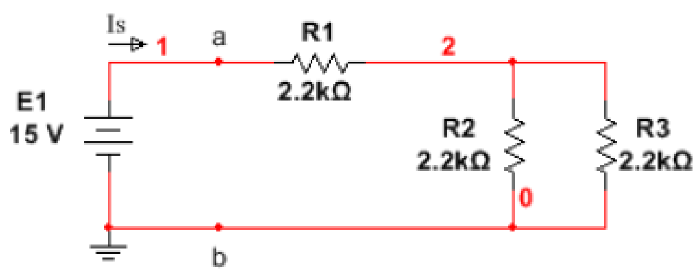

fig. 3

For the circuit of fig.3, the measured value of Is was closest to:
Question 1 options:

- ◯ 2.12 mA
- ◉ 4.55 mA
- ◯ 8.62 mA
- ◯ 6.82 mA

Question 2 (5 points)

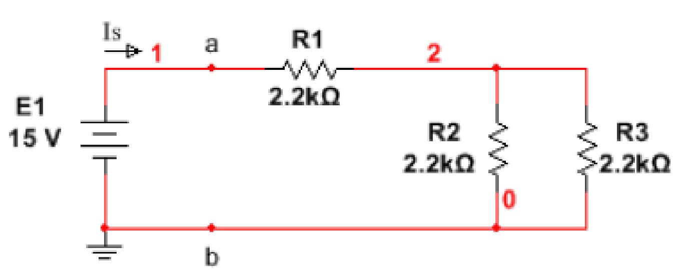

fig. 3

For the circuit shown in fig.3, if E1 was increased to 30V, the current that would flow, Is would equal:
Question 2 options:

- ○ 4.6 mA
- ◉ 9.1 mA
- ○ 13.6 mA
- ○ 6.8 mA

Question 3 (5 points)

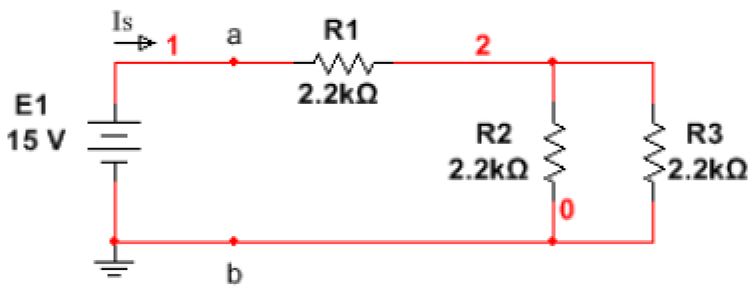

fig. 3

In the circuit of fig.3, if R1=R2=R3=3.3 k-ohms, the equivalent resistance, Req, would be:
Question 3 options:

- ○ 9.9 k-ohms
- ○ 1.1 k-ohms
- ◉ 4.95 k-ohms
- ○ 2200 ohm

Question 4 (5 points)

The equivalent resistance of 4 parallel 1000 ohm resistors is:
Question 4 options:

- ○ 1420 ohms
- ○ 500 ohms
- ○ 4000 ohms
- ◉ 250 ohms

Appendix B

Lab Handout for Lab #3

DC Circuits Laboratory **Lab # 3**

Ohm's Law, Parallel Circuits, and KCL

Lab Objective:

When this lab exercise is completed, the student should be able to:

1. Measure voltages across and currents through elements in a parallel circuit built on a protoboard.
2. Measure and understand voltage at a point and double subscript voltages.
3. Calculate, and experimentally find an equivalent resistance.
4. Use data taken to demonstrate Ohm's Law and Kirchhoff's Current Law.
5. Build a parallel circuit on a protoboard in such a way that others can easily recognize the components and take measurements.

Pre-Laboratory Prep. :

Prior to your scheduled laboratory meeting time the following items need to be completed. (Note the prelab quiz will be based on this preparation.

1. **Research**
   a. On the internet, find a 1 page article or app note that explains Kirchoff's Current Law. Print it, read it, and hand it in with your lab work, listing the source. *You may refer to this article when taking the lab quiz.*
2. **Analyze** (calculate the voltage across and current through each circuit element)
   a. On green engineering paper or quadrille paper, analyze the parallel circuits of fig. 1 and fig.2. NOTE: The results of this analysis will be part of the prelab quiz.
3. **Use Excel** to create a data table for recording the measured voltages and currents in fig. 1, and fig. 2. The data table should have spaces for all the voltages and currents called out in each circuit. Design your data table so that you can compare the calculated and measured values using the data tables from Lab 1 and Lab 2 as a model. Your instructor must sign off on your data table and analysis at the beginning of lab on the grade sheet.
4. **Preparation for quiz**: The quiz for this lab may include the following topics:
   a) Calculating voltages and currents using Ohm's Law, KVL and KCL in series and parallel circuits
   b) Understanding Ohm's Law, KVL and KCL
   c) Measuring voltages and currents in parallel circuits.
   d) Identifying the nodes in a parallel circuit.
   e) Calculating an equivalent resistance given a circuit or circuit segment.

DC Circuits Lab Procedure - Part 1: Parallel Circuit

1. Build the circuit shown in fig 1.
2. In the data table you created in the prelab, record all the currents and voltages called out in the figure.
3. Repeat steps 1 and 2 for the circuit in fig. 2.
4. Answer the questions below. Have your data signed off by your instructor or TA.

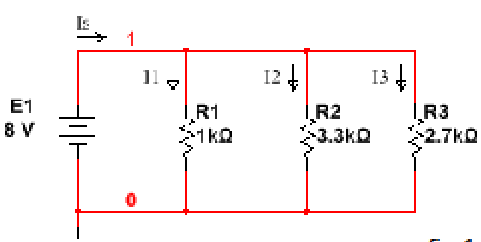

fig. 1

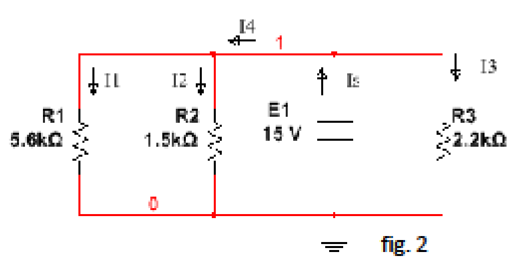

fig. 2

DC Circuits Laboratory **Lab # 3**

Ohm's Law, Parallel Circuits, and KCL

Note: make sure you submit your signed off and completed Excel data table and your prelab analysis with the questions (see Documentation).

Questions:

1. In fig.1, the total current splits into I_1, I_2, and I_3. Use your data to verify Kirchhoff's Current Law ($I_1 + I_2 + I_3 = I_S$). Was there any error in the result? Where did it come from?

Instructor sign off on the grade sheet.

Part 2: Equivalent Circuits.

1. Build the circuit shown in fig. 3 below.
2. Measure and record the source current I_S below:

   I_S = ____________

3. Use Ohm's Law, the applied voltage and source current to calculate and record the calculated value of the equivalent resistance Req "seen" by the source (see Lab Note 1).

   R_{eq} = ____________

4. Using your calculated value of R_{eq} build the circuit in fig. 4, measure and record below the resulting current I_S:

   I_S = ____________

5. Answer the following questions. Have your instructor sign off on this section on the grade sheet.

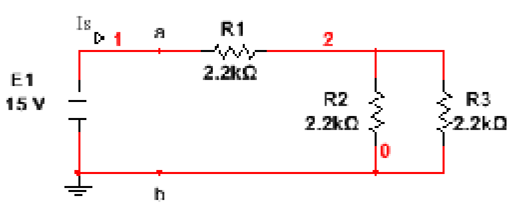

fig. 3

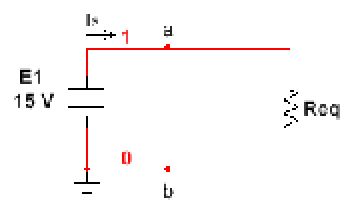

fig. 4

DC Circuits Laboratory Lab # 3

Ohm's Law, Parallel Circuits, and KCL

Questions:

1. The equivalent resistance, in this case, turned out to be a standard value. How would you make up a different equivalent resistance of 7.9kΩ ±5% using series and parallel combinations of standard value resistors (no more than 4 resistors) Draw the circuit below, and show the calculations including the % error calculation if needed.

Instructor sign off on the grade sheet.

Post Lab Requirements and Lab Notes - Documentation for this lab consists of the following pages in the following order

- Your grading cover sheet, completely filled in with signatures
- Your analysis of the circuits of Fig 1 and Fig 2 from the prelab, step 2a
- The completed data tables for the circuit voltages and currents for both figures 1 and 2 (including calculated and measured values as well as percent-errors with the percent error formula)
- Pages 2 and 3 of the lab handout (containing completed Q1 for part 1, your data for part 2 and your completed Q1 for part 2)

After lab, <u>during a time specified by your instructor</u>, take the post lab quiz. You may use the prelab work, the lab data and answers to the lab questions as reference material for this quiz. Submit the completed documentation at the beginning of next week's lab <u>before</u> you take that week's prelab quiz.

Lab Note 1: Equivalence

When someone says that two circuits are equivalent, it doesn't necessarily mean that they are identical. Think of the equivalence between a 1 dollar bill, and four quarters. One is a piece of paper, the other four metal coins. But because they can be used interchangeably to buy something that costs $1.00, they are **equivalent**. In much the same way, two circuits can be equivalent to one another. Two circuits that cause the same current to flow when attached to the same source (i.e. fig. 3 and fig. 4 in the lab today) are **equivalent**. When you look at terminals a and b on each circuit, with the sources removed, fig, 3 will have the same resistance between terminals a and b that fig. 4 does. That makes fig. 3 and fig.4 **equivalent**, even though they are not the same.

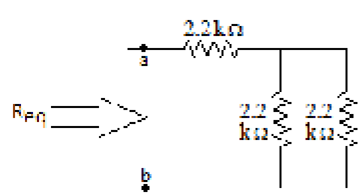

fig. 3

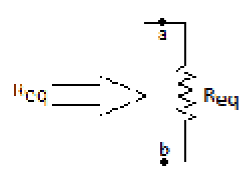

fig. 4

DC Circuits Laboratory **Lab # 3**

Ohm's Law, Parallel Circuits, and KCL

Name : ....

Program : ....

Lab Partner : ....

LABORATORY GRADE

Pre-Lab work (all work done neatly and submitted on time)	/10
Pre-Lab Quiz	/30
Laboratory Results (all work done neatly, completed on time, with signoffs in place)	/30
Post Lab Quiz (taken on line after lab)	/20
Documentation (neatly organized and in order, handed in on time with questions answered)	/10
Final Grade............................	/100

Instructor: Sign Off for Prelab _______________

Instructor: Sign Off for Part 1 _______________

Instructor: Sign Off for Part 2 _______________

Instructor comments:

Appendix C

Grading Rubric for the Lab Results Component of Lab #3

The lab results component for lab #3 is worth 50 points and includes (from the cover/grading sheet) the prelab work, laboratory results and documentation.

Grading breakdown:

Prelab work		**10 Points**
Figure 1 Circuit		5 points
- Schematic	2 points	
- Analysis correct	3 points	
Figure 2 Circuit		5 points
- Schematic	2 points	
- Analysis correct	3 points	
Instructor signature for prelab work not used		
Laboratory Results		**30 Points**
Part 1 signature (completion)		10 points
Part 2 signature (completion)		10 points
Data Table for Figure 1		5 points
- Calculated & Measured values	2 points	
- Units	1 point	
- % Error calculations	2 points	
Data table for Figure 2		5 points
- Calculated & Measured values	2 points	
- Units	1 point	
- % Error calculations	2 points	
Documentation		**10 Points**
Q1, part 1	2 points	
Part 2 Data	6 points	
- Step 2	2 points	
- Step 3	2 points	
- Step 4	2 points	
Q1, part 2	2 points	