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THE EFFECTS OF LABORATORY INSTRUMENTATION AND PARTNERING ON STUDENTS IN A FRESHMAN ELECTRICAL ENGINEERING COURSE

by

Rex N. Fisher

A dissertation

submitted in partial fulfillment

of the requirements for the degree of

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Idaho State University

Fall 2014

COMMITTEE APPROVAL

To the Graduate Faculty:

The members of the committee appointed to examine the dissertation of REX FISHER find it satisfactory and recommend that it be accepted.

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May 15, 2014

Rex Fisher
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RE: Your application dated 5/7/2014 regarding study number 4100: The effects of engineering labs modality and partner selection on student achievement, transfer, and motivation

Dear Mr. Fisher:

I agree that this study qualifies as exempt from review under the following guideline: 1. Research on educational practices in educational settings. This letter is your approval, please, keep this document in a safe place.

Notify the HSC of any adverse events. Serious, unexpected adverse events must be reported in writing within 10 business days.

You are granted permission to conduct your study effective immediately. The study is not subject to renewal.

Please note that any changes to the study as approved must be promptly reported and approved. Some changes may be approved by expedited review; others require full board review. Contact Tom Bailey (208-282-2179; fax 208-282-4723; email: humsubj@isu.edu) if you have any questions or require further information.

Sincerely,

Ralph Baergen, PhD, MPH, CIP
Human Subjects Chair

Phone: (208) 282-2592 • Fax: (208) 282-4723 • www.isu.edu/research

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ABSTRACT

This study assessed the instructional design effectiveness of two electrical engineering laboratory modalities by measuring how well they fulfilled the learning objectives of reinforcing theoretical concepts, developing transferrable practical skills, and promoting student motivation to continue studying engineering for students in their first engineering laboratory course at a private, medium size university in the Intermountain West. This experiment was a quantitative, posttest-only design with stratified random assignment of 72 students. The control group (n = 36) used traditional bench-top instruments. The treatment group (n = 36) used a “lab-in-a-box”, consisting of the *myDAQ* data acquisition instrument from *National Instruments*. Results of this study indicated that lab-in-a-box can be effectively used to reinforce conceptual knowledge without degradation of ability to make accurate measurements in the future with bench-top instruments and without reduced motivation to continue studying engineering. However, students who learned with the lab-in-a-box required 13% more time to adapt to unfamiliar bench-top laboratory instruments than students who learned with traditional laboratory instruments. The difference in time was statistically significant. This study also investigated whether pairing laboratory partners according to their cognitive ability influenced the achievement of these learning objectives. One set of partnerships consisted of two students with different levels of ability (one high and one low). The other set of partnerships consisted of two students with a similar level of ability (both medium). Findings suggested that

students with a high level of ability might be somewhat helpful to students who have a lower level of ability. This conclusion, however, was based on the data's effect size, and not their statistical significance.

CHAPTER I

Introduction

Most of the research in instructional design of engineering courses has focused on curriculum and classroom methodologies, whereas the development and assessment of engineering laboratories has lagged behind (Watai, Francis, & Brodersen, 2007). Laboratories, however, “are almost equally as important” (Wolf, 2010, p. 221) as classroom activities. Engineering is a profession that requires practical, hands-on skills (Feisel & Rosa, 2005). Undergraduate engineering laboratories provide a way for students to develop those hands-on skills that are essential for their future success as engineers (Abdulwahed & Nagy, 2008). Students apply their knowledge, understand and interpret unfamiliar information, and solve problems during their laboratory experiences (Malaric, Jurcevic, Hegedus, Cmuk, & Mostarac, 2008). Laboratory experimentation provides a validation process that helps to correct misconceptions and create meaning, both of which are necessary for true conceptual understanding (Psillos, 1998). Furthermore, laboratory courses can be motivating for students (Montes, Castro, & Riveros, 2010). The laboratory is, therefore, “a crucial part of an undergraduate engineering degree” (Lindsay, Long, & Imbrie, 2007, p. 1).

Because the cost of providing on-campus laboratory space and equipment has become a strain on university budgets, the development of effective, less-expensive alternatives to the traditional laboratory is necessary (Sicker, Lookabaugh, Santos, &

Barnes, 2005). Universities are also turning to online course delivery as a method of extending the opportunity for education to an increasing number of students without investing in additional physical facilities to accommodate them on campus (Valian & Emami, 2013). As with on-campus courses and laboratories, however, the development of effective online laboratories, has not yet reached the same level as the online courses they support (Khedher, 2010).

For all of these reasons, research to improve the efficacy of engineering laboratories "is of the highest importance" (Montes, et al., 2010, p. 490). Research into alternative laboratory delivery methods has been increasing and is usually focused on two: (a) virtual laboratories, also called simulated laboratories or computer simulations, and (b) remote laboratories, also called distance laboratories or remotely controlled experiments (Gomes & Bogosyan, 2009). Although both types of alternative laboratories require fewer of the university's physical resources, and increase the opportunity of students to access them, they have drawbacks compared to the traditional hands-on laboratories they attempt to replace (Malaric, et al., 2008).

Despite the weaknesses of computer simulations, some courses rely on them for the laboratory component because studies show that virtual laboratories satisfy some of the intended learning objectives (Azad, 2010; Harms, 2008). Stefanovic, Cvijetkovic, Matijevic, and Simic (2011) claimed, however, that computer simulations could never replace actual experiments, performed with physical instruments and circuits. Some computer-literate engineering students find "short-cuts" (Clark, Flowers, Doolittle, Meehan, & Hendricks, 2009, p.1) in the computer simulations and do not always gain the significant understanding from them that was intended. Nedic, Machotka, and Nafalski

(2003) were concerned that computerized (virtual and remote) laboratories may even "cognitively de-skill students" (p. 846). Salomon, Perkins, and Globerson (1991) explained that this is because a virtual laboratory involves "a partnership of individual and intelligent technology that performs well but leaves the human partner to persevere with a naive preconception when functioning without the technology" (p. 5).

In an attempt to provide a more realistic experience than computer simulations, remote laboratories allow students to manipulate real instruments via computer, and provide real data over the Internet instead of displaying simulated results calculated by software (Nickerson, Corter, Esche, & Chassapis, 2007). Remote laboratories are, however, time-consuming to set up and have a significant amount of down time (Coble, et al., 2010). Moreover, many students participating in remote laboratories do not have "a feeling of real presence in the lab" (Balamuralithara & Woods, 2009, p. 109). The feeling of presence is important to educators because it keeps students focused on the laboratory and contributes to higher student performance of the task (Lindsay & Good, 2005; Ma & Nickerson, 2006).

Research has already been conducted that confirms the effectiveness of traditional hands-on laboratories at reinforcing theoretical concepts (Montes, et al., 2010). The effectiveness of virtual and remote laboratories, however, is still being debated (Corter, Esche, Chassapis, Ma, & Nickerson, 2011). This is because the reported results of comparisons between different laboratory modalities are sometimes skewed (Ma & Nickerson, 2006). The cause may be "a lack of agreement on what constitutes effectiveness" (Ma & Nickerson, 2006, p. 7). More testing is required to confirm that students who use an alternative laboratory understand theoretical concepts as well as students who use a traditional laboratory (Morton & Uhomoibhi, 2011).

Research findings also support the conclusion that traditional laboratories are effective in helping students gain practical skills (Watai, et al., 2007). The success of transferring practical skills from the laboratory to other contexts, however, has received less attention from researchers and deserves further study (Feisel & Rosa, 2005). One subsequent study found “a failure to relate the theoretical concepts and/or practical knowledge gained in the laboratory to new, unfamiliar problems” (Hall, Palmer, Ferguson, & Jones, 2008, p. 277). More study is needed to evaluate how well students develop and use the “practical skills in using basic electronic components, operating basic electrical instruments such as power supplies as well as operating measuring instruments such as ammeter, voltmeter, multi-meter, oscilloscope and digital probe” (Salim, Puteh, & Daud, 2012. p. 548).

“Experimentation brings the course theory alive” (Malaric, et al., 2008, p. 300). One study found that laboratories are motivating for students (Melkonyan, Akopian, & Chen, 2009). However, thirty-six percent (36%) of the students in another study disagreed that laboratories are motivating (Hall, et al., 2008, p. 276). Serrano-Camara, Paredes-Velasco, Alcover, and Velazquez-Iturbide (2014) defined motivation as “a natural well spring of learning and achievement that can be systematically catalyzed or undermined by instructor practices” (p. 2). The laboratory’s ability to motivate – or de-motivate – students requires more study (Montes, et al., 2010).

These are some of the reasons that the National Engineering Education Research Colloquies has placed engineering laboratories in one of its five “main categories of needed research" (Garrett, Coleman, Austin, & Wells, 2008, p. 11). Providing an effective, non-traditional engineering laboratory is also an important issue for universities that must reduce the cost of their on-campus laboratories, or are expanding their online course offerings to include engineering courses (Kilicay-Ergin & Laplante, 2013). These universities must develop cost-effective laboratories to accompany their online courses in order to improve the knowledge, skills, and attitudes of the enrolled students (Montes, et al., 2010).

Finally, there is evidence that students who work with a partner are more likely to successfully complete the course and stay in the program (McDowell, Werner, Bullock, & Fernald, 2006). Teaching a peer is also one of the best ways for students to learn themselves (Fisher, 2004). Studies with paired computer science students show that their level of individual programming skill increases, especially among students with low SAT scores (Braught, Wahls, & Eby, 2011). Similar results occur with paired computer engineering students working on software projects (Carver, Henderson, He, Hodges, & Reese, 2007). A study of biotechnology students concluded that their performance in the laboratory is higher when laboratory partners have dissimilar abilities, even though the students prefer working with someone of similar academic ability (Miller, Witherow, & Carson, 2012). This may apply to engineering students performing laboratory work, and there may be an optimal way to pair them, thus increasing laboratory effectiveness even further.

Purpose

The purpose of this study was to assess the instructional design effectiveness of two electrical engineering laboratory modalities by measuring how well they fulfilled the learning objectives of reinforcing theoretical concepts (knowledge), developing transferrable practical skills (skills), and promoting student motivation to continue studying engineering (attitudes) for students in their first engineering laboratory course at a private, medium size university in the Intermountain West. It also investigated whether pairing laboratory partners according to their cognitive ability influenced the achievement of these learning objectives.

Research Questions

1. Does the type of laboratory (traditional or lab-in-a-box) or the method of pairing laboratory partners (one with high ability and one with low ability, or both with medium ability) affect a student's knowledge acquisition, as measured by a concept test?
2. Does the type of laboratory (traditional or lab-in-a-box) or the method of pairing laboratory partners (one with high ability and one with low ability, or both with medium ability) affect a student's transfer of skill with one set of laboratory instruments to another set of unfamiliar laboratory instruments, as measured by a speed-of-use test?
3. Does the type of laboratory (traditional, or lab-in-a-box) or the method of pairing laboratory partners (one with high ability and one with low ability, or both with medium ability) affect a student's transfer of skill with one set of laboratory instruments to another set of unfamiliar laboratory instruments, as measured by an accuracy-of-use test?
4. Does the type of laboratory (traditional or lab-in-a-box) or the method of pairing laboratory partners (one with high ability and one with low ability, or both with

medium ability) affect a student's motivation to continue studying engineering, as measured by the Pittsburgh Freshman Engineering Attitudes Survey?

Definitions

Types of laboratory instruments.

Bench-top instrument: This is usually a self-contained device for generating or measuring electrical signals. Too large to use while holding in one hand, it is normally operated while situated on a flat surface such as a bench-top. The electronics are packaged together with the user interface. The instrument is controlled with knobs, buttons, and/or dials to specify the operating parameters and the results are usually shown on a built-in numeric or graphic display. Some instruments use a built-in computer to control the electronics and produce the display. See some examples of bench-top instruments in Figure 1. This type of instrument is usually used in the traditional hands-on laboratory modality.

Figure 1. Examples of bench-top instruments used for making electrical measurements.

Hand-held instrument: This is a self-contained device for generating or measuring electrical signals. Often less complicated than a bench-top instrument, it is small enough to operate with one hand while holding it in the other. The electronics are packaged together with the user interface. The instrument is controlled with knobs, buttons, and/or dials to specify the operating parameters and the results are usually shown on a built-in numeric or graphic display. Figure 2 shows someone making an electrical measurement with a small, hand-held instrument. This type of instrument is normally used in the traditional hands-on laboratory modality.

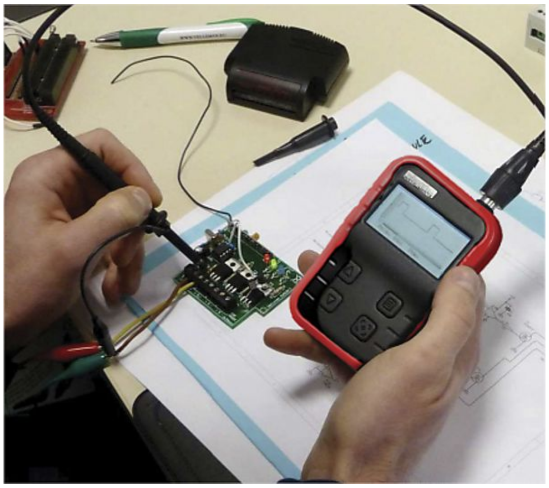

Figure 2. Example of hand-held instrument being used in a traditional laboratory.

Data acquisition (DAQ) instrument: This is a physically real laboratory instrument. The electronics used to measure or generate electrical signals are usually packaged without built-in controls or displays. The device is connected to a computer, which acts as the user interface to control the instrument and display measured values. It offers the functionality of a bench-top instrument in a more portable and less expensive package. Figure 3, on page 9, illustrates a data acquisition instrument connected to a computer and making an electrical voltage measurement. This type of instrument is used in the lab-in-a-box (LIAB) laboratory modality. The specific data acquisition instrument used in this study is the *myDAQ*, manufactured by *National Instruments*.

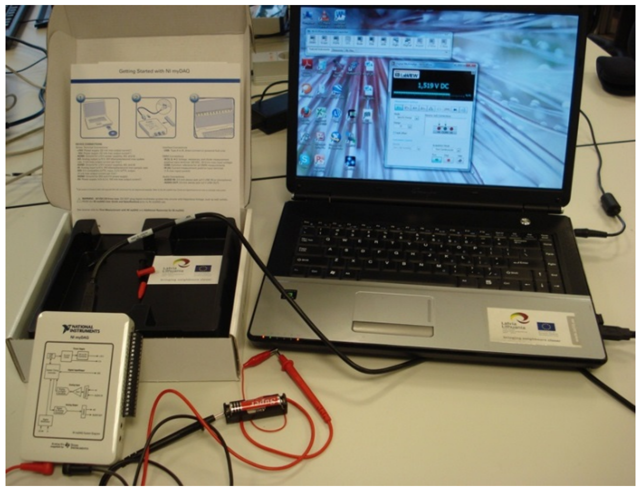

Figure 3. Data acquisition instrument with computer for control and display.

Digital multi-meter (DMM): This instrument measures electrical characteristics such as voltage, current, and resistance, and presents their values on a numeric display. This is often a hand-held instrument. See Figure 4, on page 10, for an example of a hand-held DMM.

Figure 4. Digital multi-meter (DMM) used for making electrical measurements.

Function generator: This instrument produces a voltage of variable amplitude, frequency, and wave shape. It is normally a bench-top instrument. Figure 5 shows a typical bench-top function generator.

Figure 5. Function generator used for producing AC voltages.

Oscilloscope: This instrument measures electrical characteristics such as the amplitude and frequency of a voltage and displays them graphically. It is normally a bench-top instrument. A bench-top oscilloscope is shown in Figure 6, on page 11.

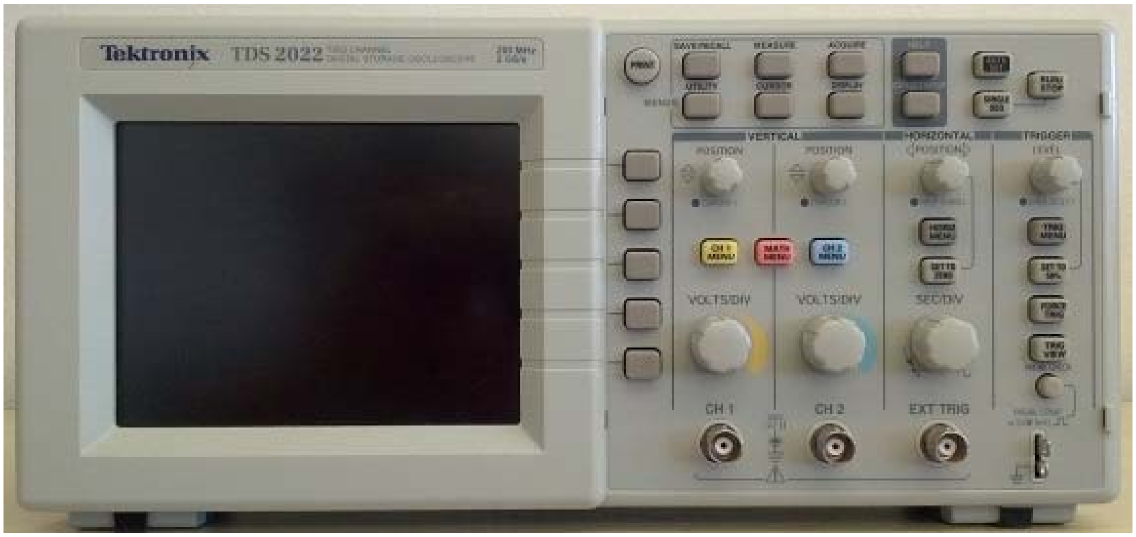

Figure 6. Oscilloscope used for graphically representing voltages.

Types of laboratory modalities.

Distance laboratory: This is also called a remote laboratory. Students use a computer connected to the Internet, or other network, to control actual instruments at another location (Ma & Nickerson, 2006).

Hands-on laboratory: The actual laboratory equipment (usually bench-top instruments) is physically proximate to the students using it, even if it is computer-controlled (Ma & Nickerson, 2006). These laboratory instruments are “physically real” (p. 5). See Figure 1 on page 7, Figure 2 on page 8, Figure 4 and Figure 5 on page 10, and Figure 6 for examples of instruments used in hands-on laboratories.

Lab-in-a-Box (LIAB): This is a variation of the hands-on laboratory. It is a physically real data acquisition instrument connected directly to a personal computer and controlled locally by the student (Clark, et al., 2009). It is similar in operation to a remote or distance laboratory, except that the actual computer-controlled measuring equipment is physically proximate to the student. This is not a simulation. It provides actual hardware functionality similar to traditional bench-top instruments, but with a more abstract user interface. See Figure 3, on page 9, for an example of a data acquisition instrument used for the lab-in-a-box.

Remote laboratory: See *distance laboratory*.

Simulated laboratory: This is also called a virtual laboratory. No physical laboratory instruments are used. This is an interactive computer simulation with no physical link to electronic measuring equipment (Tzafestas, Palaiologou, & Alifragis, 2006). These laboratories are "imitations of real experiments" (Ma & Nickerson, 2006, p. 6).

Traditional Laboratory: See *hands-on laboratory*.

Virtual laboratory: See *simulated laboratory*.

Experimental groups.

TRAD groups: For the purpose of this study, these are experimental groups in which students use the traditional laboratory.

LIAB groups: For the purpose of this study, these are experimental groups in which students use the lab-in-a-box (LIAB).

HL groups: For the purpose of this study, these are experimental groups in which laboratory partners consist of one student with a high (above average) level of cognitive ability (whose ACT score is in the top 25% of students in the study) and one student with a low (below average) level of cognitive ability (whose ACT score is in bottom the 25% of students in the study). Their ACT scores usually differ by about eight points.

MM groups: For the purpose of this study, these are experimental groups in which laboratory partners consist of two students with a medium level of cognitive ability (whose ACT scores are between the top 25% and the bottom 25% of students in the study). Paired students in these groups had the same ACT score whenever possible. No pair of MM students had ACT scores that differed by more than one point.

Instructional Design Terms.

Transfer: This is how "learning in one context improves performance in some other context" (Perkins & Salomon, 1988, p. 22).

Near transfer: This type of transfer takes place when contexts and performances are closely related (Perkins & Salomon, 1992).

Far transfer: This type of transfer occurs in different contexts with dissimilar activities (Perkins & Salomon, 1992).

Low road transfer: This is usually the mechanism of near transfer. It is reflexive and involves semi-automatic responses in situations that are very similar to those under which the initial learning took place (Salomon & Perkins, 1989).

High road transfer: This applied to far transfer. It requires a deliberate effort to draw on experience (Salomon & Perkins, 1989).

Engineering fidelity: This describes how authentic a simulation appears to the person using it (Maran & Glavin, 2003).

Psychological fidelity: This is the level of how accurately a simulation represents the specific motions or behaviors a person must perform to accomplish the real task (Maran & Glavin, 2003).

Organizations.

ABET: This is the official name of the organization, not an acronym. "ABET is a nonprofit, non-governmental organization that accredits college and university programs in the disciplines of applied science, computing, engineering, and engineering technology” ("ABET: About ABET," 2011).

ASEE: **“**The American Society for Engineering Education is a nonprofit organization of individuals and institutions committed to furthering education in engineering and engineering technology” ("ASEE: About ASEE," 2013).

IEEE: “IEEE . . . stands for the Institute of Electrical and Electronics Engineers. As the world's largest technical professional association, IEEE's membership has long been composed of engineers, scientists, and allied professionals” ("IEEE: History," 2014).

Limitations

Most threats to the internal validity of this study were controlled by random assignment of participating students and its short duration. There were, however three things that were a challenge to control because of the physical proximity of the different experimental groups.

1. Compensatory rivalry: Students using one type of laboratory equipment could have seen those using the other type and might have worked harder than usual because they felt they were in a competition. This would have either eroded or magnified the difference between the groups caused by the treatment (Cook & Campbell, 1986). Keeping the duration of the study short and working with only one group each day were attempts to minimize this threat to validity.
2. Resentful demoralization: Students using one type of laboratory equipment could have seen those using the other type and might have reduced their effort because they believed that the others were given more desirable laboratory equipment.

This would have either eroded or magnified the difference between the groups caused by the treatment (Cook & Campbell, 1986). A short duration and working with only one group each day also minimized the opportunity for this threat to occur.

3. Treatment diffusion: Students could have shared their experiences with others in the study, which would tend to equalize the outcomes (Borg, 1984). In addition to minimizing this with a short duration and working with only one group each day, participants were instructed not to discuss what they are doing with anyone except their laboratory partner, the instructor, or the laboratory assistants during the study. This also required proctoring and a physical distance between each pair of laboratory partners during their laboratory work to prevent sharing information among pairs, or overhearing other conversations. Because only about half of the class performed each laboratory at a time, providing this physical separation was possible.

Delimitations

The scope of this study was limited to students in their first engineering laboratory course. Participants were students who enrolled in ECEN 150 at a private, medium size university in the Intermountain West. This course usually comprises all of the university's first semester, electrical engineering and computer engineering students. Non-majors taking this course were also among the participants.

There are several ways to provide an alternative to the traditional engineering laboratory, but this study focused on a method that has been called lab-in-a-box in the literature (Clark, et al., 2009, p. 2). Other laboratory modalities, such as computer simulations or remotely controlled laboratories, were not studied. The chosen lab-in-a-box instrument platform was a data acquisition instrument called the *myDAQ* from *National Instruments*. It provides actual hardware functionality similar to traditional bench-top instruments, but with a different user interface. The *myDAQ* was selected from among the commercially available data acquisition instruments because it is relatively inexpensive and its user interface most closely resembled the controls of a bench-top instrument. Although operation of the *myDAQ* is more abstract than that of traditional bench-top laboratory equipment, it is not a simulation. It is connected directly to a personal computer and is controlled locally by the student. This version of lab-in-a-box may be used almost anywhere, whether that be on-campus in a formal laboratory setting or at home. This can free up university resources and provide temporal and spatial flexibility to students (Malaric, et al., 2008).

The effects of pairing laboratory partners with different levels of cognitive ability were also examined. One set of partnerships consisted of one student with an above average level of cognitive ability and one student with a below average level of cognitive ability. The other set of partnerships consisted of two students with a medium level of cognitive ability. The effects of pairing two students having other characteristics or combinations of cognitive ability were not studied.

Each pair of laboratory partners collaborated face-to-face in real time during the treatment. This minimized differences in the dependent variables that could have been caused by using different methods of collaboration. The effects of other collaboration methods were not studied.

To ensure that extraneous variables not associated with the treatment – such as course format and teaching style – were controlled, all participants in this study were on-campus students taking the course from the same instructor. The only discernable difference between students in the TRAD groups and those in the LIAB groups were whether they used the traditional laboratory or the lab-in-a-box. The only discernable difference between students in the HL groups and those in the MM groups were whether they were paired with someone of different cognitive ability or with someone of similar cognitive ability. This study cannot be generalized to other laboratory modalities or pairing combinations.

Research Design

This experiment was a quantitative, posttest-only design with stratified random assignment to laboratory modality. This strong, true experimental design minimized most of the threats to its internal validity (Campbell & Stanley, 1963).

The 2 x 2 factorial structure (type of laboratory equipment crossed with type of pairing) compared the knowledge, skills, and attitudes of four experimental groups of students (TRAD-HL, TRAD-MM, LIAB-HL, or LIAB-MM). Each group completed two engineering laboratories under different conditions. Students in the TRAD-HL group performed traditional laboratories and collaborated with partners who had a different level of cognitive ability (one partner with a high ACT score and one with a low ACT score). Students in the TRAD-MM group performed traditional laboratories and collaborated with partners who had the same (or similar) level of cognitive ability (both with average ACT scores). Students in the LIAB-HL group used the lab-in-a-box and collaborated with partners who had a different level of cognitive ability (one partner with a high ACT score and one with a low ACT score). Students in the LIAB-MM group used the lab-in-a-box and collaborated with partners who had the same (or similar) level of cognitive ability (both with average ACT scores). Knowledge was measured with a concept test consisting of questions that had been previously validated. Skill was measured by a performance test developed and validated especially for this study. Attitudes, specifically motivation to continue studying engineering, were measured by the *Pittsburgh Freshman Engineering Attitudes Survey*, which was created and validated by Besterfield-Sacre & Atman (1994).

The population studied was first semester electrical engineering and computer engineering majors at a medium size university in the Intermountain West. The participants were students enrolled in ECEN 150, the first semester engineering course with a laboratory about electric circuits. The sample comprised nearly all of the students in the course for two consecutive semesters. Students without available ACT or SAT scores were not included in the study. Students not participating in this study were paired together to complete the course assignments, but their data were not included in the analysis. At the conclusion of the treatment and posttests, the results were analyzed to determine if understanding of course content (knowledge), the ability to adapt to unfamiliar laboratory equipment (skills transfer), or motivation to continue studying engineering (attitude) was affected by either the laboratory modality used or the way laboratory partners were paired.

Significance of the Study

Institutions and instructors need trustworthy information about how to provide effective undergraduate engineering laboratories (Ma & Nickerson, 2006). A particular “challenge facing universities is how they are going to place ‘real’ labs on the Internet” (Balamuralithara & Woods, 2009, p. 109) for online students. The literature regarding these issues, however, is “inconclusive” (Lowe, Murray, Lindsay, & Liu, 2009, p. 290; Ariadurai & Manohanthan, 2008; Pop, Zutin, Auer, Henke, & Wuttke, 2011). The reason it is inconclusive, according to Chen, Wu, and Su (2008), is that most of the research has a “weak methodological design” (p. 10), which cannot provide convincing evidence. This is because most studies are not true experimental designs with random assignment. Nevertheless, the literature review for this study demonstrates that researchers investigating the instructional design of engineering laboratories have cited even the weakest of the current studies on the topic. This suggests there is not enough reliable information in the body of literature to inform design and delivery decisions. This study provides additional evidence to help resolve these issues by comparing the effectiveness of a traditional laboratory with a less-expensive alternative that may be used by either on-campus or online students, i.e., bench-top instruments vs. lab-in-a-box. It also examined whether laboratory learning can improve when partners are paired according to cognitive ability, i.e., one with high ability and one with low ability vs. both with medium ability.

CHAPTER II

Literature Review

This literature review will show that instructional design research about engineering laboratories is a priority for professional engineering organizations and engineering research journals. It will describe the role that engineering laboratories have traditionally played and the supporting theoretical framework for that role. Common modalities of engineering laboratories and methods of pairing laboratory partners will be described, along with contemporary research into their effectiveness. Some weaknesses and conflicting results of that research will be identified and unresolved questions to be addressed by this study will be discussed.

Purpose

The purpose of this study was to assess the instructional design effectiveness of two electrical engineering laboratory modalities by measuring how well they fulfilled the learning objectives of reinforcing theoretical concepts (knowledge), developing transferrable practical skills (skills), and promoting student motivation to continue studying engineering (attitudes) for students in their first engineering laboratory course at a private, medium size university in the Intermountain West. It also investigated whether pairing laboratory partners according to their cognitive ability influenced the achievement of these learning objectives.

Literature Sources

Five databases were interrogated to discover relevant research about engineering laboratories: *EIRC*, *EBSCO*, *Elsevier*, *ProQuest*, and *IEEE Xplore Digital Library*. Because the different modalities of engineering laboratories go by more than one name, the following search phrases were used: *hands-on AND laboratory*, *in-person AND laboratory*, *virtual AND laboratory*, *simulation AND laboratory*, *computer AND laboratory*, *online AND laboratory*, *remote AND laboratory* and *distance AND laboratory*. Research on collaboration was found using these search terms: *laboratory AND collaboration*, *engineering AND collaboration*, *online AND collaboration*, *synchronous AND collaboration*, *asynchronous AND collaboration, peer AND learning, peer AND teaching,* and *study AND group*. Two final, catchall search phrases used were *undergraduate AND laboratory*, and *engineering AND laboratory*. The citations for educational theory and instructional design come from other sources. Some of them are landmark publications.

Research into the academic use of science and engineering laboratories peaked in 2002 and 2003, and then dropped off until 2006 when it started increasing again (Gravier, Fayolle, Bayard, Ates, & Lardon, 2008). Most of the research reviewed for this study is from 2006 to the present. Any research about engineering laboratories appearing here that is older than 2010 was published in a major journal or has been cited at least twelve times.

Importance of Instructional Design Research into Engineering Laboratories

“The laboratory is where elegant scientific theories meet messy everyday reality” (Corter, et al., 2011). Stefanovic, et al. (2011) asserted that laboratory work is “essential”

(p. 542) to the education of engineers. Because of this, research to improve the efficacy of engineering laboratories "is of the highest importance" (Montes, et al., 2010, p. 490). Ma and Nickerson (2006) found over 60 articles in engineering journals and conference reports that had addressed engineering laboratories. Abdulwahed and Nagy (2008) declared the educational use of laboratories as a "fertile arena of research" (p. 9). The *National Engineering Education Research Colloquies*, *Journal of Engineering Education (JEE)*, *Annuals of Research in Engineering Education (AREE)*, *Journal of Professional Issues in Engineering Education (JPIEE)*, *Institute of Electrical and Electronic Engineers (IEEE)*, and *American Society for Engineering Education (ASEE)* all rank improving engineering laboratories as a research priority (Garrett, et al., 2008).

Research about designing and conducting effective engineering laboratories is, engineering communities. The next section describes why laboratories are an essential component of engineering curricula.

Traditional Role of Engineering Laboratories

Chika, Azzi, Hewitt, and Stocker (2009) stated that engineering laboratories play a "critical role in instruction and learning" (p. 26). The laboratory's essential role it to instill skills in problem solving, analytical thinking, and the manipulation of tools and materials (Abdulwahed & Nagy, 2008). Laboratories foster the ability to gather, interpret, and report experimental data (Aloul, Zualkernan, El-Hag, Husseini, & Al-Assaf, 2010). Laboratories facilitate learning to work on a team (Salim, et al., 2010). Finally, laboratories often increase the desire of students to learn more (Tan, 2012).

Laboratory courses are the first practical experience that some students have (Montes, et al., 2010). Clark, et al., (2009) found that even though students used a plethora of electronic gadgets in their daily lives, “they had no experience in dealing with electronics from an experimental point of view” (p. 1). This was attributed to the decreasing interest in ham radio, assembling electronics kits, and rebuilding computers because technology has made components too small and difficult for hobbyists to work on (Clark, et al., 2009). Feisel and Rosa (2005) came to the same conclusion “that fewer students come to the university with experience as ‘shade tree mechanics’ or amateur radio operators” (p. 123), and that engineering laboratories are necessary to give them experience with physical systems.

Before the first engineering schools were created, engineering in the United States was taught as an apprenticeship program in which the emphasis was on practical skills, such as building inventions (Balamuralithara & Woods, 2009). Most engineers started their education as apprentices in machine shops until well into the 1800s (Seely, 1999). By the middle of the 1800s, many engineering schools had been created, and they still “placed heavy emphasis on laboratory instruction” (Feisel & Rosa, 2005, p. 122). From 1900 to 1935, engineering education continued to “teach industrial skills, facts, and methods” (Berry, DiPiazza, & Saurer, 2003, p. 467) because of pressure from industry. After World War II, however, the ASEE sponsored a committee to investigate what the future of engineering should be like (Feisel & Rosa, 2005). It concluded, “The engineers being produced were too practically oriented and were not sufficiently trained to seek solutions by referring to first principles” (p. 122). This report “transformed” (Seely, 1999, p. 289) engineering education and the emphasis on laboratories was replaced with a new focus on engineering science that lasted for nearly 40 years. The move away from the practical and toward the theoretical produced an ever widening “gulf between engineering schools and industrial practice, perhaps even an imbalance of theory and practice in the colleges" (p. 272). Feisal and Rosa (2005) described engineering graduates of this period as "steeped in theory but poor in practice" (p. 122).

At the beginning of the 21st century, ABET specified eleven required outcomes for graduates of accredited engineering programs that once again placed an importance on laboratories (Feisel & Rosa, 2005). The current ABET requirements are that engineering graduates must demonstrate:

1. Ability to apply knowledge of mathematics, science, and engineering.
2. Ability to design and conduct experiments, as well as to analyze and interpret data.
3. Ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.
4. Ability to function on multidisciplinary teams.
5. Ability to identify, formulate, and solve engineering problems.
6. Understanding of professional and ethical responsibility.
7. Ability to communicate effectively.
8. The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.
9. Recognition of the need for, and an ability to engage in life-long learning.
10. Knowledge of contemporary issues.
11. Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice (ABET, 2012, p. 3).

Although ABET's criteria do not explicitly state that laboratories are necessary, they do require students to design and conduct experiments, analyze and interpret experimental data, function on teams (work with lab partners), communicate effectively (write laboratory reports), and use techniques, skills, and modern engineering tools (including laboratory instruments). These are all things that are facilitated by laboratories (Nedic, et al., 2008; Nickerson, et al., 2007; Wei, Zhuang, Xin, Al-Shamma'a, & Shaw, 2012).

Harms (2008) presented a more specific list of objectives for laboratory work that are compatible with ABET's criteria:

1. To support the learning of theory by
    a. illustrating/demonstrating phenomena.
    b. applying theory to real situations.
    c. demonstrating the limitations of theory.
    d. interacting with phenomena in authentic situations.
2. To develop a body of knowledge about
    a. materials, devices and techniques.
    b. safety codes and practices.
    c. specific equipment and techniques.
3. To develop a body of skills involving
    a. manual skills.
    b. critical observation, interpretation, and assessment.
    c. diagnostic skills.
    d. planning and organizing.

e. practical problem solving.

4. To develop attitudes which

    a. stimulate an interest in engineering.

    b. highlight ‘getting the job done.’

    c. generate self-confidence.

In summary, although engineering curricula de-emphasized laboratories for a few decades, they were re-integrated again into engineering curricula because graduates were missing some essential skills that laboratory experience helped to develop. Those skills are now required outcomes for accredited engineering programs. The next section describes the theoretical framework of how those skills are developed in the laboratory.

Theoretical Framework for Engineering Laboratories

The constructivist model is the most widely used in science education, including laboratories (Lunetta, 1998). This theoretical framework emphasizes that learning is an active, iterative process of interpreting personal experiences and constructing meaning from them (Tobin, 1990). “Laboratory activities [are] a way of allowing students to learn with understanding and, at the same time, engage in a process of constructing knowledge by doing” (p. 405).

It is not enough to learn theory in the classroom (Jara, Candelas, Torres, Dormido, & Esquembre, 2012). Experimentation provides a “deep understanding” (p. 124) of the theory that is vital for science and engineering students. Laboratories are “learning experiences in which students interact with materials and/or with models to observe and understand the natural world” (Hofstein & Lunetta, 2003, p. 31). Polman (1999) added that this happens by solving meaningful, real-world problems. Physical activity, such as laboratory work, is an important part of the learning process (Johnson & Aragon, 2002). Gardner (1983), who proposed a theory of multiple intelligences, also validated this concept.

But, said White and Gunstone (1992), laboratories must emphasize the manipulations of ideas, not just materials and procedures. Barron et al. (1998) asserted that reflection is an indispensible part of the process. According to Bain (2004), “When we can successfully stimulate our students to ask their own questions, we are laying the foundation for learning” (p. 31).

According to Ausubel and Youssef (1963), the failure to elaborate on how new information differs from what students already know will cause them to ignore the new information and perpetuate their existing misconceptions. This has typically been a major problem in science and engineering courses (Sneider & Ohadi, 1998). Laboratories can help with this by increasing understanding through elaboration and the application of learned principles (Hofstein & Lunetta, 2003).

Vygotsky (1978) found that the social environment was a major factor in learning and he stressed the importance of personal interaction. Peer collaboration during laboratories is a technique based on Vygotsky’s ideas (Fawcett & Garton, 2005). Peer collaboration is defined as “the acquisition of knowledge and skill through active helping and supporting among status equals or matched companions” (Topping, 2005, p. 631). Longfellow, May, Burke, and Marks-Maran (2008) observed that collaboration with peers results in more learning than is achieved by students working alone. This is because the “explainer” (Roma & Pueo, 2010, p. 478) learns more by teaching and those hearing the explanation benefit from the new perspective. According to Havnes (2008), peer collaboration leads to more creativity in the learning process. It facilitates "real scientific inquiry" (van Joolingen, de Jong, & Dimitrakopoulout, 2007, p. 115). Collaboration also helps students to "become part of a learning community" (Beldarrain, 2006), p. 145).

Most traditional hands-on laboratories are performed by students working together in a group as laboratory partners (Lowe, et al., 2009). Composition of the group is particularly important for effective collaborative learning (Serrano-Camara, et al., 2014). Yuof, Sanusi, and Mat (2012) elaborated that performance in the laboratory depends on the prior abilities of the collaborating group members (laboratory partners). When pairing students according to ability, Christiansen and Bell (2009) found that the more capable partner benefits the most because "reorganizing and communicating information can promote a deeper understanding of the subject area" (p. 805).

Laboratories should be designed to encourage and facilitate effective student collaboration (Arango, Chang, Esche, & Chassapis, 2007). Johnson and Aragon (2002) went even further by stating that laboratory instructors should "require" (p. 1028) peer interaction. Peer collaboration should be used not only for traditional hands-on laboratories, but also for other laboratory modalities (Ma & Nickerson, 2006).

Some studies have shown that laboratories are motivating for students (Havnes, 2008; Malaric, et al., 2008; Melkonyan, et al., 2009). Research has also indicated that the attrition of students in engineering programs is because of their negative attitudes toward engineering more than a lack of ability (Hilpert, Stump, Husman, & Kim, 2008). Increased motivation to study engineering leads to more persistence (Serrano-Camara, et al., 2014), and an increased desire to collaborate with peers (Hilpert, et al., 2008).

Simulations have become increasingly important in engineering education (Gustavsson et al., 2009). In addition to using hands-on learning, concepts and principles may also be reinforced through simulations (Corter, et al., 2011). Simulations are “simple depictions of reality” (Karadimas & Efstathiou, 2007, p. 37). Using mathematical models, they offer a visualization that may not be directly observable in the physical world (Coble, et al., 2010).

The extent to which a simulation imitates reality is called fidelity (Choi, 1998). There are two types of fidelity: (a) engineering fidelity, which is how authentic the simulation appears, and (b) psychological fidelity, which is how accurately it represents the specific motions or behaviors required to accomplish the task (Maran & Glavin, 2003). Studies in engineering education have shown that high fidelity results in more learning (Potkonjak, Jovanovic, Holland, & Uhomoibhi, 2013). Studies in some other fields, however, have found “no significant advantage” (Norman, Dore, & Grierson, 2012, p. 636) of high fidelity over low fidelity simulations.

A common use of simulation in engineering is the computer-control of real laboratory instruments (Ma & Nickerson, 2006). Many computer-controlled instruments have a graphical user interface that realistically portrays the controls of an actual, manually controlled instrument on a computer screen (Balamuralithara & Woods, 2009). This simulated interface is an abstraction of the control panel on the real hardware (Lindsay & Good, 2005). According to Potkonjak, et al. (2013), the “command panel” (p. 80) should have high fidelity in order to facilitate realistic training.

The laboratory is the primary tool for helping engineering students acquire necessary transferable skills (Abdulwahed & Nagy, 2008, p. 9). Transfer is defined to occur “when learning in one context improves performance in some other context” (Perkins & Salomon, 1988, p. 22). These transferrable skills are highly valued by employers (Tan, 2012).

There are two types of transfer: (a) near transfer, and (b) far transfer (Perkins & Salomon, 1992). Near transfer takes place when contexts and performances are closely related; far transfer occurs in different contexts with dissimilar activities (Perkins & Salomon, 1992). The mechanisms for transfer are high road transfer and low road transfer (Salomon & Perkins, 1989). Low road transfer, usually the mechanism of near transfer, is reflexive and involves semi-automatic responses in situations that are very similar to those under which the initial learning took place (Salomon & Perkins, 1989). High road transfer, the mechanism of far transfer, requires a deliberate effort to draw on experience (Salomon & Perkins, 1989).

Laboratories, therefore, should be learning activities where students are motivated to construct knowledge and acquire transferable skills by ‘doing’ (or through simulations) in collaboration with peers. The attitudes and prior abilities of those peers can affect the quality of the collaborative learning. The next section describes the various types of laboratory experiences that can be used in an engineering course.

Types of Engineering Laboratories

The literature places laboratories into three major groups: (a) hands-on, (b) virtual, and (c) remote laboratories (Gomes & Bogosyan, 2009). A fourth group, distance kits, has support from industry ("Digilent," 2014; Meehan, 2012; "National Instruments," 2014), but has received less attention from researchers (Clark, et al., 2009; Meehan, 2012). Each one has its advantages and disadvantages.

Hands-on laboratory. The actual equipment is physically proximate to the students using it, even if it is computer-controlled (Ma & Nickerson, 2006). These laboratories are "physically real" (p. 5). This is the traditional engineering laboratory, which is the most common form of laboratory (Gomes & Bogosyan, 2009).

Advantages: Students are able to "experience the backbone of engineering" (Chen, Song, & Zhang, 2010, p. 3843). Students get "a 'feel' (Balamuralithara & Woods, 2009, p. 112) for real things. There is the possibility of unexpected data because of noise, problems with the equipment, and other real-world uncertainties, which students need to experience (Malaric, et al., 2008). Because of the real environment, students develop confidence in their results (Khedher, 2010). Students are also "physically present" (Coble, et al., 2010, p. 1085) where they can directly manipulate laboratory instruments and communicate face-to-face with classmates.

Disadvantages: Hands-on laboratories require expensive equipment, space, and maintenance staff (Wolf, 2010). Scheduling the physical facilities may be difficult (Perez-Garcia, Beltran-Hernandez, & Khotiaintsev, 2012). They are usually not accessible to online students (Balamuralithara & Woods, 2009).

Virtual laboratory. This is also called a simulated laboratory because no physical laboratory equipment is used (Gomes & Bogosyan, 2009). This is an interactive computer simulation with no physical link to actual instruments (Tzafestas, et al., 2006). These laboratories are "imitations of real experiments" (Ma & Nickerson, 2006, p. 6).

Advantages: Virtual laboratories are considerably less expensive to implement than the other types (Nickerson, et al., 2007). There are no constraints on space or scheduling (Gomes & Bogosyan, 2009). The limitations of simulation may actually be an advantage because they can focus students' attention on important details (Finkelstein et al., 2005). Simulations have the ability to provide a vantage point for observers that may not be otherwise available (Coble, et al., 2010). Students can access the laboratory at any time and almost any place (Perez-Garcia, et al., 2012).

Disadvantages: Students may not be confident in their results because virtual laboratories are "a sort of artificial imitation" (p. 1) of the actual phenomenon (Khedher, 2010). Mathematical models do not allow students to experience the variation of results that randomly occurs in a real environment (Agrawal & Srivastava, 2007).

Remote laboratory. This is also called a distance laboratory (Balamuralithara & Woods, 2009). Students use a computer connected to the Internet, or other network, to control actual instruments at another location (Hercog, Geric, Uran, & Jezernik, 2007). Ma and Nickerson (2006) called this "mediated reality" (p. 6).

Advantages: Students interact with real equipment, although at a distance, instead of the "simple depiction of reality" (Karadimas & Efstathiou, 2007, p. 37) provided by a simulation. It is the "second best thing to being there" (Harms, 2008, p. 2). Remote laboratories are often accessible at any time a student has an Internet connection (Stefanovic, et al., 2011). Remote laboratories provide students with experience in remotely controlling equipment, which may be useful to them in the future (Ashby, 2008).

Disadvantages: Developing a comprehensive set of experiments is usually too complex and expensive for a single university (Tetour, Boehringer, & Richter, 2011). This disadvantage may be mitigated however, by developing a network of shared remote experiments, of which there are several examples in Europe (Tetour, et al., 2011). The image quality of the video is dependent on the bandwidth of the student's Internet connection (Truong, Lee, & Nguyen, 2011). Because they are accessible through the Internet, remote laboratories are vulnerable to cyber-attacks (Salzmann & Gillet, 2007). Remote laboratories also "dissociate the students from the underlying apparatus" (Lindsay & Good, 2005, p.628).

Distance Kits. Home experimentation can introduce distance students to a hands-on laboratory experience where they can directly manipulate electric circuits and instruments using personally owned equipment (Gustavsson et al., 2009). Students connect a commercially available data acquisition instrument to their personal computers to measure and display electric circuit characteristics ("Digilent," 2014; "National Instruments," 2014). The controls and displays of an oscilloscope, multi-meter, function generator, and DC power supply are presented on the computer screen to look and act like the real instruments (Balamuralithara & Woods, 2009). Virginia Polytechnic Institute and State University called their version of this the "Lab-in-a-Box" (Clark, et al., 2009, p. 2).

Advantages: This system has many of the same advantages of remote laboratories: (a) students may perform the laboratory experiments at any time, (b) students may perform the laboratory experiments from nearly any place; and (c) students are dealing with actual measurement data, not simply computer simulations of it (Clark, et al., 2009). Students have the additional advantage of being able to configure their own circuits instead of using pre-built circuits controlled over the internet. "The student can improve its manual skill, which represents one of the most important purposes of laboratory activity" (Bonatti, Pasini, Peretto, Pivello, & Tinarelli, 2007, p. 6). From the university's point of view, an advantage is that none of its space, equipment, or other physical resources is being used (Clark, et al., 2009).

Disadvantages: Students often must purchase the data acquisition equipment, especially if it is for use at home (Clark, et al., 2009). Although it costs much less than bench-top instruments, it is still in the range of $250 to $500 ("Digilent," 2014; "National Instruments," 2014). Another disadvantage is that staff support while performing the laboratories away from campus may be limited (Bohne, Faltin, & Wagner, 2002).

Research about Engineering Laboratory Design

This section will discuss and evaluate some of the recent research into the learning effectiveness of laboratories. It begins with some basic selection criteria for this review. An overview of some general weaknesses common to many of the papers follows. Finally, the specific details of six recent papers will be presented and critiqued.

Most of the research in instructional design of engineering courses has focused on curriculum and classroom methodologies, whereas the development and assessment of engineering laboratories is lagging behind (Watai, et al., 2007). Engineering educators, therefore, do not have many studies to inform their decisions on how to design and conduct effective laboratories (Corter, et al., 2011). Of the research that does address laboratories, "less than 10%" (Shanab, Odeh, Hodrob, & Anabtawi, 2012, p. 19) of it measures their effectiveness with real students. Gomes and Bogosyan (2009), and Grober, Vetter, Eckert, and Jodl (2007) confirmed that nearly all of the published research about engineering laboratories report only implementation of the technical details for a new idea, but no actual experiment to assess its effectiveness with students. Ma and Nickerson (2006) speculated that the motivation for creating many of these laboratories may simply “come from an engineer’s desire to build something” (p. 4). Some recent examples of these technically oriented research articles are Perez-Garcia, et al., (2012); Tawfik (2012); Hosseinzadeh, Hesamzadeh, & Korki, (2011); Maiti, (2011); Tetour, et al., (2011); Villar-Zafra, Zarza-Sanchez, Lazaro-Villa, & Fernandez-Canti, (2012). Technical papers will not be reviewed here. Instead, papers representing a cross-section of research into the learning effectiveness of laboratories will be discussed.

“Weak methodological design” (Chen, Wu, & Su, 2008, p. 10) permeates current educational research about engineering laboratories. Small sample sizes and failure to validate measurement instruments are problems as well with “most research” (Chen, et al., 2008, p. 10). “Only a few studies” (Corter, et al., 2011, p. 2055) about engineering laboratories identify and evaluate learning outcomes. All of the studies reviewed here have weaknesses. In some of the papers, numerical data was presented, but little or no statistical analysis was performed to determine its significance. Nearly all of them have threats to their internal and external validity that are not reported by the researchers. Threats frequently evident within these papers are (a) testing – exposure to a pre-test may have influenced participants’ performance on a post-test, (b) mortality – participants – sometimes dropped out of the study when they found it required too much time or effort, and (c) multiple-treatment interference – participants’ responses to subsequent treatments may have been affected by prior treatments (Campbell & Stanley, 1963). According to Borrego, Douglas, and Amelink (2009), these weaknesses are normal for research reported by engineering educators “who are often not directly rewarded for their engineering education research” (p. 62). A discussion of some recent publications follows.

Shanab, Odeh, Hodrob, and Anabtawi (2012) published a conference paper that has been cited 14 times. It was a “comparative evaluation” (p. 19) of student reactions to a laboratory experiment delivered in three formats: hands-on, virtual, and remote. It provided an overview of the implementation for a remote laboratory that performs an experiment with series-parallel electric circuits, and measured its success with Palestinian engineering students. This was a non-randomized, one-group, posttest-only design. A single group received multiple different treatments with a post-test after each one. The post-test results were compared to evaluate the effectiveness of each treatment. Thirty students participated in the study. Each participant completed the laboratory experiment three times, once using each of the delivery modes. After each laboratory, the students answered a questionnaire by indicating how strongly they agreed (1 to 5) with eight statements about that particular laboratory modality:

1. Easy to use.
2. Easy to understand the concept theory.
3. Available for enough time.
4. Satisfying the knowledge theory.
5. Safety environment.
6. Progress new skills.
7. Teamwork’s lab is encouraged.
8. Comfortable physical place (Shanab, et al., 2012, p. 20).

“The raw data [were] collected and analyzed” (Shanab, et al., 2012, p. 19) and placed on a bar graph that compared responses for each of the three laboratories. The conclusion was that the remote laboratory “is superior to hands-on and virtual labs”

(p. 21) in every category except number 7, the encouragement of teamwork. Except for the graph, however, no evidence of statistical analysis was presented to support that conclusion. Additionally, non-randomized, one-group, posttest-only designs like this one are extremely weak (Campbell & Stanley, 1963).

A journal paper by Stefanovic, Cvijetkovic, Matijevic, and Simic (2011) has been cited 26 times. It reported research on an engineering laboratory that included implementation details and an assessment of its effectiveness with Serbian engineering students over a period of three semesters. This was a static-group comparison design, which is a quasi-experiment. One group of 88 students took the engineering course without a laboratory. A comparison group of 88 students was able to access the remote laboratory while taking the same course. A written examination at the end of the course measured how well the students achieved the eleven learning objectives. The students also completed a questionnaire.

Stefanovic, et al. (2011) listed the eleven learning objectives along with average scores on each one for both groups of students. The group participating in the laboratory had a higher score for each objective. "Results show that students who had access to web laboratory (they could perform laboratory exercises on their own, repeat them, and analyze the results) have better scores and better fulfillment of educational goals compared with other group" (p. 546). "Students like to perform online experiments" (p. 546). "Fulfillment of educational goals and average grades of students show that usage of web laboratories produce better results and contribute to better control engineering education" (p. 547). There was no evaluation of statistical significance. Even so, according to the standards set by Campbell & Stanley (1963), this study had the strongest design of all those reviewed here.

Another journal paper, by Wolf (2010), has been cited 24 times. The study measured the amount of learning that occurred during classroom activities (lectures) and compared it with the amount learned during a remote laboratory that accompanied the course about computer networking. In addition to quantifying student learning in an American university on the east coast, it promised to offer a method of assessing student learning in laboratories for other courses. This was a one-group, pretest-posttest design, repeated several times. One-group pretest-posttest designs are "worth doing when nothing better can be done" (Campbell & Stanley, 1963, p. 7). A single group received multiple different treatments with a pre-test before and a post-test after each one. The post-test results were compared to evaluate the effectiveness of each treatment. Twenty-nine students participated in four learning modules over the period of one semester. Even though participation was voluntary, all students who enrolled in the course chose to take part. To determine when student learning took place, three assessments, asking the same multiple-choice questions, were given to every student for each of the four modules:

1. A pre-lecture assessment measured prior knowledge.
2. A post-lecture assessment measured learning from the classroom lecture.
3. A post-laboratory assessment measured learning from the laboratory work.

Each assessment was submitted electronically by students during a specific window of time. The amount of student learning was plotted on graphs. Two results were reported. First, "definite learning can be observed in up to 27.7% of the assessment questions" (Wolf, 2010, p. 221). Second, 54.1% of the "definite learning" (p. 221) was from listening to lectures and 45.9% of it was from performing laboratory experiments. The conclusion was that "learning can indeed be observed and that the amount of learning in the [remote laboratory] is approximately equal to learning in the lecture" (p. 221). No explanation was offered about how the amount of learning was calculated. There was also little evidence of any statistical analysis of the data.

In this case, the exact same questions were asked three times within a period of about one week. This threat to internal validity increases as the time between the pre-test and post-test decreases (Campbell & Stanley, 1963). The researchers, however, reported this as a strength of the study, "since students are asked the same questions before the lecture, between lecture and lab, and after the lab, a progression of student performance over time can be observed" (Wolf, 2010, p. 219). The paper did suggest that "studying how much students learn by simply repeating assessment questions (without lectures or labs)" (p. 221) would be appropriate future research. Wolf (2010) also noted that participation in this study "dropped considerably" (p. 220) after only the first two assessments. According to Campbell and Stanley (1963), this mortality is a threat to the study's validity.

Rojko, Hercog, and Jezernik (2010) published a journal paper that has been cited 19 times. It described a network of remote laboratories in Europe and attempted to discover what Slovenian students thought about remote experiments. This was a variation of the one-group, multiple-treatment, posttest-only design, which is weak according to Campbell & Stanley (1963). The posttest was used to compare the treatments. Eighteen electrical engineering students participated in this study. After performing both types of laboratories, participants compared the two laboratory modalities by completing an anonymous questionnaire. The objectives of the experiment were to do the following:

1. Find out to which extent the remote laboratory can be implemented in practice, in order to complement and optionally replace the conventional laboratory exercises.
2. Test the functionality and stability of the remote laboratory.
3. Make sure that the materials and exercises provided for the course are clear and concise.
4. Find out what is the student's personal attitude toward the e-learning and remote experiments (Rojko, et al., 2010), p. 3352).

There were three possible responses to each of the 12 statements on the questionnaire: (a) Agree, (b) Undecided, and (c) Disagree. Responses to each statement were tallied for its total score. Even though all twelve statements are listed in the paper, only a few of the most relevant ones will be discussed here. Seventy-two percent (72%) of the students said remote laboratories are suitable for acquiring new knowledge. Ninety-five percent (95%) of the students said remote laboratories are a useful addition to conventional laboratories. Twenty-two percent (22%) of the students said remote laboratories could entirely replace conventional laboratories; seventy-seven percent (77%) of them disagreed with that. Sixty-one percent (61%) of the students preferred performing conventional laboratory experiments more than remote laboratory experiments. Finally, 78% of the student said they learn more in a conventional laboratory than in a remote laboratory.

These were the conclusions:

1. Conventional laboratories are “highly valued” (p. 3353) by students.
2. Remote laboratories are a “welcome supplement” (p. 3353) to conventional laboratories.
3. Remote laboratories cannot replace conventional laboratories (Rojko, et al., 2010).

Nickerson, Corter, Esche, and Chassapis (2007) have been cited 90 times. This journal paper compared the relative effectiveness of remote laboratories to hands-on laboratories used by engineering students in an American, East Coast University. The paper presented a model for others to follow for “systematic testing of educational objectives” (Nickerson, et al., 2007, p. 710). This was a one-group, posttest-only design, repeated several times with another posttest at the very end. The post-tests were used to compare the effectiveness of the treatments. Twenty-nine mechanical engineering students participated in this study. All 29 students completed three remote laboratories and three hands-on laboratories. The major objective of the laboratories was to “deepen students’ understanding of the concepts and techniques taught in the course” (p. 718).

The data collected to measure the amount learned were (a) test scores, particularly questions that targeted knowledge and skills learned during the laboratories, (b) laboratory grades, and (c) a questionnaire about student preferences. The specific content of the questionnaire was provided, but the test questions and laboratory-grading criteria were not. The method of calculating scores for these measures was described, however, and the descriptive statistics were shown in a table. “The results suggest that remote labs are comparable in effectiveness to hand-on labs with respect to the educational objective of teaching students to solve problems based on concepts taught in the course" (Nickerson, et al., 2007, p. 722).

In order to correlate laboratory performance with characteristics of individual students, their characteristics were assessed using demographic information, SAT scores, GPA, and scores on the VARK (Visual, Aural, Read/write, and Kinesthetic) assessment. A correlation of student ability (SAT scores) and academic achievement (GPA) with students perceptions of satisfaction and laboratory effectiveness was done. The VARK sub-scores were also correlated with student preferences and levels of satisfaction. All of these results were listed in a table for detailed examination.

Over 90% of the participants reported that the remote laboratories were equivalent or better than the hands-on laboratories. Test scores and laboratory grades also indicated this. The features of remote laboratories most appreciated by students were (a) they took less time, (b) they could be performed from home, and (c) they were available at any time.

SAT scores were only marginally correlated with student satisfaction of remote laboratories, and they did not correlate with any other factors measured in this study. There were also no significant correlations between the cognitive style measures of the VARK and other measured outcomes. GPA and SAT score had a positive correlation with test scores for the hands-on laboratories, but only GPA correlated with test scores for remote laboratories. "Because GPA is a measure of performance, and is affected by motivation, but SAT scores are a measure of only aptitude, learning in remote labs may require more student motivation" (Nickerson, et al., 2007, p. 722).

Campbell & Stanley (1963) called one-group research designs like this one, weak, "pre-experimental designs" (p. 6). The researchers claimed, however, that using a single group was a strength of their research design: "[It] allowed for carefully controlled comparisons of the two lab formats, because exactly the same students took part in both types of labs" (Nickerson, et al., 2007, p. 722). The learning objectives were clearly articulated. The method of calculating the amount of learning was explained and the statistical analysis of the data was described.

The researchers stated that the study should be replicated with larger samples, and to explore "a broader range of topics and tested skills" (Nickerson, et al., 2007, p. 722). Research into alternative interfaces and levels of student interaction were specifically recommended.

A journal paper by Finkelstein et al. (2005) has been cited 165 times. Although a few years older than the previous papers, it had a scientific, rather than an engineering, point of view. Another difference between this paper and much of the more recent research is that it concentrated on virtual laboratories instead of remote laboratories. It compared a single virtual laboratory experiment with an equivalent hands-on laboratory experiment about DC electric circuits. This study was conducted with physics students studying electromagnetism at an American west-coast university.

This was a nonrandomized, nonequivalent comparison group design, for which Campbell & Stanley (1963) said a pre-test was required to mitigate pre-existing differences between the groups. No pre-test was used in this study. The nonequivalent control group of 107 students took the calculus-based physics class with no laboratory. The first treatment group (CCK) of 99 students took the algebras-based physics course with a laboratory using computer simulations. The second treatment group (TRAD) took the algebra-based physics course with a traditional, hands-on laboratory.

The laboratory work was similar for each group except that the TRAD group used physical equipment and the CCK group used computer simulations. At the end of the laboratory, both groups were asked to build an electric circuit from its schematic diagram, and then explain what happens when the switch is opened and closed. The nonequivalent control group, which had done only course work and no laboratory, was given the same assignment. The final examination, given twelve weeks later to all three groups, had three questions about the same circuit. The same study was later repeated, but with a smaller number of students (N = 80).

The data collected for each student included (a) how long it took to build the circuit, (b) the written laboratory report, and (c) performance on the three final examination questions. The mean score for each group for each of these three factors was combined and analyzed for statistical significance. The mean time to build the circuit and explain its function was 14.0 minutes for the CCK group, 17.7 minutes for the TRAD group, and 26.7 minutes for the comparison group. These differences were determined to be statistically significant. The laboratory reports were scored on a scale from zero (0) to three (3), where zero demonstrated no knowledge, and three was a complete and correct report. The mean CCK score was 1.86; the mean TRAD score was 1.64. The difference was determined to be statistically significant. A further breakdown of the scores was provided. The comparison group's score was not reported. The three test questions were listed and the mean performance on them by each group was calculated. "The two treatment groups [CCK and TRAD] are statistically identical on the 27 non-circuit questions and significantly different on the circuit questions" (Finkelstein et al., 2005, p. 5). The comparison group's score was not reported.

The researchers concluded that "the conventional wisdom that students learn more via hands-on experience is not borne out by measures of student performance on assessment of conceptual understanding, nor by their ability to construct circuits" (Finkelstein et al., 2005, p. 6). It was also stated that performance of the comparison group corroborated that both laboratory modalities support "student capabilities with circuits" (p. 6).

Conclusions

Many of the studies discussed in the previous section have weak designs, disparate objectives, conflicting results, and threats to their validity. Their conclusions, therefore, are based on unreliable data and may be incorrect. Ma and Nickerson (2006) conducted a similar review and made a similar conclusion: "We found three things: a preponderance of articles from engineering, a lack of agreement on what constitutes effectiveness in student learning, and evangelism for one or another possible format without sufficient empirical evidence" (p. 7). Five years after Ma and Nickerson warned the research community about evangelism, it continued to find its way into contemporary publications: "The *only possible solution* [emphasis added] to ensure practical work as a part of concept of distance learning is implementation of web laboratories that consist of remotely controlled experiments with video feed-back" (Stefanovic, et al., 2011, p.538). These strong opinions suggest there is a definite bias among some researchers toward particular types of laboratories.

In addition to having weak support, many of the conclusions found in the literature about engineering laboratories disagree. These are a few examples of conflicting research conclusions regarding hands-on, virtual, and remote laboratories:

1. "No other approach can take the place of actual physical experiments in engineering education" (Gomes & Bogosyan, 2009, p. 4746). But, "Simulations have been shown to be equivalent to physical lab[s]" (Balamuralithara & Woods, 2009, p. 109).
2. "Students can perform the experiments at home knowing that the equipment in the traditional laboratory look the same and behave in the same way" (Gustavsson et al., 2008, p. 1). But, "It could be argued that using a virtual environment does not fully help the students to interact with real devices" (Gomez Tejedor, Molto Martinez, & Barros Vidaurre, 2008, p. 23).
3. "Student engineers need to be exposed to the physical experiences – and the uncertainties – of real environments, and that can be achieved only in real hands-on laboratories" (Malaric, et al., 2008, p. 300). But, "The conventional wisdom that students learn more via hands-on experience is not borne out by measures of student performance on assessment of conceptual understanding, nor by their ability to construct circuits" (Finkelstein et al., 2005, p. 6).
4. "The virtual laboratory allows students to learn how to operate the different devices found in a laboratory . . . they practice with virtual devices which resemble real ones" (Gomez Tejedor, et al., 2008, p. 23). But, "Simulation based labs cannot provide a 'feel' for real things" (Balamuralithara & Woods, 2009, p. 112).

5. "Without confrontation with real instruments with all the influencing factors and the uncertainties we cannot provide good replacement for the hands-on laboratories" (Cmuk, Mutapcic, & Zoino, 2006, p. 300). But, "[the remote laboratory] is superior to hands-on and virtual labs [in every category except] . . . the encouragement of teamwork" (Shanab, et al., 2012, p. 21).
6. "Remote experiments can provide authentic laboratory experiences, essential for student's educational development" (Coble, et al., 2010, p. 1090). But, "Many [remote laboratories] hardly offer a realistic laboratory environment" (Nedic et al., 2003, p. 2). Furthermore, "Apart from being able to obtain real measurement data, students have the same feeling as performing a simulation" (p. 2).

The literature is "inconclusive" (Lowe, et al., 2009, p. 290) in these matters (see also Ariadurai & Manohanthan, 2008). That, according to Chen, et al., (2008), is because most of the research has a "weak methodological design" (p. 10), which cannot provide convincing evidence. For example, at least fourteen researchers reporting on engineering laboratories in education have cited Shanab, Odeh, Hodrob, and Anabtawi (2012), whose particular research design is described by Campbell and Stanley (1963) as having "almost no scientific value" (p. 6). Additionally, Christiansen and Bell (2009) argued that the body of knowledge about peer collaboration is insufficient and that the topic is "under researched" (p. 805). This is all evidence that there is not enough reliable information in the body of literature to inform the design and delivery decisions for engineering laboratories. This is confirmed by Nickerson, et al. (2007): "In general, there are not many studies available to inform decisions by educators on the appropriate use of laboratory technology" (p. 710).

Summary

This literature review demonstrated the importance of educational research regarding engineering laboratories. A theoretical framework supports the traditional role of laboratories, and the student collaboration they facilitate. A variety of laboratory modalities exist, some of which are possible to provide in an online format. Contemporary research into the instructional effectiveness of these modalities covers a wide spectrum of experimental rigor and has produced conflicting results. Unresolved issues include (a) how effective each laboratory modality is at reinforcing conceptual knowledge, (b) how effective each laboratory modality is at developing practical, transferrable skills, and (c) how effective each laboratory modality is at motivating students to continue their study of engineering. More research into facilitating effective peer collaboration is also needed. These issues highlight the significance of this study and its relevance to the body of research about education and instructional design that focuses on engineering laboratories.

CHAPTER III

Method

The purpose of this study was to assess the instructional design effectiveness of two electrical engineering laboratory modalities by measuring how well they fulfilled the learning objectives of reinforcing theoretical concepts (knowledge), developing transferrable practical skills (skills), and promoting student motivation to continue studying engineering (attitudes) for students in their first engineering laboratory course at a private, medium size university in the Intermountain West. It also investigated whether pairing laboratory partners according to their cognitive ability influenced the achievement of these learning objectives.

Research Questions

Research question 1 (knowledge acquisition). Does the type of laboratory (TRAD or LIAB) or the method of pairing laboratory partners (HL or MM) affect a student's knowledge acquisition, as measured by a concept test?

Research question 1A. Is there a difference in knowledge acquisition between students who use a traditional laboratory and students who use a lab-in-a-box, as measured by a concept test?

H_0: There is no difference in knowledge acquisition between students who use a traditional laboratory and students who use a lab-in-a-box.

H_A: There is a difference in knowledge acquisition between students who use a traditional laboratory and students who use a lab-in-a-box.

Research question 1B. Is there a difference in knowledge acquisition between students who have a laboratory partner with a different level of cognitive ability (one with high ability and one with low ability) and students who have a laboratory partner with a similar level of cognitive ability (both with medium ability), as measured by a concept test?

H_0: There is no difference in knowledge acquisition between students who have a laboratory partner with a different level of cognitive ability (one with high ability and one with low ability) and students who have a laboratory partner with a similar level of cognitive ability (both with medium ability).

$H_{A:}$ There is a difference in knowledge acquisition between students who have a laboratory partner with a different level of cognitive ability (one with high ability and one with low ability) and students who have a laboratory partner with a similar level of cognitive ability (both with medium ability).

Research question 1C. Is there an interaction effect between the type of laboratory and the type of laboratory partner pairing on knowledge acquisition?

H_0: There is no interaction effect between the type of laboratory and the type of laboratory partner pairing on knowledge acquisition.

H_A: There is no interaction effect between the type of laboratory and the type of laboratory partner pairing on knowledge acquisition.

Research question 2 (skill transfer – speed). Does the type of laboratory (TRAD or LIAB) or the method of pairing laboratory partners (HL or MM) affect a student's transfer of skill with one set of laboratory instruments to another set of unfamiliar laboratory instruments, as measured by a speed-of-use (measurement time) test?

Research question 2A. Is there a difference in the transfer of skill with one set of laboratory instruments to another set of unfamiliar laboratory instruments between students who use a traditional laboratory and students who use a lab-in-a-box, as measured by a speed-of-use (measurement time) test?

H_0: There is no difference in speed-skill (measurement time) transfer between students who use a traditional laboratory and students who use a lab-in-a-box.

H_A: There is a difference in speed-skill (measurement time) transfer between students who use a traditional laboratory and students who use a lab-in-a-box.

Research question 2B. Is there a difference in the transfer of skill with one set of laboratory instruments to another set of unfamiliar laboratory instruments between students who have a laboratory partner with a different level of cognitive ability, and students who have a laboratory partner with a similar level of cognitive ability, as measured by a speed-of-use test?

H_0: There is no difference in speed-skill (measurement time) transfer between students who have a laboratory partner with a different level of cognitive ability, and students who have a laboratory partner with a similar level of cognitive ability.

H_A: There is a difference in speed-skill (measurement time) transfer between students who have a laboratory partner with a different level of cognitive ability, and students who have a laboratory partner with a similar level of cognitive ability.

Research question 2C. Is there an interaction effect between the type of laboratory and the type of laboratory partner pairing on speed-skill (measurement time) transfer?

H_0: There is no interaction effect between the type of laboratory and the type of laboratory partner pairing on speed-skill (measurement time) transfer.

H_A: There is no interaction effect between the type of laboratory and the type of laboratory partner pairing on speed-skill (measurement time) transfer.

Research question 3 (skill transfer – accuracy). Does the type of laboratory (TRAD or LIAB) or the method of pairing laboratory partners (HL or MM) affect a student's transfer of skill with one set of laboratory instruments to another set of unfamiliar laboratory instruments, as measured by an accuracy-of-use (percent of measurement error) test?

Research question 3A. Is there a difference in the transfer of skill with one set of laboratory instruments to another set of unfamiliar laboratory instruments between students who use a traditional laboratory and students who use a lab-in-a-box, as measured by an accuracy-of-use (percent of measurement error) test?

H_0: There is no difference in accuracy-skill (percent of measurement error) transfer between students who use a traditional laboratory and students who use a lab-in-a-box.

H_A: There is a difference in accuracy-skill (percent of measurement error) transfer between students who use a traditional laboratory and students who use a lab-in-a-box.

Research question 3B. Is there a difference in the transfer of skill with one set of laboratory instruments to another set of unfamiliar laboratory instruments between students who have a laboratory partner with a different level of cognitive ability, and students who have a laboratory partner with a similar level of cognitive ability, as measured by an accuracy-of-use (percent of measurement error) test?

H_0: There is no difference in accuracy-skill (percent of measurement error) transfer between students who have a laboratory partner with a different level of cognitive ability, and students who have a laboratory partner with a similar level of cognitive ability.

$H_{A:}$ There is a difference in accuracy-skill (percent of measurement error) transfer between students who have a laboratory partner with a different level of cognitive ability, and students who have a laboratory partner with a similar level of cognitive ability.

Research question 3C. Is there an interaction effect between the type of laboratory and the type of laboratory partner pairing on accuracy-skill (percent of measurement error) transfer?

H_0: There is no interaction effect between the type of laboratory and the type of laboratory partner pairing on accuracy-skill (percent of measurement error) transfer.

H_A: There is no interaction effect between the type of laboratory and the type of laboratory partner pairing on accuracy-skill (percent of measurement error) transfer.

Research question 4 (attitude – motivation). Does the type of laboratory (TRAD or LIAB) or the method of pairing laboratory partners (HL or MM) affect a student's motivation to continue studying engineering, as measured by the Pittsburgh Freshman Engineering Attitudes Survey?

Research question 4A. Is there a difference in motivation to continue studying engineering between students who use a traditional laboratory and students who use a lab-in-a-box, as measured by the Pittsburgh Freshman Engineering Attitudes Survey?

H_0: There is no difference in motivation between students who use a traditional laboratory and students who use a lab-in-a-box.

H_A: There is a difference in motivation between students who use a traditional laboratory and students who use a lab-in-a-box.

Research question 4B. Is there a difference in motivation to continue studying engineering between students who have a laboratory partner with a different level of cognitive ability, and students who have a laboratory partner with a similar level of cognitive ability, as measured by the Pittsburgh Freshman Engineering Attitudes Survey?

H_0: There is no difference in motivation between students who have a laboratory partner with a different level of cognitive ability, and students who have a laboratory partner with a similar level of cognitive ability.

H_A: There is a difference in motivation between students who have a laboratory partner with a different level of cognitive ability, and students who have a laboratory partner with a similar level of cognitive ability.

Research question 4C. Is there an interaction effect between the type of laboratory and the type of laboratory partner pairing on motivation to continue studying engineering?

H_0: There is no interaction effect between the type of laboratory and the type of laboratory partner pairing on motivation to continue studying engineering.

H_A: There is no interaction effect between the type of laboratory and the type of laboratory partner pairing on motivation to continue studying engineering.

Research Design

This experiment was a quantitative, posttest-only design with stratified random assignment to laboratory modality. See Figure 7, on page 56, for a diagram of the research design. This strong experimental design minimized most of the threats to its internal validity (Campbell & Stanley, 1963). The threats of experimental mortality, treatment diffusion, compensatory rivalry, and resentful demoralization were controlled by the short duration of the experiment and working with only one group at a time. Although a pretest would have been psychologically comforting to ensure the groups were equivalent before the treatment, “randomization can suffice without the pretest” (p. 25). Furthermore, students in this population typically have little or no experience with engineering laboratory instruments and a pretest under those conditions would not have produced useful comparison data (Swart, 2009).

R_S	X_1	O_1	O_2	O_3	O_4
R_S	X_2	O_1	O_2	O_3	O_4
R_S	X_3	O_1	O_2	O_3	O_4
R_S	X_4	O_1	O_2	O_3	O_4

R_S Stratified random assignment (stratified by ability: H, M, and L).
X_1 Traditional laboratory equipment and HL laboratory partner pairing (TRAD-HL).
X_2 Traditional laboratory equipment and MM laboratory partner pairing (TRAD-MM).
X_3 "Lab-in-a-Box" laboratory equipment and HL laboratory partner pairing (LIAB-HL).
X_3 "Lab-in-a-Box" laboratory equipment and HL laboratory partner pairing (LIAB-HL).
O_1 Posttest of attitude.
O_2 Posttest of knowledge.
O_3 Posttest of speed-skill.
O_4 Posttest of accuracy-skill.

Figure 7. Research design.

Population and Sampling

The population studied was students in their first engineering laboratory course at a large university in the Intermountain West. Their characteristics are similar to the general student population because the engineering programs are open to all university students without any additional admission requirements. The most noticeable difference from the general student population is that women are underrepresented in the engineering programs, which often happens in the United States (Hill, Corbett, & Rose, 2010). The typical student is a white male from the United States, is 22 years old, is not married, has an ACT score of 24 and has a high school GPA of 3.4 (BYU-Idaho, 2014a; BYU-Idaho, 2014b). Two characteristics of these students differ from engineering students at some other universities: (a) their median ACT is six points lower ("ACT Scores," 2007), and (b) their median age is four years older (Boylen, 2003). Table 1, on page 57, lists the demographic statistics for the university as a whole.

Table 1

Descriptive Statistics of University Population (Winter 2014)

	Number	Percentage of Total	Minimum	Maximum	Median
Total Students	15,625	100%	-	-	-
ACT Score	-	-	16	-	24
SAT Score	-	-	770	-	1110
High School GPA	-	-	2.0	-	3.4
Prior Missionary Service	7,959	50.1%	-	-	-
Majors	-	-	-	-	-
Electrical Engineering	141	0.9%	-	-	-
Computer Engineering	107	0.7%	-	-	-
Age	-	-	16	65	22
16 to 17	72	0.5%	-	-	-
18 to 21	7,292	46.7%	-	-	-
22 to 25	6,685	42.8%	-	-	-
26 +	1,576	10.0%	-	-	-
Gender	-	-	-	-	-
Male	7,809	50.0%	-	-	-
Female	7,816	50.0%	-	-	-
Status	-	-	-	-	-
Married	4,313	27.6%	-	-	-
Single	11,238	71.9%	-	-	-
Other	74	0.5%			
Race	-	-	-	-	-
White	13,081	83.7%	-	-	-
Hispanic	471	3.0%	-	-	-
Black	76	0.5%	-	-	-
Other	1,997	12.8%			
Nationality	-	-	-	-	-
USA	14859	95.1%	-	-	-
Other	766	4.9%	-	-	-

All electrical engineering and computer-engineering students at the University are advised to enroll in ECEN 150 (Electric Circuit Analysis 1) during their first semester in the program. The sample was selected from the students who signed up for this course during the winter 2014 and spring 2014 semesters. About one-third of the enrolled students were not engineering majors, and had no intention of becoming one. With few exceptions, all students enrolled in ECEN 150 were included in the study. Exceptions included (a) students without an ACT or SAT score, (b) students who chose not to participate, and (c) students randomly omitted to balance the size of experimental groups. Ninety-five students enrolled in the course. Eighty-three of them were eligible and willing to participate. See the consent form in Appendix E. In order to achieve equal group sizes with three course sections over two semesters, only 72 of those students were actually included in the experiment.

Students in each section of the course were assigned to one of three strata, based on their academic ability as measured by their most recent composite ACT scores (or equivalent SAT scores) obtained from their school records. Both of these tests are good predictors of general intelligence and cognitive ability (Brown, et al., 2008; Koenig, Frey, & Detterman, 2008). Students with an above average level of cognitive ability (ACT score in the top 25% of each course section) were assigned to the high-level group (H). Students with a below average level of cognitive ability (ACT score in the bottom 25% of each course section) were assigned to the low-level group (L). Students with a medium level of cognitive ability (ACT scores in the middle 50% of each course section) were assigned to the medium-level group (M). See Figure 8, on page 59, for a diagram of these assignments.

Course Section 1:

ACT Score	Student Group Assignments
31	H
30	
29	H H
28	H H
27	H H
26	H M
25	M M M M M M
24	M
----------	Section 1 Mean Score = 23.1
23	M M M
22	M M M M M
21	L L L
20	L
19	L
18	L L
17	L

Course Section 2:

ACT Score	Student Group Assignments
31	H
30	
29	H
28	H H
27	
26	H
25	H
24	M M
----------	Section 2 Mean Score = 23.3
23	M M M M M M M
22	M M M
21	L
20	L L L
19	
18	L
17	L

Course Section 3:

ACT Score	Student Group Assignments
28	H
27	H H
26	H
25	M
24	M
----------	Section 3 Mean Score = 22.5
23	M M M
22	M
21	M M
20	L L
19	L
18	L

Figure 8. Student assignments to high (H), low (L), and medium (M) groups.

Treatment

Each of the 18 students in group H was then paired with one of the 18 students in group L to form 18 HL laboratory partnerships. This was done by pairing the highest-scoring H student with the highest-scoring L student, followed by pairing the second-highest H and L students, and so forth. This resulted in each HL partnership having one student with an above average level of cognitive ability and one student with a below average level of cognitive ability. Their ACT scores differed by either eight or nine points. Similarly, the 36 students in group M were paired to form 18 MM laboratory partnerships. This was done by pairing the two highest-scoring M students, followed by the next two highest-scoring M students, and so forth. Each of these MM partnerships had two students with a medium (average) level of cognitive ability whose ACT scores differed by no more than one point. The effects of other pairing combinations were not studied. See Figure 9, on page 61, for a diagram of how the pairs were created. Students not participating in this experiment were paired together to complete the course assignments, but their data were not included in the analysis. Nine of the eighteen HL pairs and nine of the eighteen MM pairs were randomly selected to use the traditional laboratory (TRAD). The other HL and MM pairs were assigned to the lab-in-a-box (LIAB).

The TRAD groups (TRAD-HL and TRAD-MM) used a traditional laboratory consisting of bench-top and hand-held instruments. See these instruments in Figure 10(a) on page 62, Figure 11(a) on page 63, and Figure 12(a) on page 64. Students in the TRAD-HL experimental group worked with a traditional laboratory and collaborated with partners who had a different level of cognitive ability (one high and one low).

Students in the TRAD-MM experimental group worked with a traditional laboratory and collaborated with partners who had the same, or similar, level of cognitive ability (both medium).

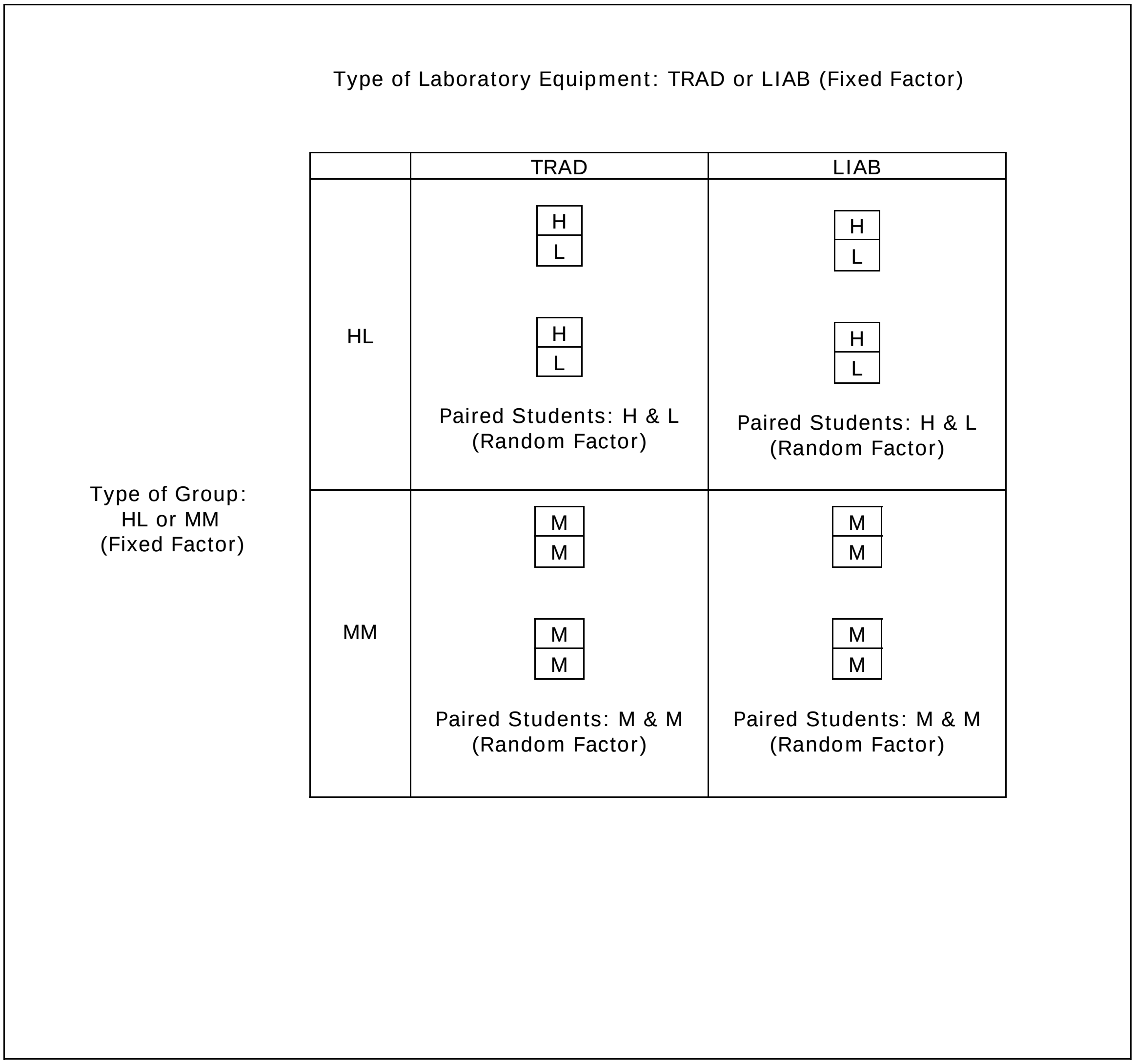

Figure 9. Assignment of individual students to experimental groups. Each group consists of multiple pairs. One H student and one L student comprise an HL pair. Similarly, two M students comprise each MM pair.

Figure 10(a). Traditional hand-held DMM.

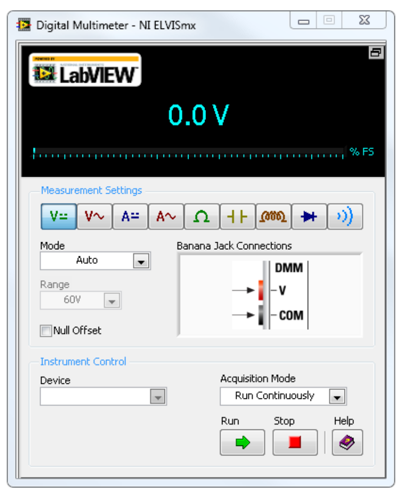

Figure 10(b). myDAQ DMM (controls and display as shown on computer screen).

Figure 10. Digital multi-meters used in traditional and lab-in-a-box modalities.

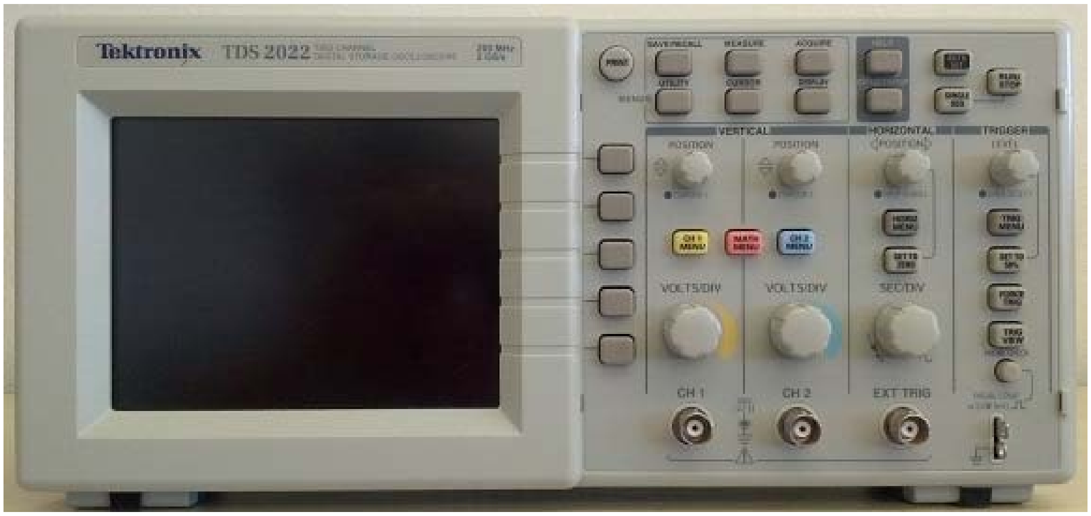

Figure 11(a). Traditional bench-top digital oscilloscope.

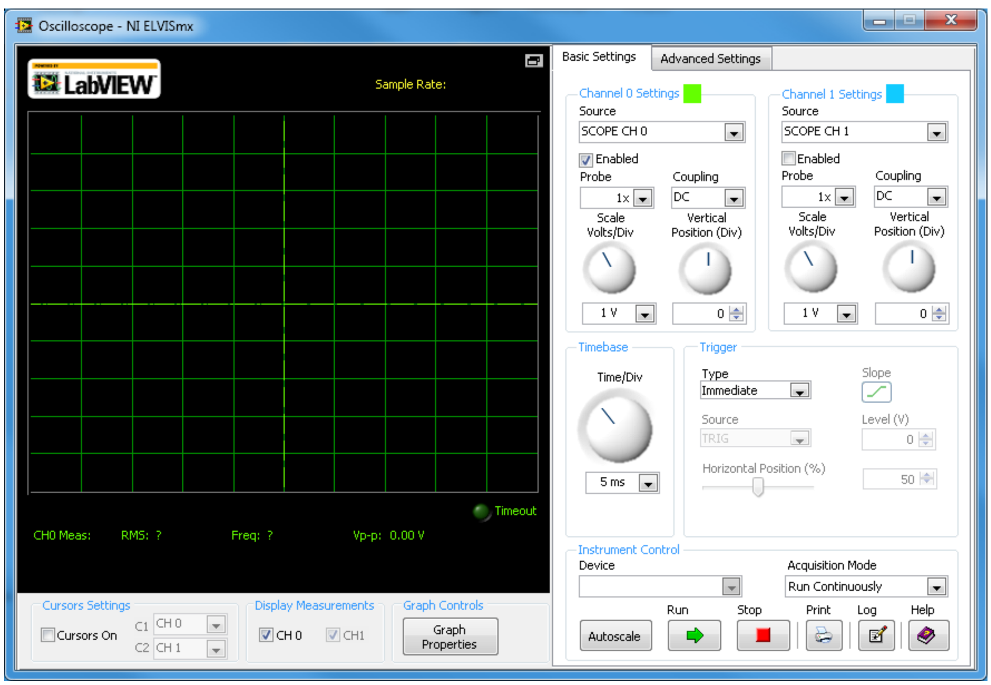

Figure 11(b). myDAQ digital oscilloscope (controls and display as shown on computer).

Figure 11. Digital oscilloscopes used in traditional and lab-in-a-box modalities.

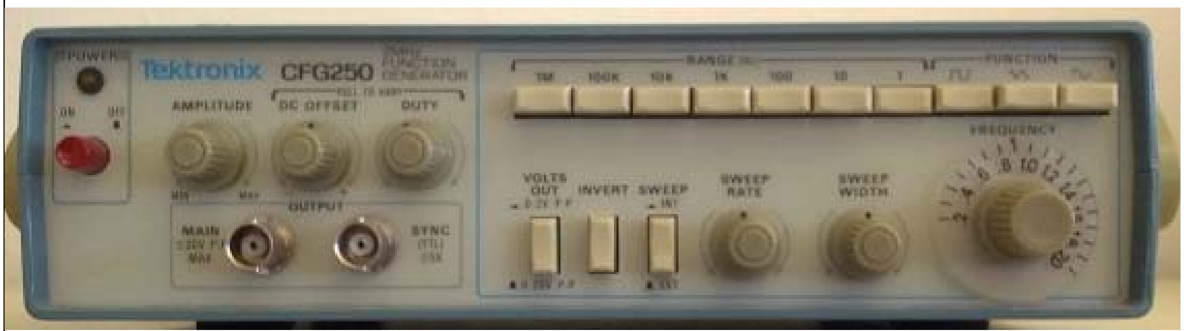

Figure 12(a). Traditional bench-top function generator.

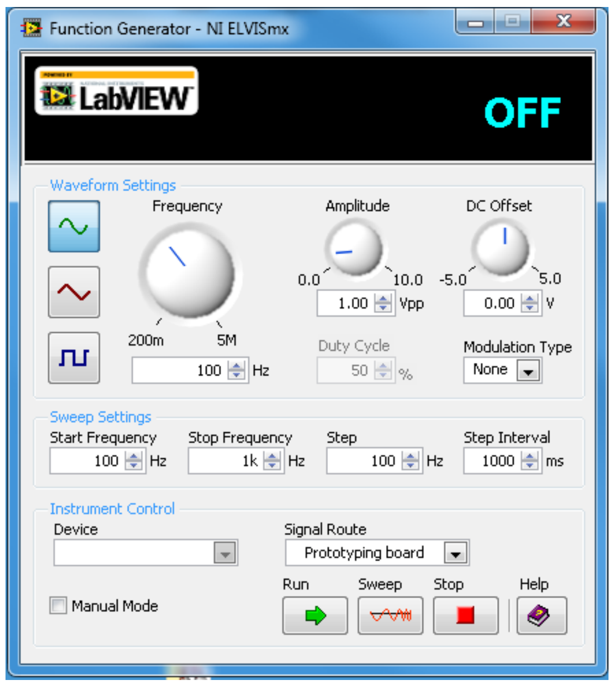

Figure 12(b). myDAQ function generator (controls and display as shown on computer).

Figure 12. Function generators used in traditional and lab-in-a-box modalities.

The LIAB groups (LIAB-HL and LIAB-MM) used a lab-in-a-box consisting of the *myDAQ* connected to a computer for instrument control and measurement display. See the *myDAQ* in Figure 13 on page 65. The *myDAQ* is a small device, about the size of a calculator, which combines many laboratory instruments, including a digital multi-meter, a digital oscilloscope, and a function generator. See these instruments in Figure 10(b) on page 62, Figure 11(b) on page 63, and Figure 12(b) on page 64. The displayed *myDAQ* data are not software simulations. These instruments, operated through a virtual interface that resembles the controls of bench-top instruments, measure the actual characteristics of real electrical circuitry and display those measurements on a computer screen.

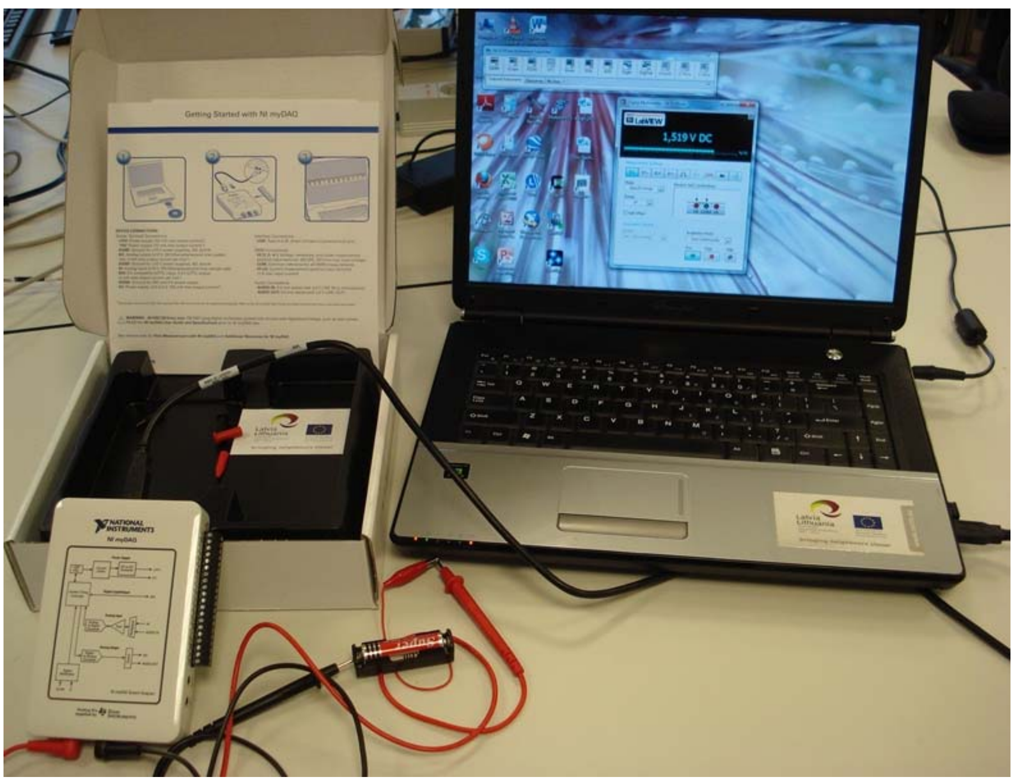

Figure 13. myDAQ hardware connected to computer for lab-in-a-box modality.

Although the electrical measurements made with the lab-in-a-box are not simulations generated by software, the instrument controls and displays are simulations of those found on bench-top instruments. Figure 10, Figure 11, and Figure 12 show that the engineering fidelity of the interface is high because the *myDAQ* accurately portrays the controls and display of each corresponding traditional bench-top instrument. For example, knobs on the traditional instruments are simulated by knobs on the *myDAQ*. Likewise, the numeric display on the traditional DMM and the graphical display on the traditional oscilloscope have similar formats on the *myDAQ*. The psychological fidelity, however, is lower. Hovering over and clicking controls with a mouse feels much different from turning a knob or pushing a button.

The necessary equipment was provided at no cost to students in the LIAB groups in order to eliminate any confounding effects of financial burden. Students were aware that an experiment was being conducted to improve the engineering curriculum, but the specific research questions were withheld. This made it more difficult for students to anticipate the “correct” results and artificially skew them in a specific direction.

To isolate the TRAD and LIAB groups from each other, they were not in class simultaneously for the duration of the treatment. Because of the difficulty in keeping the groups isolated from each other, this experiment ran for only three weeks during the semester, which included two laboratories. The short duration may have limited the treatment’s effect size, but it also reduced threats to validity due to experimental mortality, treatment diffusion, compensatory rivalry and resentful demoralization.

The laboratories used in this study were created using principles of instructional design. See the laboratories in Appendices A, B, C, and D. See Appendix F for a summary of the design process used to create them. A homework assignment that required reviewing previous material, not directly related to the laboratories, was given to students on the class days when they were not performing one of the laboratories in order to keep them engaged in the course.

Instruments

The purpose of this study was to assess the instructional design effectiveness of two electrical engineering laboratory modalities by measuring how well they fulfilled the learning objectives of reinforcing theoretical concepts (knowledge), developing transferrable practical skills (skills), and promoting student motivation to continue studying engineering (attitudes) for students in their first engineering laboratory course at a private, medium size university in the Intermountain West. It also investigated whether pairing laboratory partners according to their cognitive ability influenced the achievement of these learning objectives.

Knowledge. Knowledge was measured with an in-class, 120-minute, 30-question, closed book, concept test. The purpose of this test was to determine how well the concepts were reinforced during the traditional laboratory and the lab-in-a-box. Using a concept test to assess knowledge is widely documented in the literature (Newhouse, 2011).

The 30 questions on the test were mapped to the learning objectives. See the knowledge-test blueprint in Appendix G. These test questions had been used during the previous six semesters of the course. The engineering faculty and one curriculum designer verified the content validity of these test questions. The possible range of scores was 0 to 30 on a ratio scale. Higher scores indicated more knowledge. Students knew that this test score was part of their course grade, even if they were not participants in the study. Although the test questions were similar to items from earlier semesters, there was no evidence that the subjects had previously seen these questions because the mean test score was 20 points and only three students scored 25 points or higher. The highest score earned by any student was 27 points.

Skills. Skills, specifically skills transfer, were measured by a speed and accuracy performance test, developed for this study. According to Salomon and Perkins (1989), transfer occurs when "something learned in one context has helped in another" (p. 22). The purpose of the performance test was to determine how well the practical skills acquired during the traditional laboratory and the lab-in-a-box would transfer to a different set of laboratory instruments. Specifically, it assessed the time required for making measurements and the accuracy of those measurements. The laboratory instruments used for the performance test had functionality similar to the equipment used by the students during the treatment, but the specific configuration of the equipment was unfamiliar to them. The unfamiliar equipment used in the performance test is shown in Figure 14, on page 69. Skill transfer to a similar context like this is called near transfer (Perkins & Salomon, 1992).

Figure 14(a). Digital multi-meter (DMM).

Figure 14(b). Analog oscilloscope.

Figure 14(c). Function generator.

Figure 14. “Unfamiliar” bench-top laboratory instruments used in the performance test.

Salim, Puteh, and Daud (2012) identified four levels of skill that should be included in a laboratory performance test, and which require the demonstration of skill transfer: (a) level 1 – the ability to recognize basic electrical components, (b) level 2 – the ability to construct a circuit, (c) level 3 – the ability to operate a test instrument, and (d) level 4 – the ability to interpret the measurement. The performance test verified all four of those skill levels with tasks that required demonstration of technical skill – not simply knowledge of the theory. See the performance test, and how it measured the four skill levels, in Appendix H. Its content validity was verified by the university's engineering faculty.

The performance test measured two dimensions of skill: (a) how quickly a student performed the measurements, and (b) how accurately a student performed the measurements. The speed score for each student was calculated by summing the elapsed times for all of the performed measurements. The total elapsed time on a ratio scale indicated how quickly the measurements were performed. Lower times indicated higher speed. The test consisted of four parts. The maximum time allowed for each part was 15 minutes, resulting in a maximum test time of 60 minutes. The accuracy score for each student was calculated by summing the percent of error for all of the performed measurements. The total percent of error on a ratio scale indicated how accurately the measurements were performed. Lower error percentages indicated higher accuracy. The maximum error was capped at 100% for each of the four parts of the test, resulting in a maximum test error of 400%. Students knew this hands-on laboratory test was part of their course grade, even if they were not participants in the study. Only the accuracy score applied toward their grade, but both speed and accuracy data were collected.

Attitudes. Attitudes, specifically motivation to continue studying engineering, was measured with the *Pittsburgh Freshman Engineering Attitudes Survey*, created and validated by Besterfield-Sacre and Atman (1994). Since its design, this closed-form questionnaire has been used to assess student attitudes about engineering at over 25 engineering colleges (McGourty et al., 2002). It has also been used in peer-reviewed studies on retention of engineering students (Bernold, Spurlin, & Anson, 2007; Burtner, 2004, 2005; Hilpert, et al., 2008).

Most of the 50 Likert items required students to record the intensity of their agreement or disagreement. The item categories are shown in Figure 15. An example Likert item is shown in Figure 16 on page 72. See the entire survey in Appendix I.

Self- Reported Attitude or Ability	Assessed by Likert Item(s)
1. Positive attitude toward studying engineering	1, 2, 3, 5, 7
2. Negative attitude toward studying engineering	4, 6, 8, 9, 16
3. Positive attitude toward group study and group work	37
4. Negative attitude toward group study and group work	43, 45
5. Confidence in STEM skills	29, 30, 31, 32, 35, 42, 44, 47, 48
6. Confidence in related skills	33, 34, 38, 40, 49, 50
7. Good study habits	46
8. Poor study habits	39
9. Perceived engineer prestige, employability, and salary	10, 14, 17, 18, 21, 23, 24
10. Contribution of engineering to society	11, 20, 22
11. Perceived characteristics of engineers	12, 15, 25, 26, 28
12. Type of school subjects enjoyed	13, 19

Figure 15. Attitudes and abilities assessed by survey.

1. I expect that engineering will be a rewarding career.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Figure 16. Example Likert item.

Because the specific attitude being measured was the motivation to continue studying engineering, only the responses to questions in the first two categories were used in this study. For scoring, each of the five Likert responses was assigned a number on the ratio scale:

1. Strongly Disagree = 1
2. Disagree = 2
3. Neutral = 3
4. Agree = 4
5. Strongly Agree = 5

A high score indicated a high level of agreement with the item. To quantify a student's motivation to continue studying engineering, the total score for questions in the second category (negative attitude toward studying engineering) was subtracted from the total score for questions in the first category (positive attitude toward studying engineering). The possible scores ranged from +20 to -20. A positive score indicated a high motivation (positive attitude), and a negative score indicated a low motivation (negative attitude).

Besterfield-Sacre and Atman (1994) validated the survey, and it has been used by at least 25 universities since then. Cronbach's alpha is a statistic that can be used to determine the internal consistency and reliability of a multi-point survey on a scale of 0 to 1, where 0.7 or higher is usually an acceptable level of reliability (Santos, 1999). The Chronbach's alpha was calculated to be 0.851 for this study.

Data Collection

At the conclusion of the laboratories (treatment), all students met together during the regular time for their course section. Each of the sections normally meets for two 135-minute blocks each week. The *Pittsburgh Freshman Engineering Attitudes Survey* was administered during the first 15 minutes, and the remaining 120 minutes was spent taking the knowledge test. To reduce anxiety that the course instructor would see what a student wrote on the survey, it was passed out and collected by a teaching assistant, without the instructor being present. Each survey was identified only by the pair of laboratory partners to which the participating student belonged ("TD1", "LS2", etc.) Students not participating in the study were given surveys marked "TX.". This identification method was meant to reduce the fear of reprisal and encourage honesty. Completing the attitude survey before taking the knowledge and performance tests was done to reduce the likelihood that those test scores would affect a student's attitude afterward.

The performance test was given last. It took place with unfamiliar bench-top laboratory equipment set up in a room that had never been used by these students for laboratories. This ensured that no student had the advantage of a familiar setting. Students completed the performance test individually and were proctored by the instructor and by lab assistants who were trained to administer the performance test consistently. The performance test had four sections (see Appendix H). To reduce the number of outlier scores, the maximum measurement error for each section was limited to 100% and the maximum measurement time for each section was limited to 15 minutes. Because only four students were able to take the test simultaneously, they were randomly assigned to one of the three test days. Each student remained isolated from other students during this performance test and they were instructed not to discuss it with anyone until all of the testing was completed.

Data Analysis

This experiment had two crossed independent variables: (a) the type of laboratory (TRAD or LIAB), and (b) the method of pairing laboratory partners (HL or MM). The four dependent variables tested were knowledge, accuracy-skill, speed-skill, and attitude. Whether knowledge of course content was affected either by the type of laboratory modality (TRAD or LIAB) or by the method of pairing laboratory partners (HL or MM) was measured by scores earned in the knowledge test. Whether the ability to adapt to new, unfamiliar laboratory equipment (skill transfer) was affected either by the type of laboratory modality (TRAD or LIAB) or by the method of pairing laboratory partners (HL or MM) was measured by scores earned in the performance test. Whether motivation to continue studying engineering was affected either by the type of laboratory modality (TRAD or LIAB) or by the method of pairing laboratory partners (HL or MM) was measured by responses in the attitude survey.

To analyze the data properly, the correct unit of analysis had to be identified (Blair, Higgins, Topping, & Mortimer, 1983). "Treatment applied independently to units in a group make the units the experimental units, but treatments applied to a group of units together makes the entire group a single experimental unit" (Perrett, 2012, p. 3). Because the two treatments (type of laboratory and type of pairing) were applied to laboratory partnerships instead of individual students, according to Perrett (2012), the unit analyzed should be the laboratory partnerships. Following this rationale, there were 18 experimental units using each type of laboratory equipment (TRAD and LIAB) and 18 experimental units in each type of partnership (HL and MM). Therefore, the data were analyzed with a 2 x 2 factorial ANOVA that crossed type of laboratory with type of paring and used the mean scores of knowledge, skill, and attitude for each partnership as the dependent variables.

There are three assumptions concerning the dependent variable when performing the ANOVA statistical test: (a) independence of observations, (b) normality of distribution, and (c) homogeneity of variance. All three assumptions were satisfied. The assumption of independence was met by the design of the study. There was no systematic relationship between the mean scores of the separate laboratory partnerships. One method of verifying normality of distribution is to calculate its skewness with SPSS statistical software. As shown in Table 2 on page 76, the skewness statistic for each dependent variable was less than +/- 1.0, which indicates that they were all approximately normal (Leech, Barrett, & Morgan, 2011). The assumption of homogeneity was verified with Levene's test. If the significance of *F* calculated by SPSS for Levene's test is greater than 0.05, the variance is homogenous and the assumption is met. As shown in Table 3 on page 76, this assumption was satisfied.

Table 2

Skewness Calculations to Verify Normality

Dependent Variable	Skewness
Knowledge	-0.41
Speed-Skill	-0.09
Accuracy-Skill	0.64
Attitude	-0.89

Table 3

Levene's Test to Verify Homogeneity

Dependent Variable	*F*	*p*
Knowledge	0.36	.783
Speed-Skill	1.24	.311
Accuracy-Skill	0.51	.678
Attitude	0.80	.502

Note: $p > 0.05$ means homogeneity of variance

Unless the sample size is large, there will not be enough statistical power to detect small effects caused by the treatment (Raudenbush, Martinez, & Spybrook, 2007). With a sample size of 18 partnerships for each laboratory treatment, it was calculated that a difference of 10% between the means of each experimental group could be identified with a power of 0.98. This provided confidence that important treatment effects would be observed. These calculations used a “known” population mean of 79 and a “known” population standard deviation of 8.38. The known mean and standard deviation were based on the test scores of 71 students taking ECEN 150 during the previous semester. Their test scores represented their level of knowledge. It was assumed that using existing data about population knowledge would also apply to skills and attitudes, for which no population data existed.

Using α = 0.05 normally provides reasonable protection against a Type I error (Myers, Well, & Lorch R. F, 2010). Because the analysis in this study required four different ANOVA calculations, however, the Type I error rate would be inflated beyond the level indicated by α = 0.05 (Ilakovac, 2009). The probability of making at least one Type I error would be $1 - (0.95)^4 = 0.185$ when performing four tests. To compensate for this, the value of α could have been adjusted using the Bonferroni method by dividing the original value of α by the number of tests performed (Ilakovac, 2009). In this case, the new $\alpha = 0.05 / 4 = 0.0125$. Although this adjustment would have reduced the likelihood of Type 1 errors, it would increase the chances of Type II errors (Ilakovac, 2009). It was anticipated that the motivation for most instructional designers of engineering laboratory courses to use the lab-in-a-box instead of a traditional laboratory would be to conserve campus resources (Clark, et al., 2009; Wolf, 2012) or to provide a laboratory experience for online students (Stefanovic, et al., 2011; Valian & Emami, 2013) without reducing the laboratory's effectiveness at fulfilling learning objectives. Failing to find a true difference in the two laboratories, if lab-in-a-box were actually less effective than the traditional laboratory, could lead to ignorantly selecting a less-effective laboratory. Making a Type II error, therefore, would be more detrimental to students than a Type I error. Neither type of error would be particularly damaging to students when deciding whether to assign laboratory partnerships according to ability. A Type I error would result in more unnecessary work for the instructor, but would have little negative effect on the students in the course. Nothing would change from the current pairing methods being used by instructors in the event of a Type II error. For these reasons, α = 0.05 was retained for each calculation.

Summary

Four research questions were studied to determine the influence of the type of laboratory (traditional or lab-in-a-box) and the method of pairing laboratory partners (one with high ability and one with low ability or both with medium ability) on students' knowledge of concepts, transfer of practical skills to unfamiliar laboratory instruments, and motivation to continue studying engineering. Students were assigned to one of four groups: (a) using a traditional laboratory with a partner of dissimilar cognitive ability, (b) using a traditional laboratory with a partner of similar cognitive ability, (c) using a lab-in-a-box with a partner of dissimilar cognitive ability, and (d) using a lab-in-a-box with a partner of similar cognitive ability. The treatment for each of the four groups consisted of performing two laboratory experiments under one of the conditions described above. The posttest for knowledge of concepts was a concept test. The posttest for skills transfer was a speed and accuracy performance test with unfamiliar laboratory instruments. The posttest for motivation was an attitude survey. The assumptions of ANOVA were checked and verified. The two main effects and their interaction for each dependent variable were analyzed using a 2 x 2 factorial ANOVA with SPSS statistical software.

CHAPTER IV

Results

The purpose of this study was to assess the instructional design effectiveness of two electrical engineering laboratory modalities by measuring how well they fulfilled the learning objectives of reinforcing theoretical concepts (knowledge), developing transferrable practical skills (skills), and promoting student motivation to continue studying engineering (attitudes) for students in their first engineering laboratory course at a private, medium size university in the Intermountain West. It also investigated whether pairing laboratory partners according to their cognitive ability influenced the achievement of these learning objectives

Sample

The population studied was students in their first engineering laboratory course at a medium size university in the Intermountain West. The engineering programs are open to all students admitted by the university, and engineering students share many of the same characteristics as the general student population. The typical student in the university's general population is 22 years old, is not married, has an ACT score of 24, and has a high school GPA of 3.4 (BYU-Idaho, 2014a; BYU-Idaho, 2014b). See Table 1, on page 57, for demographic details.

The sample taken from that population for this experiment was 72 students enrolled in ECEN 150 during the winter 2014 and spring 2014 semesters. It is noteworthy that the percentage of women in the engineering course is much lower than the university's student population (8.3% vs. 50.0%). The typical student in this sample was otherwise similar to the general population. Students in the sample had these characteristics: a white male from the United States, 23 years old, not married, and an ACT score of 23. Table 4 presents the demographic statistics for the sample of 72 students enrolled in the engineering course.

Table 4

Descriptive Statistics of Sample

	Number	Percent of Total	Min	Max	Median	Mean	Standard Deviation
ACT	72	-	17	31	23	23.35	3.31
75^{th} Percentile	-	-	26	31	-	-	-
25^{th} Percentile	-	-	17	21	-	-	-
Age	72	-	18	41	23	22.65	3.04
75^{th} Percentile	-	-	24	41	-	-	-
25^{th} Percentile	-	-	18	21	-	-	-
Gender	72	-	-	-	-	-	-
Male	66	91.7%	-	-	-	-	-
Female	6	8.3%	-	-	-	-	-
Status	72	-	-	-	-	-	-
Married	11	15.3%	-	-	-	-	-
Single	61	84.7%	-	-	-	-	-
Race	72	-	-	-	-	-	-
White	63	87.5%	-	-	-	-	-
Black	1	1.4%	-	-	-	-	-
Hispanic	8	11.1%	-	-	-	-	-
Nationality	72	-	-	-	-	-	-
USA	71	98.6%	-	-	-	-	-
Other	1	1.4%	-	-	-	-	-

As shown in Table 4, on page 80, the engineering students comprising this sample differ from engineering students at many other universities in two important ways: (a) the median ACT score is six points lower ("ACT Scores," 2007), and (b) the median age is four years older (Boylen, 2003). The lower ACT score is a result of the university's admissions criteria; only 40% of them are based on academic ability (BYU-Idaho, 2014a). The other 60% of the criteria are based on an applicant's adherence to the tenants and principles of the religious institution that sponsors the university. Serious and dedicated students may be admitted even though their academic ability is not remarkable. The typical student in this sample is also older because he has performed two years of missionary service at his own expense, often in a foreign country (BYU-Idaho, 2014b). This suggests that even though these students may have a lower level of academic ability, they also have greater maturity and life experience than the typical 19-year-old freshman, engineering student. Possible implications of this will be discussed in Chapter 5.

Method of Analysis

The hypotheses for each research question were tested with a 2 x 2 factorial ANOVA that crossed the type of laboratory (TRAD or LIAB) with the type of pairing (HL or MM) using SPSS statistical software. Following the recommendations of Perrett (2012), the dependent variables tested were the laboratory partnerships' mean scores instead of the individual students' scores. The assumptions of ANOVA were checked and verified. See the SSPS data table in Appendix J and the complete SPSS results in Appendix K.

Research Question 1

The first research question considered the learning of theoretical concepts (knowledge): Does the type of laboratory (TRAD or LIAB) or the method of pairing laboratory partners (HL or MM) affect a student's knowledge acquisition, as measured by a concept test?

This question was answered by collecting data on how well students learned theoretical concepts during the treatment. It was done using a 30-question, closed book concept test. Students were given a 2-hour time limit for completing the test. Resulting scores had a possible range of 0 to 30 points, with higher test scores indicating greater knowledge. The knowledge test scores for both laboratory partners in each pair were averaged to calculate the score for each of the 36 experimental units (pairs). The entire knowledge test is in Appendix G.

Research question 1A. The first part of the research question analyzed the main effect of laboratory type: Is there a difference in knowledge acquisition between students who use a traditional laboratory and students who use a lab-in-a-box, as measured by a concept test?

H_0: There is no difference in knowledge acquisition between students who use a traditional laboratory and students who use a lab-in-a-box.

$H_{A:}$ There is a difference in knowledge acquisition between students who use a traditional laboratory and students who use a lab-in-a-box.

The difference in knowledge acquisition, as determined by knowledge test scores, between students who used the traditional laboratory (*M* = 19.89, *SD* = 2.62) and students who used the lab-in-a-box (*M* = 20.11, *SD* = 2.22) was 0.22 points out of a maximum possible difference of 30 points. The results of the factorial ANOVA showed that this difference was not statistically significant, $F(1, 32) = 0.07$, $p = .791$. The results of this analysis indicated a failure to reject the null hypothesis. This indicates that the type of laboratory used had no effect on knowledge acquisition. Further, the Cohen's *d* value was 0.09, which represented a very small effect size (Gravetter & Wallnau, 2009). This also supports the conclusion that the type of laboratory used did not affect knowledge acquisition.

Research question 1B. The main effect of pairing was also examined: Is there a difference in knowledge acquisition between students who have a laboratory partner with a different level of cognitive ability (one with high ability and one with low ability) and students who have a laboratory partner with a similar level of cognitive ability (both with medium ability), as measured by a concept test?

H_0: There is no difference in knowledge acquisition between students who have a laboratory partner with a different level of cognitive ability (one with high ability and one with low ability) and students who have a laboratory partner with a similar level of cognitive ability (both with medium ability).

$H_{A:}$ There is a difference in knowledge acquisition between students who have a laboratory partner with a different level of cognitive ability (one with high ability and one with low ability) and students who have a laboratory partner with a similar level of cognitive ability (both with medium ability).

The difference in knowledge test scores, which represented the amount of knowledge acquisition, between the laboratory partners with different cognitive ability ($M = 20.00$, $SD = 2.24$) and the laboratory partners with similar cognitive ability ($M =$

20.00, *SD* = 2.61) was 0.00 points out of a maximum possible difference of 30 points. This indicated no difference, $F(1, 32) = 0.00$, $p = 1.000$. The ANOVA procedure produced results that failed to reject the null hypothesis. There was no evidence that the type of laboratory partner pairing used affected knowledge acquisition. Moreover, there was literally no difference between the means of the two groups. This resulted in an effect size of 0.00, which further indicated that laboratory partner pairing did not affect knowledge acquisition.

Research question 1C. The last part of this research question pertains to the interaction of the main effects: Is there an interaction effect between the type of laboratory and the type of laboratory partner pairing on knowledge acquisition?

H_0: There is no interaction effect between the type of laboratory and the type of laboratory partner pairing on knowledge acquisition.

H_A: There is no interaction effect between the type of laboratory and the type of laboratory partner pairing on knowledge acquisition.

The interaction effect between the type of laboratory and the type of laboratory partner pairing was not statistically significant, $F(1, 32) = 0.02$, $p = .895$. This result led to a failure to reject the null hypothesis. There was no indication that learning theoretical concepts was influenced by the interaction between the type of laboratory and the type of laboratory partner. The Cohen's *d* value was 0.06. This value represented a very small effect size (Gravetter & Wallnau, 2009), and provided further support that there was no interaction effect on knowledge acquisition.

Table 5, on page 85, summarizes the ANOVA results for the first research question. Neither the type of laboratory nor the type of laboratory partner paring had a statistically significant effect on knowledge of the theoretical concepts in the course. There was also no interaction effect. The standard errors and confidence intervals are shown in Table 6 on page 84.

Table 5

Knowledge: Laboratory and Pairing

	df	*MS*	*F*	*p*	*d*
Type of Laboratory	1	0.44	0.07	.791	0.09
Type of Pairing	1	0.00	0.00	1.000	0.00
(Type of Laboratory) * (Type of Pairing)	1	0.11	0.02	.895	0.06
Error	32	6.25	-	-	-

Note: Knowledge acquisition is not affected by the type of laboratory, type of partner, or the interaction between them.

Table 6

Knowledge: Means and Confidence Intervals

			95% Confidence Interval	
	M	*S.E.*	Lower Bound	Upper Bound
Grand Mean	20.00	0.42	19.15	20.85
TRAD	19.89	0.59	18.69	21.09
LIAB	20.11	0.59	18.91	21.31
HL	20.00	0.59	18.80	21.20
MM	20.00	0.59	18.80	21.20

Note: TRAD = traditional laboratory, LIAB = lab-in-a-box, HL = high-low ability partnership, MM = medium-medium ability partnership

Research Question 2

The second research question investigated the transfer of skill, specifically the time required make electrical measurements with unfamiliar laboratory equipment: Does the type of laboratory (TRAD or LIAB) or the method of pairing laboratory partners (HL or MM) affect a student's transfer of skill with one set of laboratory instruments to another set of unfamiliar laboratory instruments, as measured by a speed-of-use test?

Answering this question required collecting data on how quickly students were able to make electrical measurements on a laboratory performance test. The laboratory performance test had four different circuits, on which students were to perform nine measurements using four different laboratory instruments. Students were given a maximum of 15 minutes to make measurements on each of the four circuits. The speed test score for each student was the total number of minutes required to make all nine measurements. Lower speed test scores equated to faster measurements. The 60-minute time limit for the entire test reduced the effects of outliers. The speed test scores for both laboratory partners in each pair were averaged to calculate the score for each pair. The unfamiliar instruments were similar in purpose, but different in appearance and operation from the instruments the students had used during their laboratories. Compare the original instruments in Figure 10 on page 62, Figure 11 on page 63, Figure 12 on page 64, and Figure 13 on page 65, with the unfamiliar instruments in Figure 14 on page 68. The laboratory performance test is presented in Appendix H.

Research question 2A. The first part of the research question evaluated the main effect of laboratory type on the transfer of speed-skill: Is there a difference in the transfer of skill with one set of laboratory instruments to another set of unfamiliar laboratory instruments between students who use a traditional laboratory and students who use a lab-in-a-box, as measured by a speed-of-use (measurement time) test?

H_0: There is no difference in speed-skill transfer between students who use a traditional laboratory and students who use a lab-in-a-box.

H_A: There is a difference in speed-skill transfer between students who use a traditional laboratory and students who use a lab-in-a-box.

The difference in speed scores, as determined by measurement time in the laboratory performance test, between students who used the traditional laboratory (M = 38.77, SD = 8.55) and students who used the lab-in-a-box (M = 44.17, SD = 5.95) was 5.40 minutes (13.02%). This difference in measurement time was statistically significant, $F(1, 32) = 5.00$, $p = .032$. The null hypothesis was rejected and it was concluded that the type of laboratory used had an effect on skill transfer, as indicated by measurement time with unfamiliar laboratory instruments. The standard error was 2.41, and the 95% confidence interval was 0.48 to 10.32. The Cohen's d value was 0.70, which represented a medium-to-large effect size (Gravetter & Wallnau, 2009). This supports the finding that speed-skill transfer was affected by the type of laboratory used. Students who had been using a traditional laboratory (TRAD) were able to make electrical measurements with unfamiliar bench-top instruments 5.40 minutes more quickly than students who had been using a lab-in-a-box (LIAB). Possible implications of this will be discussed in Chapter 5.

Research question 2B. The second part of the question examined the main effect of laboratory partner pairing: Is there a difference in the transfer of skill with one set of laboratory instruments to another set of unfamiliar laboratory instruments between students who have a laboratory partner with a different level of cognitive ability, and students who have a laboratory partner with a similar level of cognitive ability, as measured by a speed-of-use test?

H_0: There is no difference in speed-skill (measurement time) transfer between students who have a laboratory partner with a different level of cognitive ability, and students who have a laboratory partner with a similar level of cognitive ability.

H_A: There is a difference in speed-skill (measurement time) transfer between students who have a laboratory partner with a different level of cognitive ability, and students who have a laboratory partner with a similar level of cognitive ability.

The difference in speed scores, representing measurement time in minutes, between the laboratory partners with different cognitive ability (M = 42.48, SD = 7.52) and the laboratory partners with similar cognitive ability (M = 39.47, SD = 7.68) was 4.01 minutes (9.67%). This difference was found to be not statistically significant, $F(1, 32) = 2.76$, $p = .106$. The ANOVA results failed to reject the null hypothesis. The conclusion was that skill transfer, measured by how quickly the students performed, was not affected by the type of laboratory partner pairing used.

Although these results were not statistically significant, the Cohen's *d* value was 0.52, which represented a medium effect size (Gravetter & Wallnau, 2009). The observed power calculated by SPSS was 0.36. Possible implications will be discussed in Chapter 5.

Research question 2C. The interaction of the main effects was also analyzed: Is there an interaction effect between the type of laboratory and the type of laboratory partner pairing on speed-skill (measurement time) transfer?

H_0: There is no interaction effect between the type of laboratory and the type of laboratory partner pairing on speed-skill (measurement time) transfer.

H_A: There is no interaction effect between the type of laboratory and the type of laboratory partner pairing on speed-skill (measurement time) transfer.

The interaction effect between the type of laboratory and the type of laboratory partner pairing was not statistically significant, $F(1, 32) = 0.39$, $p = .536$. Analysis of the results failed to reject the null hypothesis. There was no indication that the interaction between the type of laboratory and the type of laboratory partner affected skill transfer, as demonstrated by measurement time. The Cohen's *d* value was 0.18, which represented a very small effect size according to Gravetter and Wallnau (2009). This also suggested that speed-skill transfer was not affected by an interaction between the type of laboratory and the type of laboratory partner.

Table 7 lists the ANOVA results for the second research question. The type of laboratory used by the students had a statistically significant effect on the time required to make measurements with unfamiliar laboratory instruments. The type of laboratory partner paring, however, did not affect this aspect of skill transfer. There was also no interaction effect. The standard errors and confidence intervals are shown in Table 8 on page 90.

Table 7

Speed: Laboratory and Pairing

	df	MS	*F*	*p*	*d*
Type of Laboratory	1	262.44	5.00	.032	0.70
Type of Pairing	1	144.80	2.76	.106	0.52
(Type of Laboratory) * (Type of Pairing)	1	20.55	0.39	.536	0.18
Error	32	57.46	-	-	-

Note: Measurement time with unfamiliar equipment is affected by the type of laboratory, but not by the type of partner, or the interaction between them.

Table 8

Speed: Means and Confidence Intervals

	M	*S.E.*	95% Confidence Interval	
			Lower Bound	Upper Bound
Grand Mean	40.47	1.21	39.01	43.93
TRAD	38.77	1.71	35.30	42.25
LIAB	44.17	1.71	40.70	47.65
HL	43.48	1.71	40.00	46.96
MM	39.47	1.71	35.99	42.94

Note: TRAD = traditional laboratory, LIAB = lab-in-a-box, HL = high-low ability partnership, MM = medium-medium ability partnership

Research Question 3

The third research question studied skill transfer, as determined by the accuracy of measuring electric circuit parameters with unfamiliar laboratory instruments: Does the type of laboratory (TRAD or LIAB) or the method of pairing laboratory partners (HL or MM) affect a student's transfer of skill with one set of laboratory instruments to another set of unfamiliar laboratory instruments, as measured by an accuracy-of-use test?

In order to answer this question, data were collected on how accurately students could make electrical measurements on a laboratory performance test. As previously described, the laboratory performance test required students to make nine measurements with unfamiliar instruments on four different circuits. Although unfamiliar in appearance and operation, these instruments were similar in purpose to the instruments the students had used during their laboratories. The difference between the measured values for each circuit were compared to the actual values and converted into an error percentage. The highest possible measurement error for each circuit was capped at 100%, resulting in a maximum possible error of 400% for the entire test. This limited the effects of outliers. Lower scores corresponded with better measurement accuracy. The accuracy test score for each student was the total percentage of measurement error accumulated for all four circuits. The accuracy test scores for both laboratory partners in each pair were calculated by averaging the scores for both laboratory partners.

Research question 3A. The first part of the research question investigated the main effect of laboratory type on the transfer of accuracy-skill: Is there a difference in the transfer of skill with one set of laboratory instruments to another set of unfamiliar laboratory instruments between students who use a traditional laboratory and students who use a lab-in-a-box, as measured by an accuracy-of-use (percent of measurement error) test?

H_0: There is no difference in accuracy-skill (percent of measurement error) transfer between students who use a traditional laboratory and students who use a lab-in-a-box.

H_A: There is a difference in accuracy-skill (percent of measurement error) transfer between students who use a traditional laboratory and students who use a lab-in-a-box.

The difference in accuracy scores between students who used the traditional laboratory (M = 140.11, SD = 44.42) and students who used the lab-in-a-box (M = 132.02, SD = 35.29) was 5.95%. The difference in accuracy between the two groups was not statistically significant, $F(1, 32) = 0.37$, $p = .549$. This result failed to reject the null hypothesis. This study found no evidence that skill transfer, indicated by how accurately the students made their electrical measurements, was affected by the type of laboratory used. The Cohen's d value was 0.20. This represented a small effect size (Gravetter &

Wallnau, 2009). The small effect size supported the conclusion that the type of laboratory used did not affect measurement accuracy with unfamiliar laboratory instruments.

Research question 3B. The main effect of laboratory partner pairing was also analyzed: Is there a difference in the transfer of skill with one set of laboratory instruments to another set of unfamiliar laboratory instruments between students who have a laboratory partner with a different level of cognitive ability, and students who have a laboratory partner with a similar level of cognitive ability, as measured by an accuracy-of-use (percent of measurement error) test?

H_0: There is no difference in accuracy-skill (percent of measurement error) transfer between students who have a laboratory partner with a different level of cognitive ability, and students who have a laboratory partner with a similar level of cognitive ability.

H_A: There is a difference in accuracy-skill (percent of measurement error) transfer between students who have a laboratory partner with a different level of cognitive ability, and students who have a laboratory partner with a similar level of cognitive ability.

The difference in accuracy scores, representing the percentage of measurement error, between the laboratory partners with different cognitive ability ($M = 126.79$, $SD = 40.88$) and the laboratory partners with similar cognitive ability ($M = 145.34$, $SD = 37.41$) was 13.64%. The result was not statistically significant, $F(1, 32) = 1.93$, $p = .175$. This finding failed to reject the null hypothesis. There was no indication that skill transfer, measured by how accurately the students used unfamiliar laboratory instruments, was affected by the type of laboratory partner pairing used.

Although these results were not statistically significant, the Cohen's *d* value was 0.47, which represented a small-to-medium effect size (Gravetter & Wallnau, 2009). The observed power calculated by SPSS was 0.27. Possible implications will be discussed in Chapter 5.

Research question 3C. The last part of this research question looked at the interaction of the main effects: Is there an interaction effect between the type of laboratory and the type of laboratory partner pairing on accuracy-skill (percent of measurement error) transfer?

H_0: There is no interaction effect between the type of laboratory and the type of laboratory partner pairing on accuracy-skill (percent of measurement error) transfer.

H_A: There is no interaction effect between the type of laboratory and the type of laboratory partner pairing on accuracy-skill (percent of measurement error) transfer.

The interaction effect between the type of laboratory and the type of laboratory partner pairing was not statistically significant, $F(1, 32) = 0.09$, $p = .77$. This result failed to reject the null hypothesis. The evidence indicated that skill transfer, demonstrated by measurement accuracy, was not affected by the interaction between the type of laboratory and the type of laboratory partner. The Cohen's *d* value was 0.26, which represented a small effect size (Gravetter & Wallnau, 2009). This result strengthened the finding that an interaction between the type of laboratory and the type of laboratory partner did not affect measurement accuracy with unfamiliar laboratory instruments.

A summary of the ANOVA results for this research question are shown in Table 9. There were no statistically significant effects of laboratory type, laboratory partner type, or their interaction on skill transfer measured by accuracy of performance. The standard errors and confidence intervals are shown in Table 10.

Table 9

Accuracy: Laboratory and Pairing

	df	MS	*F*	*p*	*d*
Type of Laboratory	1	588.87	0.37	.549	0.20
Type of Pairing	1	3098.78	1.93	.175	0.47
(Type of Laboratory) * (Type of Pairing)	1	144.00	0.09	.767	0.26
Error	24	1608.29	-	-	-

Note: Measurement accuracy with unfamiliar equipment is not affected by the type of laboratory, type of partner, or the interaction between them.

Table 10

Accuracy: Means and Confidence Intervals

			95% Confidence Interval	
	M	*S.E.*	Lower Bound	Upper Bound
Grand Mean	136.07	6.68	122.45	149.68
TRAD	140.11	9.45	120.86	159.37
LIAB	132.02	9.45	112.77	151.28
HL	126.79	9.45	107.54	146.04
MM	145.34	9.45	126.09	164.60

Note: TRAD = traditional laboratory, LIAB = lab-in-a-box, HL = high-low ability partnership, MM = medium-medium ability partnership

Research Question 4

The fourth research question considered student attitude, defined in this study as motivation to continue studying engineering. Does the type of laboratory (TRAD or LIAB) or the method of pairing laboratory partners (HL or MM) affect a student's motivation to continue studying engineering, as measured by the Pittsburgh Freshman Engineering Attitudes Survey?

The instrument for analyzing this aspect of student attitudes was the Pittsburgh Freshman Engineering Attitudes Survey. The survey had 50 Likert items and had a 15-minute time limit for completion. Only the responses to 10 of the Likert items were used for this study: those that measured positive and negative attitudes toward studying engineering. Those specific items are identified in Figure 15 on page 76. Attitude scores were calculated by converting the responses to numeric values and totaling the number of points. Positive values were assigned to questions that corresponded with high motivation and negative values were assigned to questions that indicated a low motivation. The highest possible score for any student on these 10 questions was +20 points and the lowest possible score was -20 points. The attitude scores for both laboratory partners in each pair were averaged. See the entire survey in Appendix I.

Research question 4A. The first part of this question looked at the main effects of laboratory type on student attitude: Is there a difference in motivation to continue studying engineering between students who use a traditional laboratory and students who use a lab-in-a-box, as measured by the Pittsburgh Freshman Engineering Attitudes Survey?

H_0: There is no difference in motivation between students who use a traditional laboratory and students who use a lab-in-a-box.

H_A: There is a difference in motivation between students who use a traditional laboratory and students who use a lab-in-a-box.

The difference in motivation, measured by points on a Likert scale, between the students who used the traditional laboratory (*M* = 8.64, *SD* = 3.18) and students who used the lab-in-a-box (*M* = 9.94, *SD* = 3.57) was 1.31 points out of a maximum possible difference of 40. The difference was not statistically significant, $F(1, 32) = 1.33$, $p = .258$. The factorial ANOVA failed to reject the null hypothesis. This result indicated that motivation to continue studying engineering was not affected by the type of laboratory used. The Cohen's *d* value was 0.39, which represented a small effect size (Gravetter & Wallnau, 2009). This also indicated that the type of laboratory used does not affect this aspect of motivation.

Research question 4B. The second part of the research question evaluated the effect of laboratory partner pairing: Is there a difference in motivation to continue studying engineering between students who have a laboratory partner with a different level of cognitive ability, and students who have a laboratory partner with a similar level of cognitive ability, as measured by the Pittsburgh Freshman Engineering Attitudes Survey?

H_0: There is no difference in motivation between students who have a laboratory partner with a different level of cognitive ability, and students who have a laboratory partner with a similar level of cognitive ability.

H_A: There is a difference in motivation between students who have a laboratory partner with a different level of cognitive ability, and students who have a laboratory partner with a similar level of cognitive ability.

The difference in motivation between the laboratory partners with different cognitive ability (*M* = 9.36, *SD* = 3.22) and the laboratory partners with similar cognitive ability (*M* = 9.22, *SD* = 3.66) was 0.14 Likert points out of a maximum possible of 40. The difference in motivation was not statistically significant, $F(1, 32) = 0.02$, $p = .903$. This result failed to reject the null hypothesis. There was no evidence found in this study that the type of laboratory partner pairing affected motivation to continue studying engineering. The Cohen's *d* value was 0.04. This represented a very small effect size (Gravetter & Wallnau, 2009), and further indicated that motivation to continue studying engineering was not affected by the type of laboratory partner pairing used in this study.

Research question 4C. Interaction effects were also analyzed: Is there an interaction effect between the type of laboratory and the type of laboratory partner pairing on motivation to continue studying engineering?

H_0: There is no interaction effect between the type of laboratory and the type of laboratory partner pairing on motivation to continue studying engineering.

H_A: There is no interaction effect between the type of laboratory and the type of laboratory partner pairing on motivation to continue studying engineering.

The interaction effect between the type of laboratory and the type of laboratory partner pairing was not statistically significant, $F(1, 32) = 1.56$, $p = .220$. This was a failure to reject the null hypothesis. There was no indication that motivation to continue studying engineering was influenced by the interaction between the type of laboratory and the type of laboratory partner. The Cohen's *d* value was 0.34, which represented a small effect size (Gravetter & Wallnau, 2009). This small effect size supports the conclusion that the interaction between the type of laboratory and the type of laboratory partner had little or no effect on motivation to continue studying.

Table 11 lists the ANOVA results. Neither the type of laboratory nor the type of laboratory partner paring had a statistically significant effect on motivation to continue studying engineering. There was also no interaction effect. The standard errors and confidence intervals are shown in Table 12.

Table 11

Attitude: Laboratory and Pairing

	df	MS	*F*	*p*	*d*
Type of Laboratory	1	15.34	1.33	.258	0.39
Type of Pairing	1	0.17	0.02	.903	0.04
(Type of Laboratory) * (Type of Pairing)	1	18.06	1.56	.220	0.34
Error	24	11.57	-	-	-

Note: Motivation to continue studying engineering is not affected by the type of laboratory, type of partner, or the interaction between them.

Table 12

Attitude: Means and Confidence Intervals

			95% Confidence Interval	
	M	*S.E.*	Lower Bound	Upper Bound
Grand Mean	9.29	0.57	8.14	10.45
TRAD	8.64	0.80	7.01	10.27
LIAB	9.94	0.80	8.31	11.58
HL	9.36	0.80	7.73	10.99
MM	9.22	0.80	7.59	10.86

Note: TRAD = traditional laboratory, LIAB = lab-in-a-box, HL = high-low ability partnership, MM = medium-medium ability partnership

Summary

Four research questions were studied to determine the influence of the type of laboratory (traditional or lab-in-a-box) and the method of pairing laboratory partners (one with high ability and one with low ability or both with medium ability) on students' knowledge of concepts, transfer of practical skills to unfamiliar laboratory instruments, and motivation to continue studying engineering. The hypotheses for each research question were tested with a 2 x 2 factorial ANOVA that crossed the type of laboratory with the type of pairing using SPSS statistical software.

The only statistically significant result was the difference in skill transfer, as indicated by performance time, between students who used the traditional laboratory and students who used the lab-in-a-box, $F(1, 32) = 5.40$, $p = .032$. Students who had used a traditional laboratory with actual bench-top instruments were able to make a series of electrical measurements with unfamiliar bench-top instruments 5.40 minutes (13.02%) faster than students who had used a lab-in-a-box with computer-based instruments. The effect size was $d = 0.70$. This will be discussed further in Chapter 5.

Although not statistically significant, differences in measurement time and measurement accuracy between the two types of laboratory partner pairing were observed. Students who had a laboratory partner with a similar level of cognitive ability (both partners of medium ability) performed measurements using unfamiliar laboratory instruments more quickly than students did who had a laboratory partner with a different level of cognitive ability (one high ability and one low ability). On the other hand, students who had a laboratory partner with a different level of cognitive ability (one high and one low) performed measurements using unfamiliar laboratory instruments more accurately than students did who had a laboratory partner with a similar level of cognitive ability (both medium). The effect size of the time difference was medium ($d = 0.52$) and the effect size of the error difference was nearly medium ($d = 0.47$).

CHAPTER V

Conclusions

The purpose of this study was to assess the instructional design effectiveness of two electrical engineering laboratory modalities by measuring how well they fulfilled the learning objectives of reinforcing theoretical concepts (knowledge), developing transferrable practical skills (skills), and promoting student motivation to continue studying engineering (attitudes) for students in their first engineering laboratory course at a private, medium size university in the Intermountain West. It also investigated whether pairing laboratory partners according to their cognitive ability influenced the achievement of these learning objectives.

Knowledge, skill, and attitude were assessed. Only one of the experimental results was statistically significant. However, the interpretation of these experimental results will consider more than their statistical significance because the significant/non-significant decision ignores “potentially important observed differences” (Gelman & Stern, 2006, p. 328). A medium effect size will be considered important in the analysis of this study’s results because “the size of an effect is at least as informative as its statistical significance” (Prentice & Miller, 1992, p. 160).

Research Question 1

The first research question considered the learning of theoretical concepts (knowledge): Does the type of laboratory (TRAD or LIAB) or the method of pairing laboratory partners (HL or MM) affect a student's knowledge acquisition, as measured by a concept test?

Summary of results. The type of laboratory (TRAD or LIAB) used had no statistically significant effect on knowledge acquisition. The size of the effect was very small (d = 0.09). This finding was similar to results from many of the previous studies about engineering laboratories, which concluded that the type of laboratory (traditional, simulated, remote, or lab-in-a-box) usually made little difference on the amount of basic engineering knowledge learned by students (Balamuralithara & Woods, 2009; Bryant, Gieskes, & McGrann, 2009; Corter, et al., 2011; Hall, et al., 2008; Nickerson, et al., 2007; Malaric, et al., 2008). The results of this study add extra weight to the conclusion because it used a true experimental design with random assignment; the cited studies did not meet this condition. The results of this study contrast with those of Finkelstein (2005), Gomes and Bogosyan (2009), Rojko, et al. (2010), Shanab, et al. (2012), and Stefanovic, et al. (2011), which did find that the type of laboratory made a difference in conceptual learning . However, those studies did not meet the requirements of experimental design because they did not randomly assign their participants to groups.

The method of pairing laboratory partners (HL or MM) had no statistically significant effect on conceptual knowledge acquisition. There was, in fact, literally no difference between the means of the two groups (HL group: M = 20.00, SD = 2.24; MM group: M = 20.00, SD = 2.61). This study extended that of Longfellow, et al. (2008), which observed that the social interaction between collaborating partners increased the amount of learning when compared to individuals working alone. This study went further by assessing whether the type of collaborating partner had an effect on learning. Both HL and MM pairings in this study had statistically equal effects on the learning of concepts.

The interaction effect between the type of laboratory and the type of laboratory partner pairing was not statistically significant. The effect size was very small ($d = 0.06$). There was no indication that learning theoretical concepts was influenced by the interaction between the type of laboratory and the type of laboratory partner.

Interpretation of results. The type of laboratory partner may have had no effect on this sample because of the collaborating experience these students brought with them to the engineering program. As described in Chapter 4, about half of the students in this sample had previously spent two years as missionaries. In addition to now being older than many first-semester engineering students are (Boylen, 2003), they had lived, worked, and studied with another missionary for every waking hour of every day during that time. They had learned to resolve differences of opinion and work together in a very intense collaboration environment that many other students may not experience until marriage. Because they were re-assigned a different missionary partner every few months, they had also learned to work with people having a variety of personalities and abilities. This may have mitigated the effect of different pairing types in this study.

Research Question 2

The second research question investigated the transfer of skill, specifically the time required make electrical measurements with unfamiliar laboratory equipment: Does the type of laboratory (TRAD or LIAB) or the method of pairing laboratory partners (HL or MM) affect a student's transfer of skill with one set of laboratory instruments to another set of unfamiliar laboratory instruments, as measured by a speed-of-use test?

Summary of results. Students who had been using a traditional laboratory, composed of bench-top instruments, were able to make electrical measurements with unfamiliar bench-top instruments 5.40 minutes (13.02%) more quickly than students who had been using the lab-in-a-box. This statistically significant result ($p = 0.032$) had a medium effect size (d = 0.70). This result supports the conclusions of Balamuralithara and Woods (2009), who speculated that students using alternative laboratory modalities would be "less skillful" (p. 111) when handling real equipment. It also supports the findings of Date, et al. (2012), which led to the conclusion that traditional hands-on laboratories are "the best way to achieve practical skills" (p. 1), although the term "practical skills" was never explicitly defined. Neither of those studies, however, specified completion time as a criterion for assessing skill with laboratory instruments.

Tzafestas, et al. (2006) did use completion time as a performance metric in comparing students who had used a traditional (real), remote, or virtual robotics laboratory for training and then tested their skill with a real robot. The robot was the same one used in the traditional and remote laboratories. The virtual laboratory used a simulation of this particular robot. Students who had learned robotics using the traditional laboratory performed the required tasks more quickly than their counterparts who had learned using alternative laboratory modalities.

This study extended the assessment of skill transfer by Tzafestas, et al. (2006) by applying it to unfamiliar equipment. It was also a true experiment with random assignment, unlike the other studies mentioned here. Furthermore, it provides reliable information for weighing the skill development trade-offs of using the lab-in-a-box as an alternative to the traditional laboratory.

The method of pairing laboratory partners (HL or MM) had a medium effect (*d* = 0.52) on how quickly students were able to make electrical measurements with unfamiliar bench-top instruments, but it did not meet the requirements of statistical significance. These results extend the findings of Braught, et al. (2011), who studied whether pairing computer science students facilitated achieving higher levels of programming skill. After pairing students randomly in one run, and pairing them according to similar ability in a subsequent run, they concluded that higher performance was achieved by students who had been paired with another student of similar ability. They speculated that pairing students with dissimilar ability would be less effective, but did not collect any evidence to support that conclusion. This study built upon their research by testing that pairing method (one high ability [H] student and one low ability [L] student). It also extended the effects of pairing from learning software tasks to learning hardware tasks.

There were no statistically significant interaction effects between the type of laboratory and the type of laboratory partner pairing. This effect size was also small (*d* = 0.18). There was no indication that the ability of students to make electrical measurements quickly with unfamiliar bench-top instruments was affected by an interaction between the type of laboratory and the type of laboratory partner.

Interpretation of results. Skill transfer in this study was limited to near transfer, where the skill was performed in a context similar to that in which it was learned. This research question focused on one aspect of skill transfer: how quickly the skill could be performed in the new context. The results from this study, combined with those from Balamuralithara and Woods (2009), Date, et al. (2012), and Tzafestas, et al. (2006), provide convincing evidence that students adapt more quickly to new hardware that is similar in look and feel to that on which they originally trained. Tzafestas, et al. (2006) explained that this was because students were better able to memorize "low-level dexterities" (p. 366) such as button pressing, which were better facilitated by manipulating the actual device through direct physical contact. That interpretation is consistent with the conclusion of O'Malley and Abhishek (2003) that haptic feedback during training improved the transfer of skill to other related tasks.

A question remains unanswered: Is the statistically significant difference in measurement time an important one? A study by Quek (2005) revealed that the most important skills required by engineering graduates are interpersonal skills, knowledge-acquiring skills, and flexibility. In other words, they must be able to work with people, learn how to learn, and adapt to the situation. One could argue that the speed with which an engineer initially uses an unfamiliar piece of equipment may not be very important if the person has those other three skills.

In contrast to the type of laboratory, the type of laboratory partner had no statistically significant influence on measurement speed. There was a medium effect size (d = 0.52. This indicated that further scrutiny of this result was warranted (Prentice & Miller, 1992). The observed power calculated by SPSS was 0.36, meaning that the actual scores (HL = 43.48, MM = 39.47), with a 9.67% difference in measurement speed between the HL and MM laboratory pairs, only had a 36% chance of being statistically significant. If this effect size represents an actual difference, it may have reached the level of statistical significance if a larger sample size had been available.

Furthermore, the unsolicited comments of two students called into question whether the intended peer learning had actually taken place. After scoring poorly on the performance test, these students expressed regret that they had only watched their laboratory partners perform all of the measurements instead of doing some themselves. They believed that was the reason they had trouble on the performance test.

The medium effect size, combined with the students' comments, prompted a question: "Did one laboratory partner dominate the laboratory instruments while the other one passively watched?" Braught, et al. (2011) found that sometimes "the stronger student will either just do things correctly when driving or quickly point out how to correct errors when navigating" (p. 17). This prevents weaker students from learning how to deal with similar problems when working alone. Scores on the performance test may have indicated this behavior for the HL pairs.

This was not one of the original research questions and the study was not designed to answer it fully. Enough data had been collected, however, to compare the amount of skill transfer demonstrated by both members of the HL pairs. The data set is shown in Appendix J. Statistically significant differences between the measurement times of students within each HL partnership might suggest that the skill transfer had been unequal, and that they had not helped each other become proficient in using the laboratory instruments.

The dependent-samples *t*-test is appropriate for assessing the difference in measurement time between two students within the same pair (Morgan, Leech, Gloeckner, & Barrett, 2004). With $\alpha = .05$, the dependent-samples *t*-test was performed to determine whether the measurement times of the laboratory partners within each HL pair differed significantly.

The difference between the mean measurement time for H students ($M = 45.33$, $SD = 9.07$) and the mean measurement time for their partners who were L students ($M = 41.71$, $SD = 12.59$) was a small positive number ($M = 3.62$, $SD = 17.27$). The positive value indicates that the H students in this sample took an average of 3.62 minutes longer to complete the performance test (electrical measurements with unfamiliar laboratory instruments) than the L students did. This difference was not, however, statistically significant, $t(17) = 0.890$, $p = .386$, $d = 0.21$. The 95% confidence interval for the mean difference between the measurement times was -4.96 to 12.21.

The lack of a statistically significant difference in measurement time suggests that both partners were able to transfer a similar level of speed-skill to unfamiliar laboratory instruments. This study, therefore, found no evidence that a dominant partner existed in the HL pairs that kept the other one from acquiring skill with the equipment. This result supports the findings of Miller, et al. (2012) who concluded that laboratory performance is improved when partners have dissimilar abilities. One reason for the similar level of speed-skill demonstrated in this study could be that the H students pulled the L students up to a higher level. According to Longfellow, et al. (2008), it may be that successful students are able to model those behaviors and help lower-achieving students learn how to be better students themselves. Further evidence of this is offered by Christiansen and Bell (2009), who observed that helping less-capable learners “brought affective gains to the senior learner who acted as facilitator” (p. 808). It may be, therefore, that there was motivation among the HL partners to collaborate. Of course, the opposite could have been true; the L students may have pulled the H students down to a lower level of performance.

Because this question was not part of the original plan for this study, the M students were not identified in any way as being different from other M students. There was, therefore, no way to format this data consistently to make comparisons similar to those of the HL pairs. It was also not possible with the existing data to compare the skill level of L students before and after the treatment to see how much it actually increased by working with H students. More study is needed to ascertain what peer mentoring, if any, actually occurred.

Research Question 3

The third research question studied skill transfer, as determined by the accuracy of measuring electric circuit parameters with unfamiliar laboratory instruments: Does the type of laboratory (TRAD or LIAB) or the method of pairing laboratory partners (HL or MM) affect a student's transfer of skill with one set of laboratory instruments to another set of unfamiliar laboratory instruments, as measured by an accuracy-of-use test?

Summary of results. The type of laboratory used (TRAD or LIAB) had no statistically significant effect on how accurately students could make electrical measurements with a set of unfamiliar traditional laboratory instruments. The size of the effect was small (d = 0.20). One corroborating study, Tzafestas, et al. (2006), also measured error rates and found no statistical difference between students who had used a traditional robotics laboratory, students who had used a remote robotics laboratory, and students who had used a virtual robotics laboratory, when the students were tested using a physical robot. This study extended the assessment of skill transfer beyond that of Tzafestas, et al. (2006) to unfamiliar equipment. It also had the advantage of being a true experiment with random assignment.

Even though it had a nearly medium effect size (d = 0.47), the method of pairing laboratory partners (HL or MM) had no statistically significant effect on how accurately students could make electrical measurements with a set of unfamiliar traditional laboratory instruments. These results contradict Braught, et al. (2011) who concluded, from anecdotal evidence, that computer science partners with similar ability would perform better on programming tasks, than would partners having dissimilar ability. They also differ from those of Miller, et al. (2012), which showed that laboratory performance is improved when biotechnology partners have dissimilar abilities. Neither of those studies, however, involved engineering students. This experiment extends the pairing research of Braught, et al. (2011) to experimentally test partners with dissimilar ability, and from a focus on developing software skills to learning hardware skills. It extends that of Miller et al. (2012) to encompass engineering skills.

There was no statistically significant interaction between the type of laboratory and the type of laboratory partner pairing. This effect size was (d = 0.26). There was no indication that the ability of students to make electrical measurements accurately with unfamiliar bench-top instruments was affected by an interaction between the type of laboratory and the type of laboratory partner.

Interpretation of results. As described earlier, skill transfer in this study was limited to near transfer. The third research question examined how accurately the skill could be performed in the new context. This study shows that the type of laboratory used by the students did not influence their ability to make accurate measurements, and supports similar findings by Tzafestas, et al. (2006).

As with measurement speed, there was no statistical evidence that measurement accuracy was affected by the type of pairing. That is, there was no statistically significant difference between the pair scores for HL partnerships and for MM partnerships. The effect size, however, was nearly medium (d = 0.47) and should be an important consideration when interpreting the results (Prentice & Miller, 1992). Although the power of this experiment to detect a 10% difference was estimated beforehand to be 0.98, the actual observed power calculated by SPSS was only 0.27. Therefore, the 13.64% difference in measurement accuracy between the HL and MM laboratory pairs only had a 27% chance of being statistically significant. A larger sample size may have produced statistically significant results.

Assuming that the differences in measurement speed and measurement accuracy caused by the type of pairing were meaningful, and that they would have been statistically significant if the sample size had been larger, an interesting pattern emerged. The HL pairs were slower in making their measurements than were the MM pairs, but those measurements were more accurate. This raises the possibility that there was a conscious or unconscious decision to sacrifice speed for accuracy among the HL pairs or that the MM pairs were less skillful and simply gave up sooner. The existence of speed vs. accuracy strategies among students should be studied.

As described earlier for Research Question 2, an unplanned *t*-test analysis was conducted in an attempt to evaluate the level of collaboration and mentoring that actually took place within the laboratory partnerships. A statistically significant difference between the scores of individual students within each HL partnership would indicate a different level of skill transfer and would suggest a failure to collaborate and teach each other effectively. Based on measurement speed, it was inferred previously that effective collaboration and peer teaching had occurred within the HL partnerships. A similar test was also performed using accuracy scores as part of the exploration of Research Question 3. The lack of statistically significant differences between the measurement accuracy of students within each HL partnership would further support the conclusion that HL partners had worked together to develop equivalent levels of skill in using the laboratory instruments. The data used for this analysis is in Appendix J.

A t-test was performed to determine whether the measurement accuracy of the laboratory partners within each HL pair differed significantly. The difference between the mean measurement accuracy for H students ($M = 109.83$, $SD = 52.45$) and the mean measurement accuracy for their partners who were L students ($M = 142.69$, $SD = 60.45$) was a negative number ($M = -32.86$, $SD = 83.75$). The negative sign on this difference means that the H students in this sample were an average of 32.86% more accurate when making electrical measurements with unfamiliar laboratory instruments on the performance test than the L students were. This difference was not, however, statistically significant, $t(17) = -1.66$, $p = .114$, $d = 0.39$. The 95% confidence interval was -74.50 to 8.79.

The lack of a statistically significant difference in measurement accuracy suggests that both partners were able to transfer a similar level of accuracy-skill to unfamiliar laboratory instruments. As discussed under Research Question 2, this could mean that peer mentoring took place within the HL laboratory partnerships and that H students helped to raise the level of accuracy skill of their L-student laboratory partners. As pointed out, however, the L students may have reduced the performance level of the H students instead. More study is needed to determine if peer mentoring actually took place. The data collected for this study were not structured properly to conduct a similar comparison between MM partners.

An interesting finding was that the error rates observed during the performance test in this study were higher than expected by the instructor. The sum of nine different measurement errors averaged 135% producing a mean error of 15% per measurement. Salim, et al. (2010) published evidence that this error rate for freshman with unfamiliar equipment may be normal. After conducting a study that measured the skill of students with basic laboratory instruments, they concluded that nearly 20% of the students in their study still needed help using a meter and 40% of them were still not able to operate a function generator or oscilloscope competently after completing a series of laboratories. Novice students may require much more practice to become truly proficient than either of these studies provided. Further study that measures the error rates for freshman students at other universities is needed to determine whether 15% is normal and acceptable.

Research Question 4

The fourth research question examined student attitude, defined in this study as motivation to continue studying engineering. Does the type of laboratory (TRAD or LIAB) or the method of pairing laboratory partners (HL or MM) affect a student’s motivation to continue studying engineering, as measured by the Pittsburgh Freshman Engineering Attitudes Survey?

Summary of results. The type of laboratory (TRAD or LIAB) had no statistically significant effect on motivation to continue studying engineering. The size of the effect was small (*d* = 0.39). This indicates that both types of laboratory were equally motivating for students. Several studies have shown that laboratories can be motivating (Corter, et al., 2011; Feisel & Rosa, 2005; Melkonyan, et al., 2009), but no comparison of motivation based on the various laboratory modalities was found. This study may be the first one to explore that question.

The method of pairing laboratory partners (HL and MM) had no statistically significant effect on motivation to continue studying engineering. The size of the effect was very small (*d* = 0.04). Havnes (2008) found that collaborative learning was more intrinsically motivating for students then working alone was. Serrano-Camara, et al. (2014) stated that motivated students tended to persevere longer with a task. This study extended those findings to examine whether the composition of the collaborating partners made a difference in their motivation to continue in the particular task of studying engineering. Both types of pairing had statistically equal motivational effects.

The interaction effect between the type of laboratory and the type of laboratory partner pairing was also not statistically significant. The effect size was small (*d* = 0.34). There was no indication that motivation to continue studying engineering was influenced by the interaction between the type of laboratory and the type of laboratory partner.

Interpretation of results. As explained earlier, about half of the students in this study had completed two years of missionary service. Missionaries are taught to set challenging goals and commit to their accomplishment. It is possible that this training mitigated one of the characteristics observed by Mina and Gerdes (2006) in freshmen engineering students, namely that they "are more apt to change to a different engineering discipline, or leave engineering altogether, rather than persevere" (p. 513) when it becomes difficult. This adult experience may have minimized the effect size of the students' motivation to continue studying engineering.

Students with prior missionary training have two traits that differentiate them from most freshman students: (a) training, and (b) higher age. Even if the missionary training had no effect, it may be that simply being older did have an effect. More maturity, motivation, and goal orientation normally accompanies increased age for young people (Figueiredo, Goncalves, Coelho E Silva, & Malina, 2009). Whether the effect is from training or age might be determined by future research to compare students who simply delay college with those who begin college after two years of missionary work, or by comparing 18 and 19-year-old freshman students with 20 and 21-year-old freshman students at other universities.

Recommendations for Future Practice

Lab-in-a-box may be effectively used to teach conceptual knowledge. It does not reduce the ability of students to make accurate measurements with bench-top instruments. It also does not affect their motivation to continue studying engineering. However, students who use the lab-in-a-box require 13% more time to adapt to unfamiliar bench-top laboratory instruments than students who use traditional bench-top instruments during laboratories. If this extra time is an acceptable trade-off, these findings support the decision of instructional designers to use the lab-in-a-box in situations where traditional laboratories would be difficult or impossible to implement. These situations include constrained on-campus resources (Clark, et al., 2009; Wolf, 2012) and online course offerings that include a laboratory component (Stefanovic, et al., 2011; Valian & Emami, 2013).

Collaborative learning is a well-established instructional method. This study suggests the possibility that students with a high level of cognitive ability may be helpful to students who have a lower level of cognitive ability. However, the evidence for this is inconclusive and there may actually be little value in using time-consuming methods to pair laboratory partners. Whether laboratory partners are paired according to ability, as in this study, or assigned randomly, as in previous research, there was no statically significant effect on their knowledge acquisition or skill transfer. Students' motivation to continue studying engineering was not affected by the way they are paired.

This study also tested the interaction between the type of laboratory and the type of partner pairing. There were no statistically significant interactions. Each of these two factors can be independently changed in a laboratory course without influencing the effect of the other one.

Recommendations for Future Research

Although the cognitive ability of the laboratory partner a student was assigned to work with had no statistically significant effect on how quickly students could adapt to unfamiliar laboratory instruments took place, the difference in speed of skill transfer had a medium effect size (d = 0.52). According to Gelman and Stern (2006), and Prentice and Miller (1992), this effect size is potentially important and warrants closer examination. The power to show statistical significance for this difference (0.36) might be increased with a larger sample size. Repeating this study with a larger number of participants may show that those effects are, indeed, statistically significant.

Laboratory partner assignment also had no statistically significant effect on how accurately students could make electrical measurements with unfamiliar laboratory instruments. However, the difference in accuracy skill transfer had a nearly medium effect size ($d = 0.47$) and the observed power was only 0.27. This indicates that these results should be verified by repeating the study with a larger sample size.

Assuming that the differences in measurement speed and measurement accuracy caused by the type of pairing were meaningful, and assuming further that they would have been statistically significant if the sample size had been larger, an interesting pattern emerged. Even though the differences were not statistically significant, the HL pairs were slower in making their measurements than were the MM pairs, but those measurements were more accurate. Was speed sacrificed for accuracy among the HL pairs or were the MM pairs less skillful and simply gave up sooner? Further research with a larger sample might discover whether students use a speed vs. accuracy strategy.

The results of this study prompted a question of whether the intended collaboration and peer learning among laboratory partners actually occurred. There was evidence of collaboration during this experiment, but it was not designed to study this. A study should be conducted specifically to examine the details of peer learning in an engineering laboratory setting.

Another question that emerged from the performance test is whether the observed error rates are typical of laboratory work by novices or if they are unique to this particular sample. A study should be conducted to determine if these error rates are typical and how much practice novice students need in order to become proficient at making electrical measurements with laboratory instruments.

Several variations of this study might be of interest to instructional designers and engineering educators. A future longitudinal study could compare the measurement times and error rates of freshman students with their skills when they are seniors, or even graduates, to determine how effectively skill improvement is facilitated by laboratory work over their academic career. Another variation could study the effects of laboratory type on scores of the Fundamentals of Engineering examination. Yet another could determine if previous electrical experience and knowledge has an additional effect on knowledge, skills, or attitudes by including a domain-specific pre-test.

Several pairing methods were not studied. These include pairing two high ability or two low ability students together. Miller, et al. (2012) observed that students prefer working with someone of similar ability, but are two low ability students able to develop sufficient skill by working together? Another pairing method would be to refrain from making any partnership assignments at all. There may be an effect on knowledge acquisition, skill transfer, or motivation to continue studying engineering if students select their own laboratory partners instead being assigned to one.

This sample is not representative of freshman across the country. The students were older (Boylen, 2003) and had lower ACT scores ("ACT Scores," 2007) than students at some other universities. Furthermore, half of them had performed missionary service for two years prior to enrolling as engineering students (BYU-Idaho, 2014b). This study, therefore, should be repeated to discover whether the results are similar at institutions. Whether any difference is from missionary training or simply because of greater age should also be studied. This could be done by comparing students who begin college after two years of missionary work with those of similar age who begin college without performing any missionary service, or by comparing college freshman students straight out of high school with those who simply delay college for a few years.

Summary

The purpose of this study was to assess the instructional design effectiveness of two electrical engineering laboratory modalities by measuring how well they fulfilled the learning objectives of reinforcing theoretical concepts (knowledge), developing transferrable practical skills (skills), and promoting student motivation to continue studying engineering (attitudes) for students in their first engineering laboratory course at a private, medium size university in the Intermountain West. It also investigated whether pairing laboratory partners according to their cognitive ability influenced the achievement of these learning objectives.

This study confirmed that the traditional laboratory and the lab-in-a-box reinforce the same level of knowledge acquisition. Results indicated that students who used the lab-in-a-box were able to transfer their skill at making accurate measurements to bench-top instruments. Furthermore, using the lab-in-a-box did not affect their motivation to continue studying engineering. However, students who used the lab-in-a-box required 13% more time to adapt to unfamiliar bench-top laboratory instruments than students who originally learned how to use traditional bench-top instruments during laboratories.

This study also investigated whether pairing laboratory partners according to their cognitive ability influenced the achievement of these learning objectives. There was no statistically significant difference in knowledge, skill, or attitudes between students who had been paired with a laboratory partner of dissimilar ability (one high and one low) and students who had been paired with a laboratory partner of similar ability (both medium).

However, the effect sizes of the results suggested that students with a high level of ability might be somewhat helpful to students who have a lower level of ability.

This study has presented credible data that helps resolve some on-going debates about the effectiveness of two types of engineering laboratories. If the extra time required to adapt to unfamiliar laboratory instruments is an acceptable trade-off, these findings support the decision of instructional designers to use the lab-in-a-box in situations where traditional laboratories would be difficult or impossible to implement. These situations include constrained on-campus resources and online course offerings that include a laboratory component. This study's experimental design gives it additional weight when compared with quasi-experimental studies in the past that obtained different results (Campbell & Stanley, 1963).

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APPENDIX A

Laboratory 1 with Bench-Top Instruments

ECEN 150 Laboratory Experiment: Basic Laboratory Instruments

Purpose:

1. Learn how to measure resistance, voltage, and current with a multi-meter.

2. Learn how to measure DC voltage with an oscilloscope.

3. Learn how to properly record data in a laboratory notebook and transfer it to the appropriate sections of the lab report.

Procedure:

Note: This procedure is more detailed than those you will receive in the future. The laboratory assignment will normally state *what* you should do, but not always give the details of *how* to do it. *This time*, you will be given the details of what to write in your laboratory notebook and what to include in your formal laboratory report. In general, the procedure section of your formal laboratory report should include instructions on *how* to perform any new operations that have not been done in a previous laboratory experiment.

1. Using a *pen*, mark the first page "page 1" or simply "1" and keep numbering them sequentially as each page is filled. After you fill a page, or quit for the day, sign your name and put the date at the end of your entries. *Always use a pen* to write in your laboratory notebook. If you make a mistake, simply cross it out, write the correct information, then initial and date the correction.

More information about your laboratory notebook can be found at http://courses.byui.edu/ECEN150/RLO/Course/LabNotebookReqs.pdf

2. Label page 1 in your laboratory notebook as "Basic Laboratory Instruments."

This is where you will start recording all the data you will need to write your formal laboratory report about this experiment.

More information about your laboratory report can be found at
http://courses.byui.edu/ECEN150/RLO/Course/LabReportFormat.pdf

See an example laboratory report at
http://courses.byui.edu/ECEN150/RLO/Course/ExampleLabReport.pdf

3. You will need three 1/2 W resistors for this experiment: 220 Ω, 3.3 kΩ, and 47 kΩ.

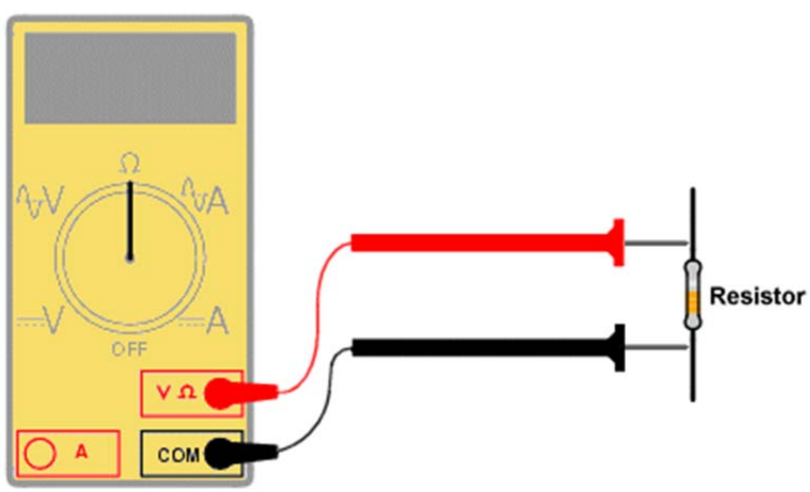
Record the nominal value (color code value) of each resistor in your laboratory notebook.

(You will later list this information as *calculated or expected data* in your formal laboratory report.)

Note: Verify the color code. Resistors are sometimes put in the wrong package or storage unit and will not be the value stated on the label.

4. Use a digital multi-meter (DMM) to measure the actual resistance of each resistor.

Caution: Resistance measurements must be made with the *power source disconnected*.



Using a multimeter to measure the resistance of a circuit component

Note: If you forgot how to do this, read the instructions at
http://learn.adafruit.com/multimeters/resistance

(You should provide details about *how* to do this in the *procedure* of your formal laboratory report because this is the first experiment where resistance is measured. In the future, you will not be required to explain *how* to make this measurement. You may want to make some notes in your laboratory notebook to remind you of what to write in your laboratory report.)

See an example laboratory report, with the expanded procedure, at http://courses.byui.edu/ECEN150/RLO/Course/ExampleLabReport.pdf

5. Record the actual resistance of each resistor in your laboratory notebook.

(You will later list this information as *measured or actual data* in your formal laboratory report.)

Repeat steps 6 through 16 for each of the three resistors:

6. Connect 5 VDC across the resistor.

Note: The DC power supplies on the laboratory benches in the Austin Building have current limiting. This can be used to prevent the fuse in the DMM from blowing out if you accidentally connect it incorrectly when it is configured to measure current. (Remember: *Never connect a current meter in parallel* with a resistor!) Follow these steps to adjust the current limit to 100 mA:

(6a) Connect a black clip-lead to the black output jack of one of the two adjustable outputs.

(6b) Connect a red clip-lead to the red output jack of the same power supply output.

(There will be a green output jack between the black and red output jacks.)

(6c) Turn the current adjustment knob *and* the voltage adjustment knob for the connected outputs fully counter-clockwise (off). The display should read zero.

(6d) Connect the red and black clips together. This creates a short circuit.

(6e) Turn the current adjustment knob clockwise until the display reads 0.10 Amps. This will be the maximum current that will be allowed to flow in your circuit. It is not enough to blow the fuse in The DMM.

(6f) Disconnect the black clip from the red clip.

(6g) Turn the voltage adjustment knob clockwise until the display reads 5 Volts.

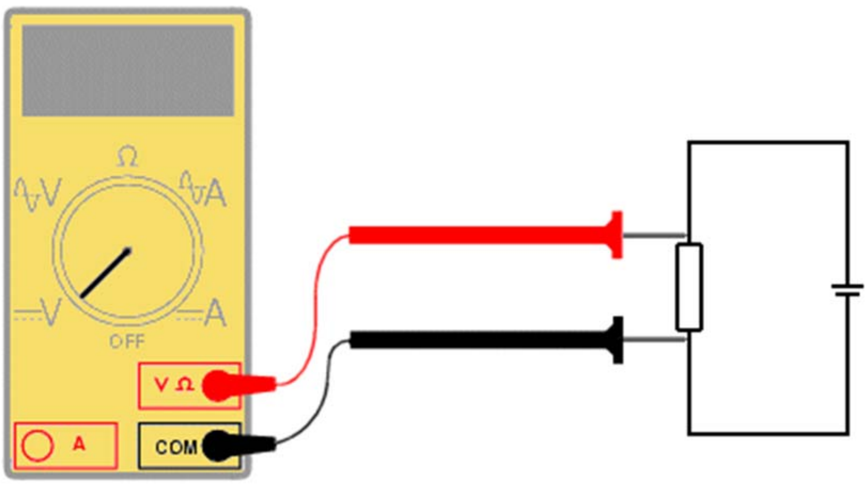
(You should provide details about *how* to do this in the *procedure* of your formal laboratory report because this is the first experiment where the power supply is used.)

7. Draw the schematic diagram for this circuit in your laboratory notebook.

(This will go in the *schematic diagrams* section of you formal laboratory report.)

8. Use a digital multi-meter (DMM) to measure the actual voltage across the resistor.

Connect the meter *in parallel* with the resistor to measure voltage.



Using a multimeter to measure the voltage across a circuit component

Note: If you forgot how to do this, read the instructions at http://learn.adafruit.com/multimeters/voltage

(You should provide details about *how* to do this in the *procedure* of your formal laboratory report because this is the first experiment where voltage is measured.)

9. Record the actual voltage of each resistor in your laboratory notebook.

(You will later list this information as *measured or actual data* in your formal laboratory report.)

10. Using the nominal resistance (color code value) of the resistor, calculate the expected current through the resistor.

(You should provide details about *how* to calculate this in the *procedure* of your formal laboratory report.)

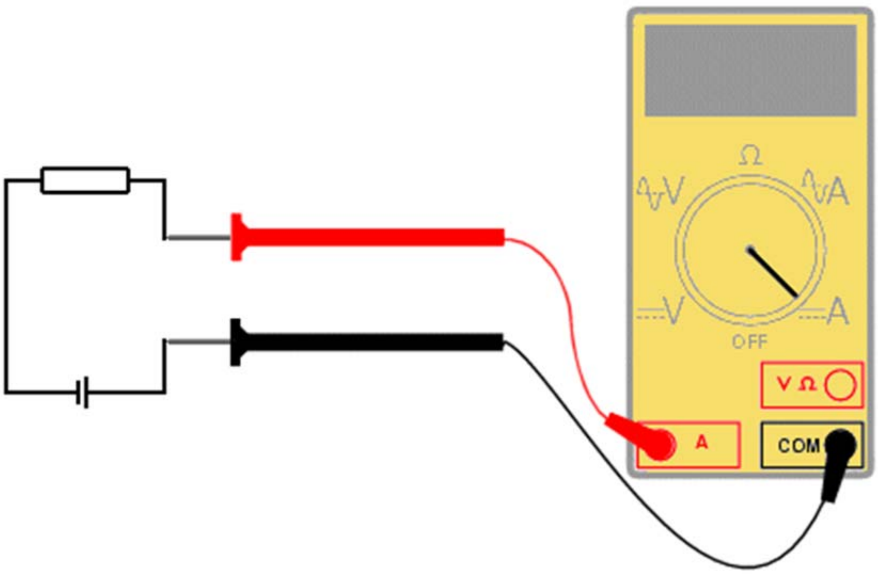
11. Record the calculated current through the resistor in your laboratory notebook.

(You will later list this information as *calculated or expected data* in your formal laboratory report.)

12. Use a digital multi-meter (DMM) to measure the actual current through the resistor.

Connect the meter *in series* with the resistor to measure current.

Caution: *Never* connect test leads *across* a component when the red lead is plugged into a socket marked "A", "mA", or "µA", which are often yellow! This will blow the internal fuse. Instead, connect the test leads *between* the resistor and the power supply, as shown below.



Using a multimeter to measure the current through a circuit

Note 1: If you forgot how to do this, read the instructions at http://learn.adafruit.com/multimeters/current

Note 2: If a measurement cannot be obtained, the fuse in your meter may be blown. Ask a Lab Assistant for a new fuse. If a new is not available, determine the measured value of the current by dividing the *measured voltage* across the resistor by the *measured resistance* of the resistor.

(You should provide details about *how* to do this in the *procedure* of your formal laboratory report.)

13. Record the actual current of each resistor in your laboratory notebook.

(You will later list this information as *measured or actual data* in your formal laboratory report.)

14. Using the *calculated or expected* values of the resistor, calculate its expected power consumption.

Is the power rating of the resistor sufficient to handle the actual power consumption?

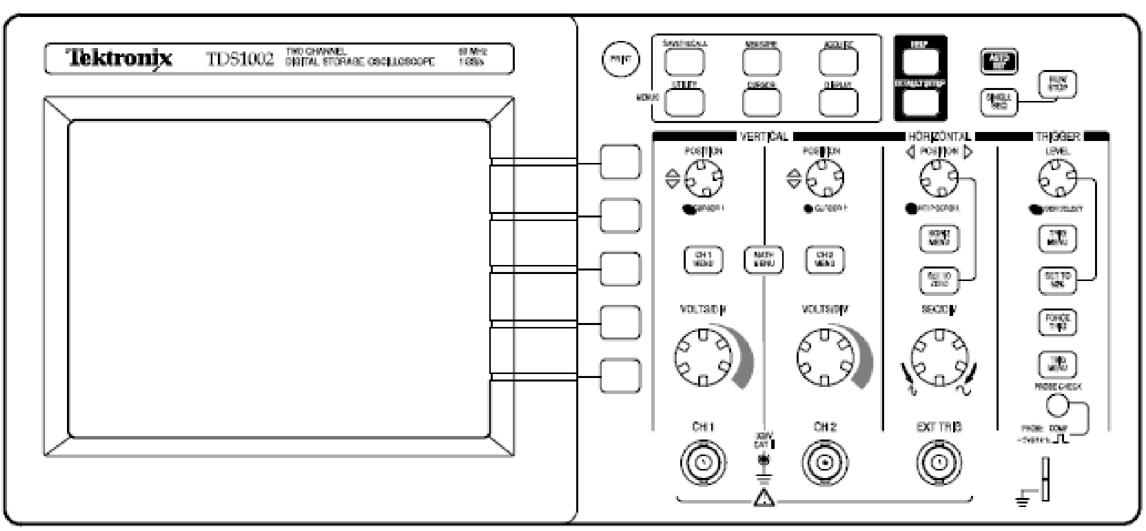
(You should provide details about *how* to calculate this in the *procedure* of your formal laboratory report.)

15. Use an oscilloscope to measure the actual DC voltage across the resistors.

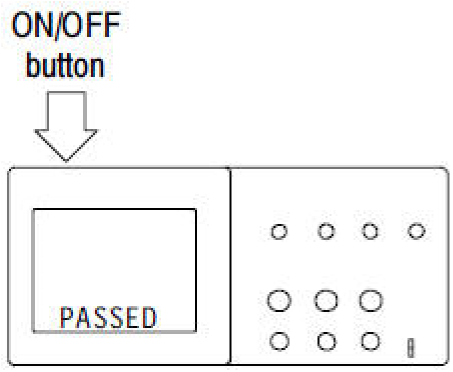
The oscilloscope is used mostly to measure changing voltages, but it can measure a constant voltage, like 5 VDC, as well.

The User Manual for the Tektronix TDS 2000 series oscilloscope can be found at http://courses.byui.edu/ECEN150/RLO/LabInstruments/TDSUserManual.pdf Look at "Functional Check" on page 5 and "Taking Simple Measurements" on page 42.

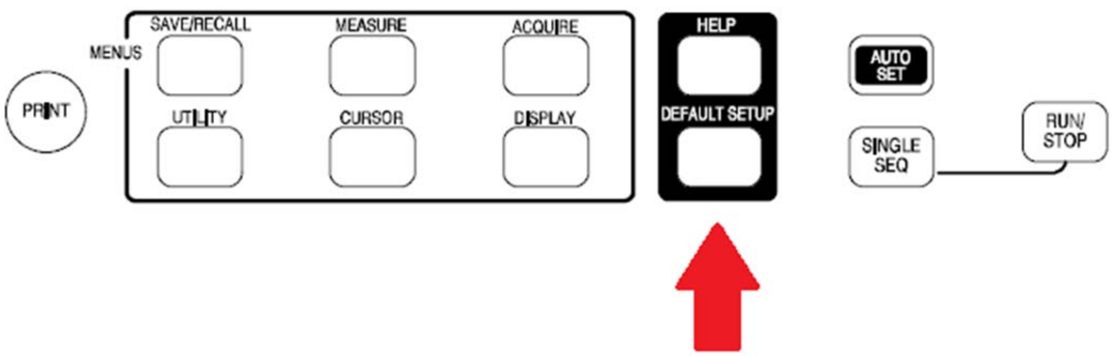
Instructions for the TDS 2000 Series Oscilloscope in the Austin Building:



(15a) Power on the oscilloscope. Wait until the display shows that all power-on tests passed.



(15b) Push the DEFAULT SETUP button.

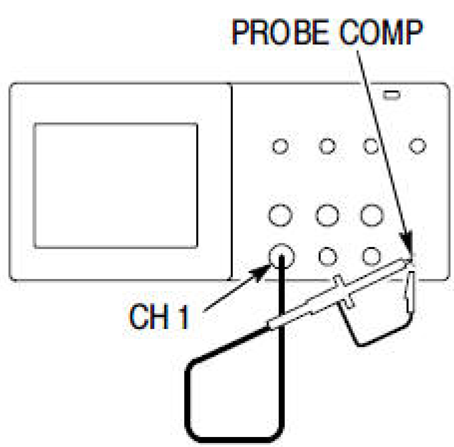


(15c) The default attenuation setting for the oscilloscope is 10X. Set the switch on the oscilloscope probe to 10X.

(15d) Connect the probe to the oscilloscope. Do this by aligning the slot in the BNC connector with the key on the CH 1 BNC of the oscilloscope.

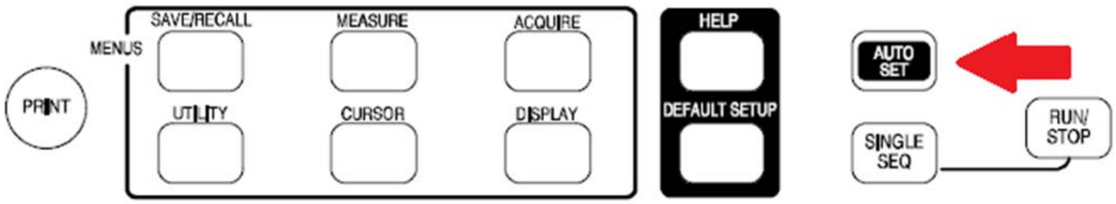
Push to connect, and twist to the right to lock the probe in place.

(15e) Connect the probe tip to the 5V *PROBE COMP* connector and the ground clip (small alligator clip) to the ground *PROBE COMP* connector on the oscilloscope.

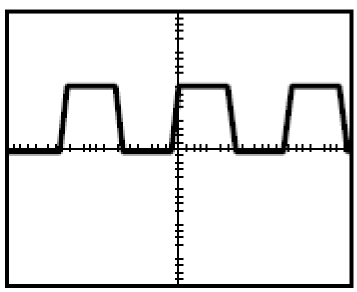


(15f) Push the *AUTOSET* button.

The Autoset function obtains a stable waveform display for you. It automatically adjusts the vertical scale, horizontal scale and trigger settings. Autoset also displays several automatic measurements in the graticule area, depending on the signal type.



Within a few seconds, you should see a square wave in the display of about 5 V peak-to-peak at 1 kHz.



The oscilloscope is functioning properly and is now ready to make a voltage measurement.

(15g) Connect the probe tip to the positive side of the resistor and the reference lead (small alligator clip) to the negative side.

(15h) Push the *AUTOSET* button.

The oscilloscope sets the vertical, horizontal, and trigger controls automatically.

If you want to optimize the display of the waveform, you can manually adjust these controls.

(You should provide details about *how* to do this in the *procedure* of your formal laboratory report because this is the first experiment where DC voltage is measured with an oscilloscope.)

Note: If you need more help doing this, here are some additional resources:

A short video clip that demonstrates how to use a digital oscilloscope with an LCD display can be seen at
http://courses.byui.edu/ECEN150/RLO/LabInstruments/Oscilloscope.html

Most digital oscilloscopes have similar controls and menus, but the details may be slightly different from those shown.

A short video clip that shows the same controls and menus as the TDS 2000 Series digital oscilloscopes on the laboratory benches in the Austin Building can be seen at
http://courses.byui.edu/ECEN150/RLO/LabInstruments/TekDigitalScope.html
(No audio.)

A short video clip that demonstrates how to use an analog oscilloscope with a CRT display can be seen at
http://courses.byui.edu/ECEN150/RLO/LabInstruments/TekAnalogScope.html M
ost analog oscilloscopes have similar controls, but the layout may be slightly different from those shown.

(You should provide details about *how* to do this in the *procedure* of your formal laboratory report because this is the first experiment where DC voltage is measured with an oscilloscope.)

16. Sketch the displayed voltage in your in your laboratory notebook. If you are using a digital oscilloscope, you can download the display to your computer for inclusion in your laboratory report. Otherwise, take a digital photograph of the displayed voltage for your laboratory report.

(This information will be *measured or actual data* in your formal laboratory report.)

Repeat steps 6 through 16 for each of the other two resistors:

17. Turn off the multi-meter, oscilloscope, and power supply. Put your other equipment and supplies away. Make sure the lab station is clean and ready for the next student.

18. Compare your *calculated data* to your *measured data*.

Discussion & Conclusions:

What conclusions can you make? Start with these:

Why are your expected data a little different from your actual data?

What are the advantages and disadvantages of the multi-meter and the oscilloscope?

How would you choose which one to use for future measurements?

Refer to the caution message at step 12; why does the fuse blow when you do this?

(Record your conclusions in the *discussion & conclusion* section of your laboratory report.)

APPENDIX B

Laboratory 1 with myDAQ Instruments

ECEN 150 Laboratory Experiment: Basic Laboratory Instruments (myDAQ)

Purpose:

1. Learn how to measure resistance, voltage, and current with a multi-meter.

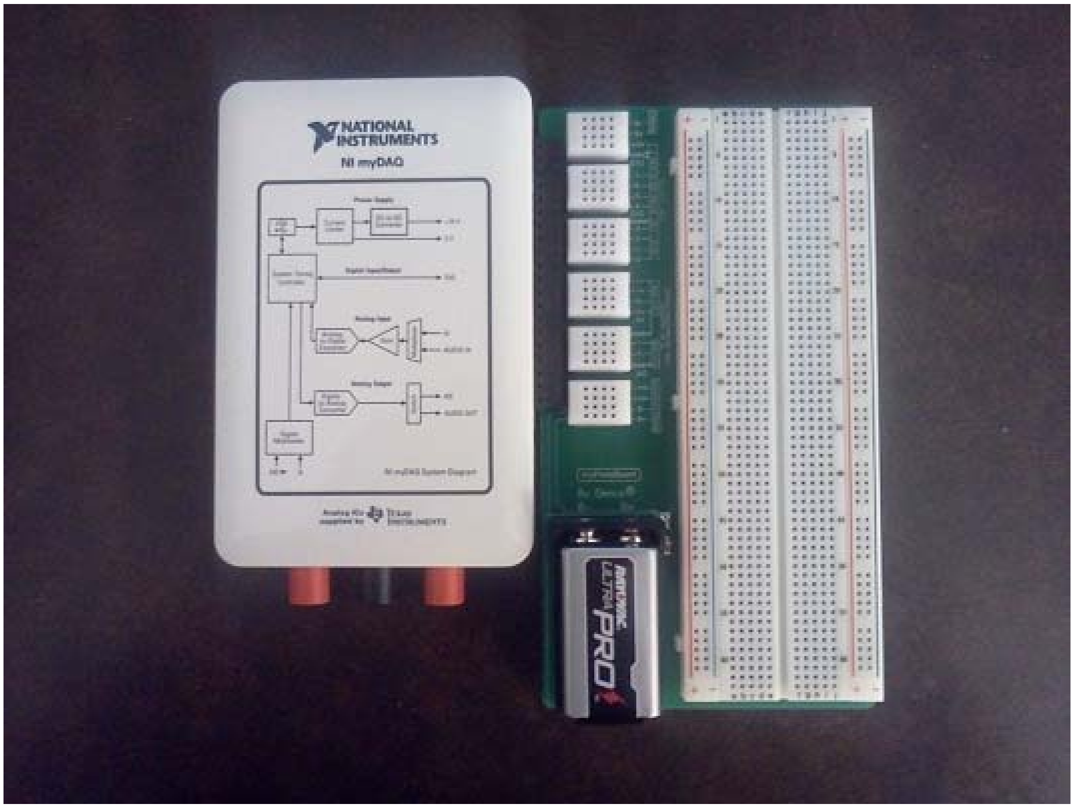
2. Learn how to measure DC voltage with an oscilloscope.

3. Learn how to properly record data in a laboratory notebook and transfer it to the appropriate sections of the lab report.

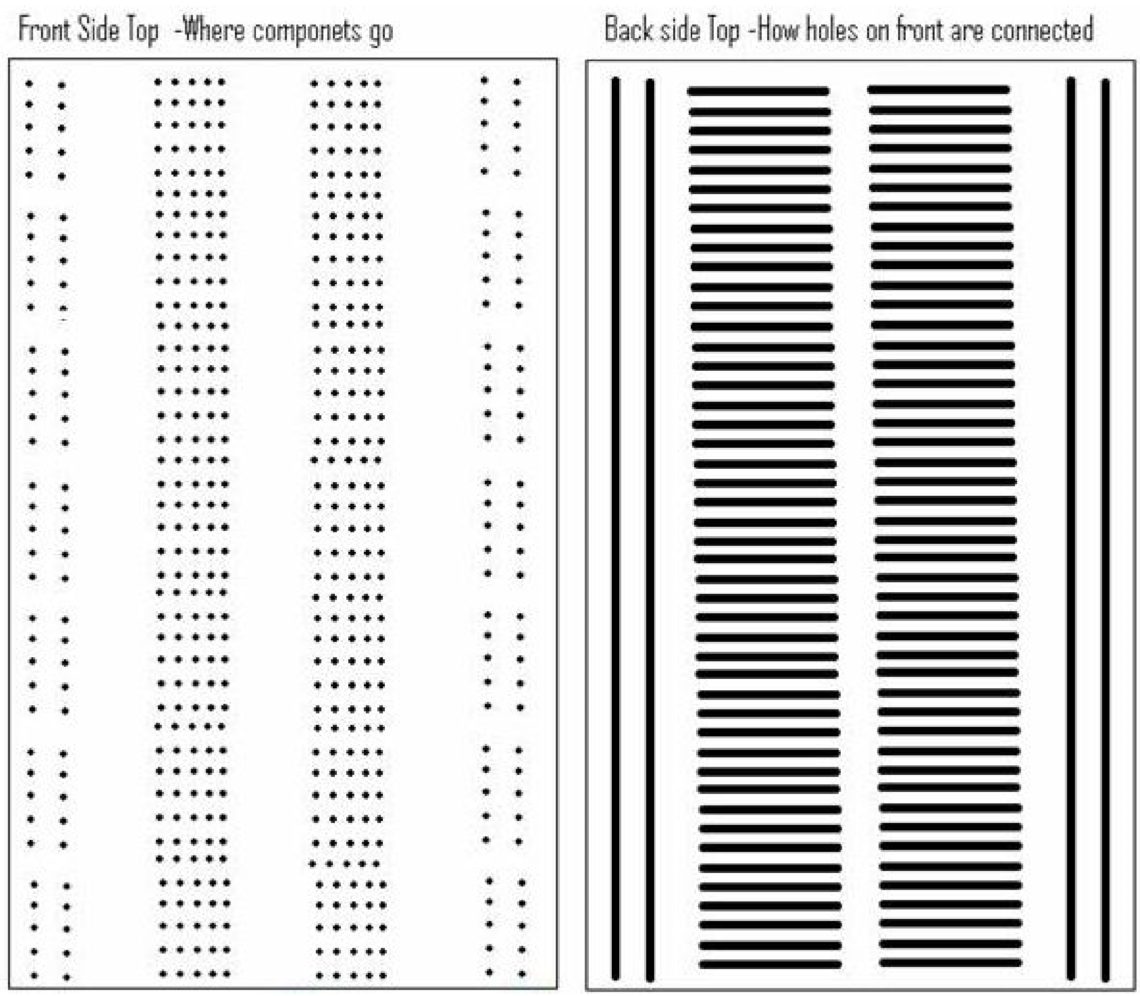
Important Information about the myDAQ:

The myDAQ DMM provides functions for measuring resistance, voltage (DC and AC), and current (DC and AC). DMM measurements are software-timed, so update rates are affected by the load on the computer and USB activity.

Before using the myDAQ with this laboratory experiment, attach the protoboard, as shown below.



The wire connectors (holes) in the protoboard are arranged as shown in the diagram below.



Detailed instructions for using it are in the myDAQ User Guide at http://courses.byui.edu/ECEN150/RLO/LabInstruments/NImyDAQ_UserGuide.pdf

Setting up your myDAQ: http://zone.ni.com/devzone/cda/tut/p/id/11431

Using myDAQ instruments: http://zone.ni.com/devzone/cda/tut/p/id/11420

Procedure:

Note: This procedure is more detailed than those you will receive in the future. The laboratory assignment will normally state *what* you should do, but not always give the details of *how* to do it. *This time*, you will be given the details of what to write in your laboratory notebook and what to include in your formal laboratory report. In general, the procedure section of your formal laboratory report should include instructions on *how* to perform any new operations that have not been done in a previous laboratory experiment.

1. Using a *pen*, mark the first page "page 1" or simply "1" and keep numbering them sequentially as each page is filled. After you fill a page, or quit for the day, sign your name and put the date at the end of your entries. *Always use a pen* to write in your laboratory notebook. If you make a mistake, simply cross it out, write the correct information, then initial and date the correction.

More information about your laboratory notebook can be found at
http://courses.byui.edu/ECEN150/RLO/Course/LabNotebookReqs.pdf

2. Label page 1 in your laboratory notebook as "Basic Laboratory Instruments."

This is where you will start recording all the data you will need to write your formal laboratory report about this experiment.

More information about your laboratory report can be found at
http://courses.byui.edu/ECEN150/RLO/Course/LabReportFormat.pdf

See an example laboratory report at
http://courses.byui.edu/ECEN150/RLO/Course/ExampleLabReport.pdf

3. You will need three 1/2 W resistors for this experiment: 220 Ω, 3.3 kΩ, and 47 kΩ.

Record the nominal value (color code value) of each resistor in your laboratory notebook.

(You will later list this information as *calculated or expected data* in your formal laboratory report.)

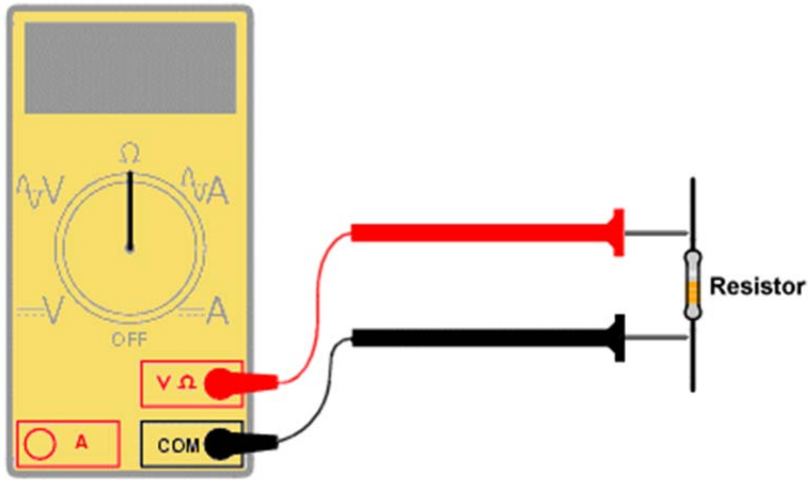
Note: Verify the color code. Resistors are sometimes put in the wrong package or storage unit and will not be the value stated on the label.

4. Use a digital multi-meter (DMM) or the myDAQ to measure the actual resistance of each resistor.

(You should provide details about *how* to do this in the *procedure* of your formal laboratory report because this is the first experiment where resistance is measured. In the future, you will not be required to explain *how* to make this measurement. You may want to make some notes in your laboratory notebook to remind you of what to write in your laboratory report.)

DMM:

Resistance measurements must be made with the *power source disconnected*.



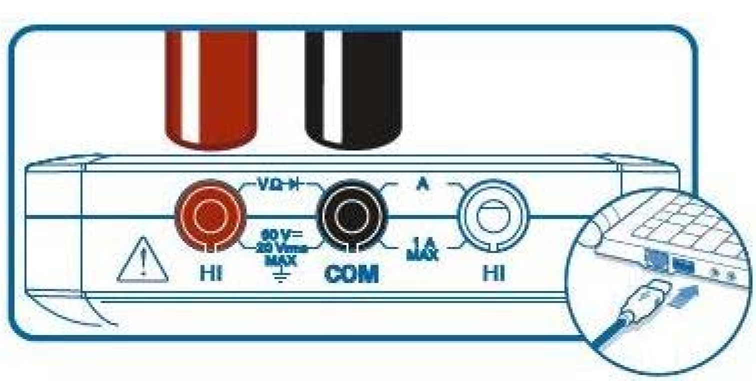
Using a multimeter to measure the resistance of a circuit component

Read the instructions at http://learn.adafruit.com/multimeters/resistance or watch the video at
http://courses.byui.edu/ECEN150/RLO/LabInstruments/MultimeterOverview.html
if you need help doing this.

myDAQ:

Instructions for using the myDAQ DMM are at
http://zone.ni.com/devzone/cda/tut/p/id/11501

Connect the meter probes as shown in the diagram below.

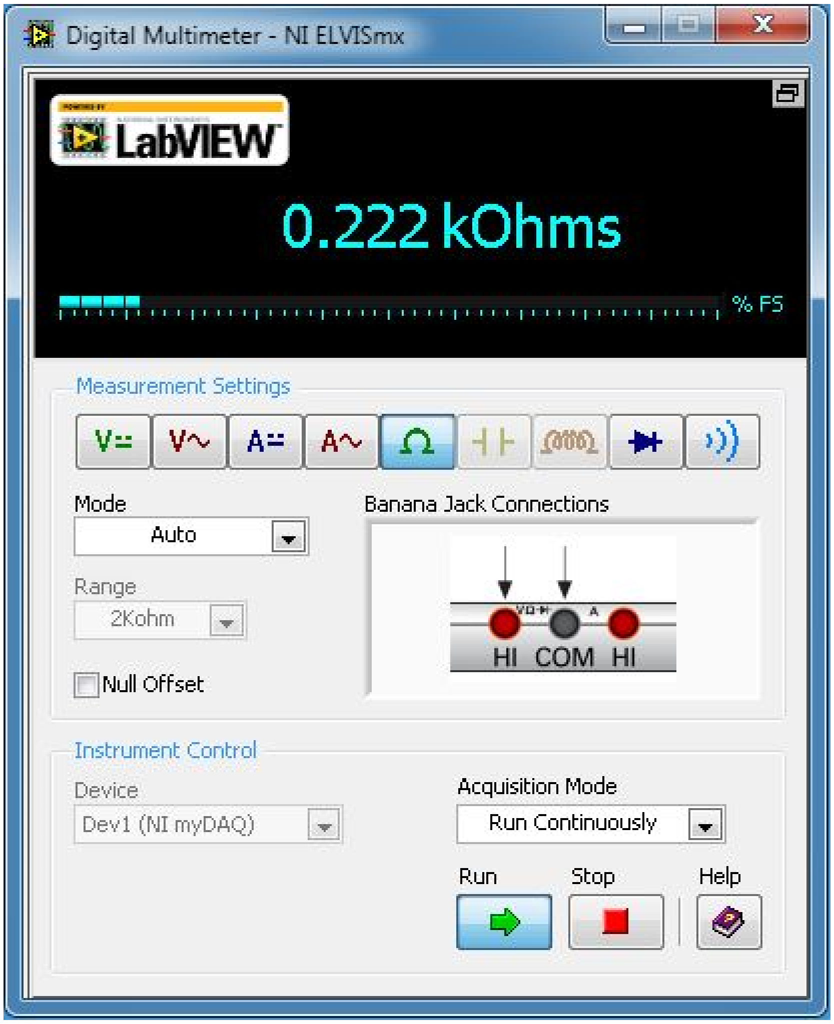


Select "Ω" under "Measurement Settings."

If you set the Mode to "Specify Range", set the Range to "2 Kohm." (Selecting the range manually will speed up the measurement.)

If you set the Mode to "Auto", the range will be selected automatically when you make your resistance measurement. (It will take a little longer for the myDAQ to determine the correct range automatically than if you set it manually.)

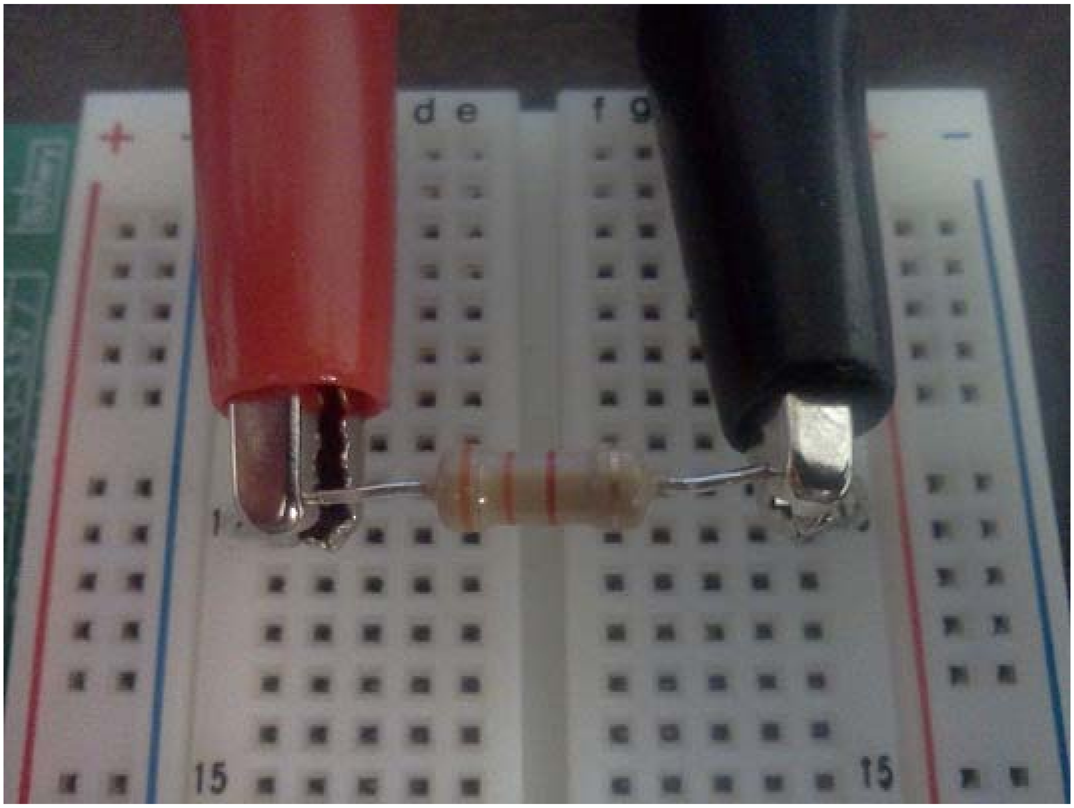
Set the Acquisition Mode to "Run Continuously."



Click on "Run."

Resistance measurements must be made with the *power source disconnected*.

Hold the red probe on one side of the resistor and the black probe on the other side to make this measurement. This is much easier if you obtain test leads with alligator clips as shown below.



More detailed instructions for doing this are in the myDAQ User Guide at http://courses.byui.edu/ECEN150/RLO/LabInstruments/NImyDAQ_UserGuide.pdf

5. Record the actual resistance of each resistor in your laboratory notebook.

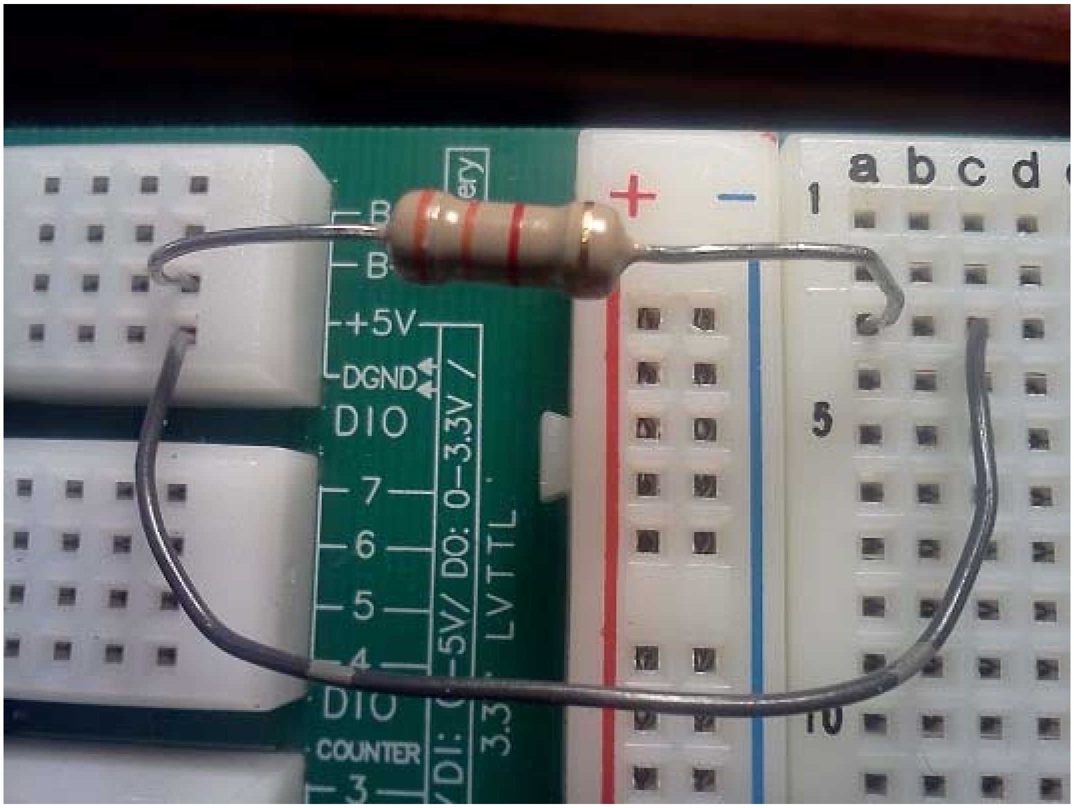
(You will later list this information as *measured or actual data* in your formal laboratory report.)

Repeat steps 6 through 16 for each of the three resistors:

6. Connect 5 VDC across the resistor.

(You should provide details about *how* to do this in the *procedure* of your formal laboratory report because this is the first experiment where the power supply is used.)

The picture below shows one end of the resistor connected to the "+5V" output of the myDAQ. The other end *could* plug directly into the "DGND" (ground) connector, but it is much easier to make measurements if the resistor is connected to a wire that goes back to ground.



7. Draw the schematic diagram for this circuit in your laboratory notebook.

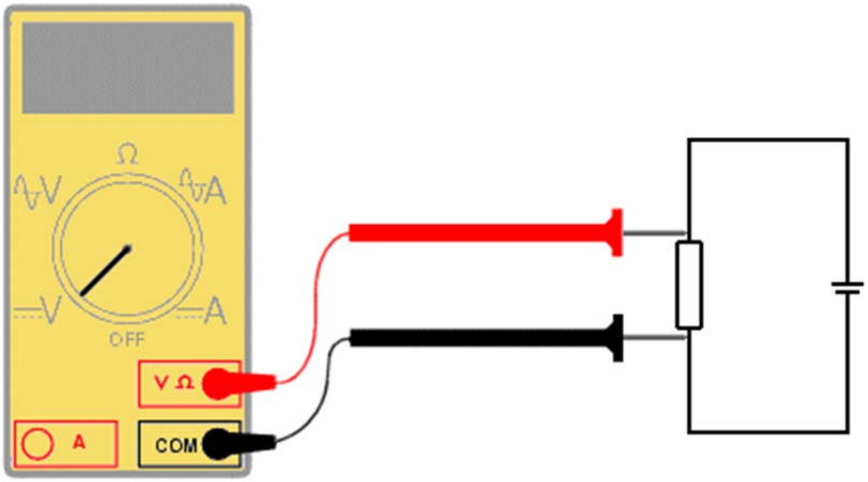
(This will go in the *schematic diagrams* section of you formal laboratory report.)

8. Use a digital multi-meter (DMM) or the myDAQ to measure the actual voltage across the resistor.

(You should provide details about *how* to do this in the *procedure* of your formal laboratory report because this is the first experiment where voltage is measured.)

DMM:

Connect the meter *in parallel* with the resistor to measure voltage.



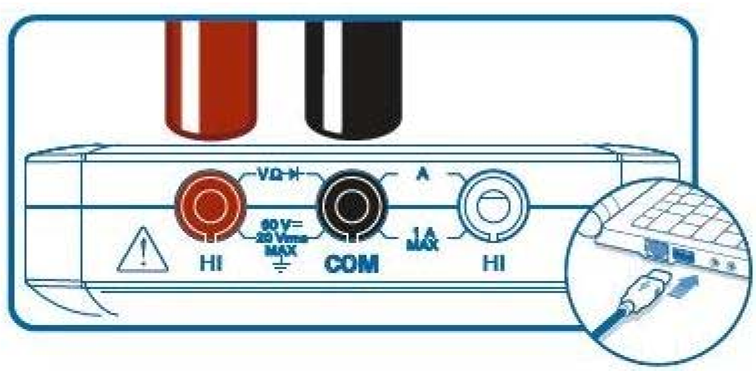
Using a multimeter to measure the voltage across a circuit component

Read the instructions at http://learn.adafruit.com/multimeters/voltage or watch the video at
http://courses.byui.edu/ECEN150/RLO/LabInstruments/MultimeterOverview.html
if you need help doing this.

myDAQ:

Instructions for using the myDAQ DMM are at
http://zone.ni.com/devzone/cda/tut/p/id/11501

Connect the meter probes as shown in the diagram below.

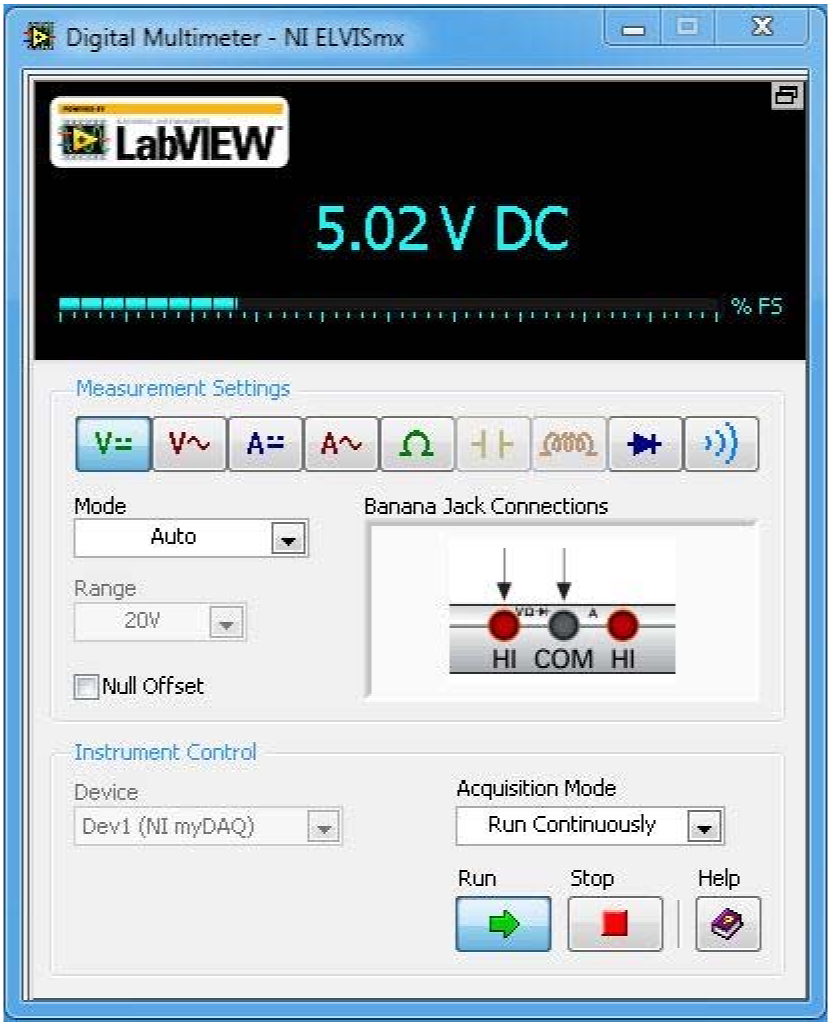


Select "V=" under "Measurement Settings."

If you set the Mode to "Specify Range", set the Range to "20 V." (Selecting the range manually will speed up the measurement.)

If you set the Mode to "Auto", the range will be selected automatically when you make your voltage measurement. (It will take a little longer for the myDAQ to determine the correct range automatically than if you set it manually.)

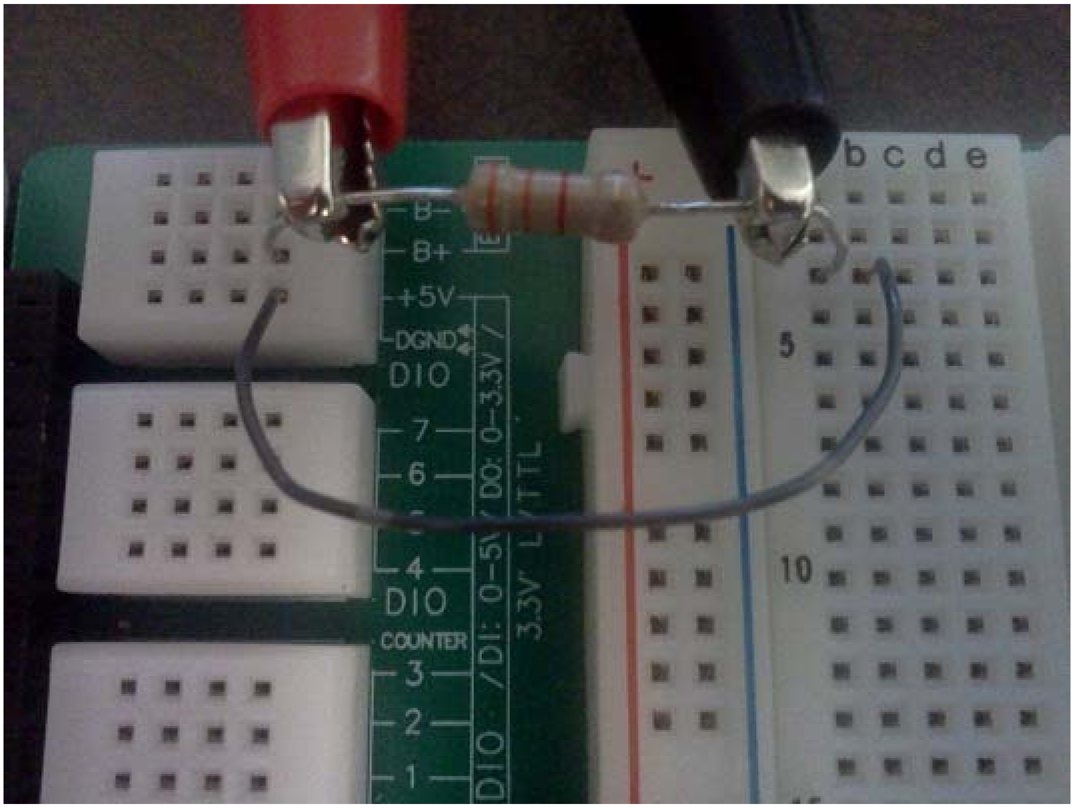
Set the Acquisition Mode to "Run Continuously."



Click on "Run."

Connect the myDAQ *in parallel* with the resistor to measure voltage.

Hold the red probe on the side of the resistor connected to "+5V" and the black probe on the other (ground) side to make this measurement.



More detailed instructions for doing this are in the myDAQ User Guide at
http://courses.byui.edu/ECEN150/RLO/LabInstruments/NImyDAQ_UserGuide.pdf

9. Record the actual voltage of each resistor in your laboratory notebook.

(You will later list this information as *measured or actual data* in your formal laboratory report.)

10. Using the nominal resistance (color code value) of the resistor, calculate the expected current through the resistor.

(You should provide details about *how* to calculate this in the *procedure* of your formal laboratory report.)

11. Record the calculated current through the resistor in your laboratory notebook.

(You will later list this information as *calculated or expected data* in your formal laboratory report.)

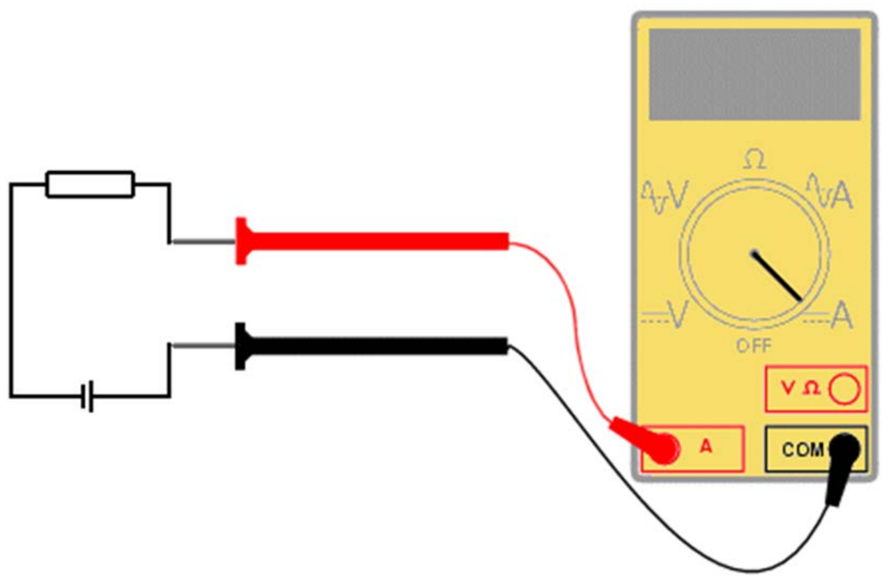
12. Use a digital multi-meter (DMM) or the myDAQ to measure the actual current through the resistor.

(You should provide details about *how* to do this in the *procedure* of your formal laboratory report.)

Caution: *Never* connect test leads *across* a component when the red lead is plugged into a socket marked "A", "mA", or "µA"! This will blow the internal fuse. Instead, connect the test leads *between* the resistor and the power supply, as shown below.

DMM:

Connect the meter *in series* with the resistor to measure current.



Using a multimeter to measure the current through a circuit

Note 1: If you need help doing this, read the instructions at http://learn.adafruit.com/multimeters/current

Note 2: If a measurement cannot be obtained, the fuse in your meter may be blown. If a new one is not available, determine the measured value of the current by dividing the *measured voltage* across the resistor by the *measured resistance* of the resistor.

myDAQ:

Instructions for using the myDAQ DMM are at http://zone.ni.com/devzone/cda/tut/p/id/11501

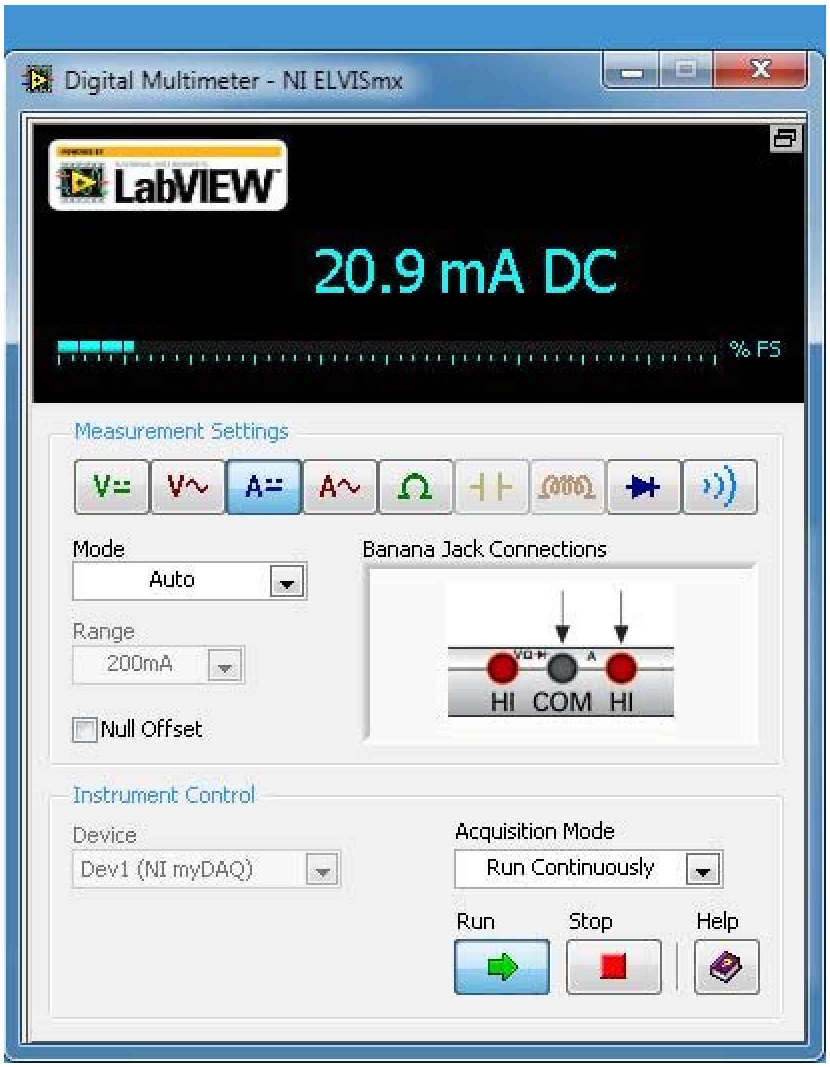
Move the red meter probe to the other red jack (marked "A") on the myDAQ in order to measure current.

Select "A=" under "Measurement Settings."

If you set the Mode to "Specify Range", set the Range to "200 mA." (Selecting the range manually will speed up the measurement.)

If you set the Mode to "Auto", the range will be selected automatically when you make your current measurement. (It will take a little longer for the myDAQ to determine the correct range automatically than if you set it manually.)

Set the Acquisition Mode to "Run Continuously."

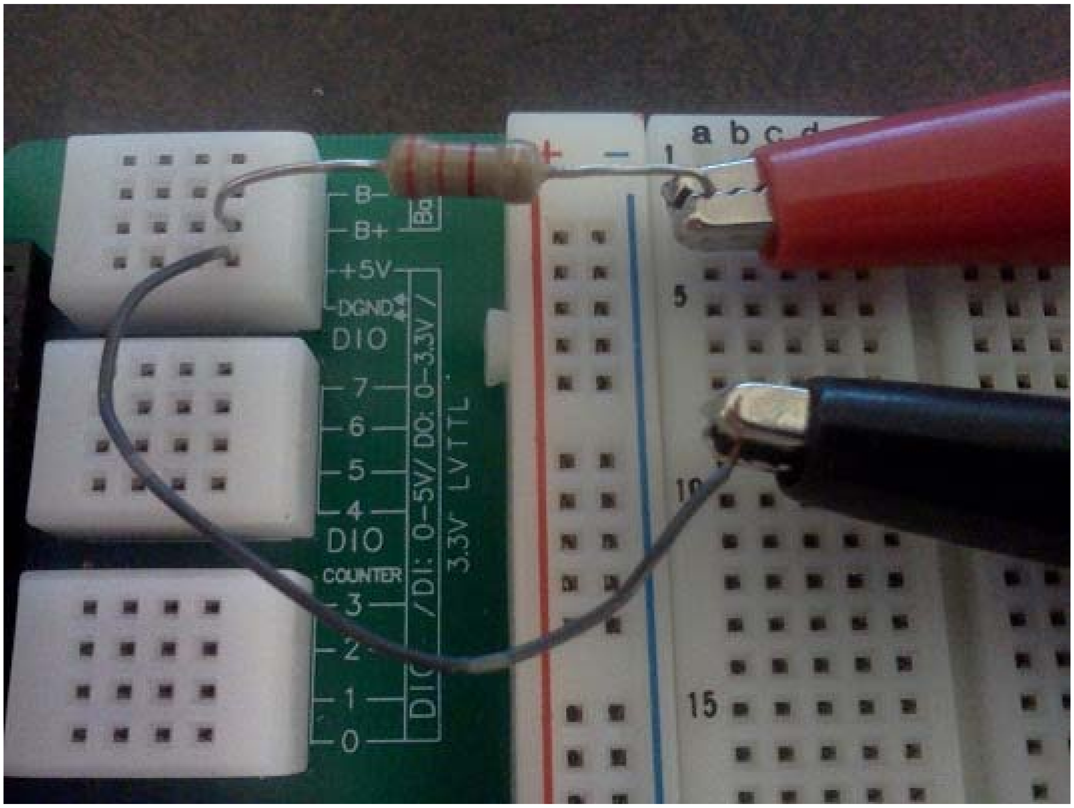


Click on "Run."

Connect the myDAQ *in series* with the resistor to measure current.

Disconnect the ground wire from the resistor. Connect the red test lead to that end of the resistor and the black test lead to the ground wire, as shown below.

This will cause current to flow through the meter on its way back to the voltage source.



Note: If a measurement cannot be obtained, the fuse* in your myDAQ may be blown. Carefully remove the 4 screws holding the case together to change the fuse. If a new one is not available, determine the measured value of the current by dividing the *measured voltage* across the resistor by the *measured resistance* of the resistor.

* Replacement fuse for myDAQ: Internal ceramic fuse, 1.25 A
250 V, fast-acting, 5 × 20 mm
F 1.25A H 250V
(Littelfuse part number 02161.25)

More detailed instructions for doing this are in the myDAQ User Guide at http://courses.byui.edu/ECEN150/RLO/LabInstruments/NImyDAQ_UserGuide.pdf

13. Record the actual current of each resistor in your laboratory notebook.

(You will later list this information as *measured or actual data* in your formal laboratory report.)

14. Using the *calculated or expected* values of the resistor, calculate its expected power consumption.

Is the 1/2 W power rating of the resistor sufficient to handle the actual power consumption?

(You should provide details about *how* to calculate this in the *procedure* of your formal laboratory report.)

15. Use the myDAQ oscilloscope to measure the actual DC voltage across the resistors.

The oscilloscope is used mostly to measure changing voltages, but it can measure a constant voltage, like 5 VDC, as well.

(You should provide details about *how* to do this in the *procedure* of your formal laboratory report because this is the first experiment where DC voltage is measured with an oscilloscope.)

Instructions for using the myDAQ Oscilloscope are at http://zone.ni.com/devzone/cda/tut/p/id/11502

Set the Source of channel 0 to AI 0.

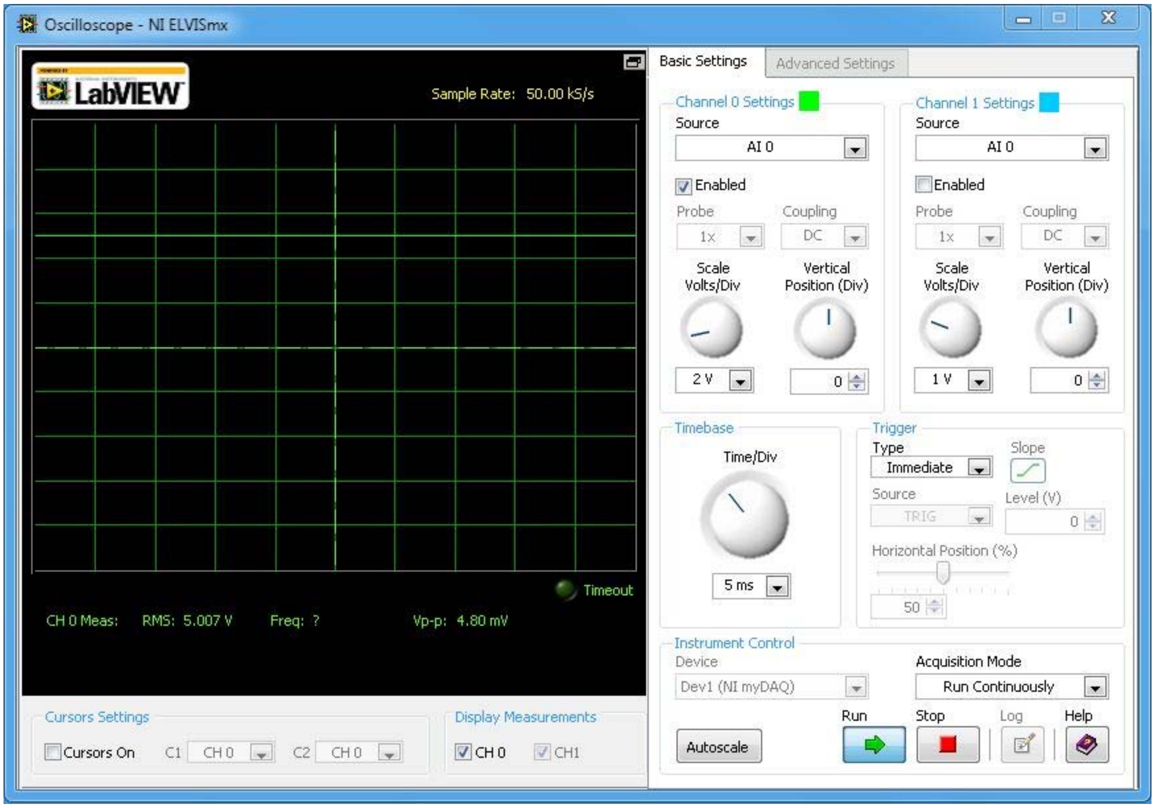
Select the "Enabled" box for channel 0.

Set the Volts/Div scale to 2 V.

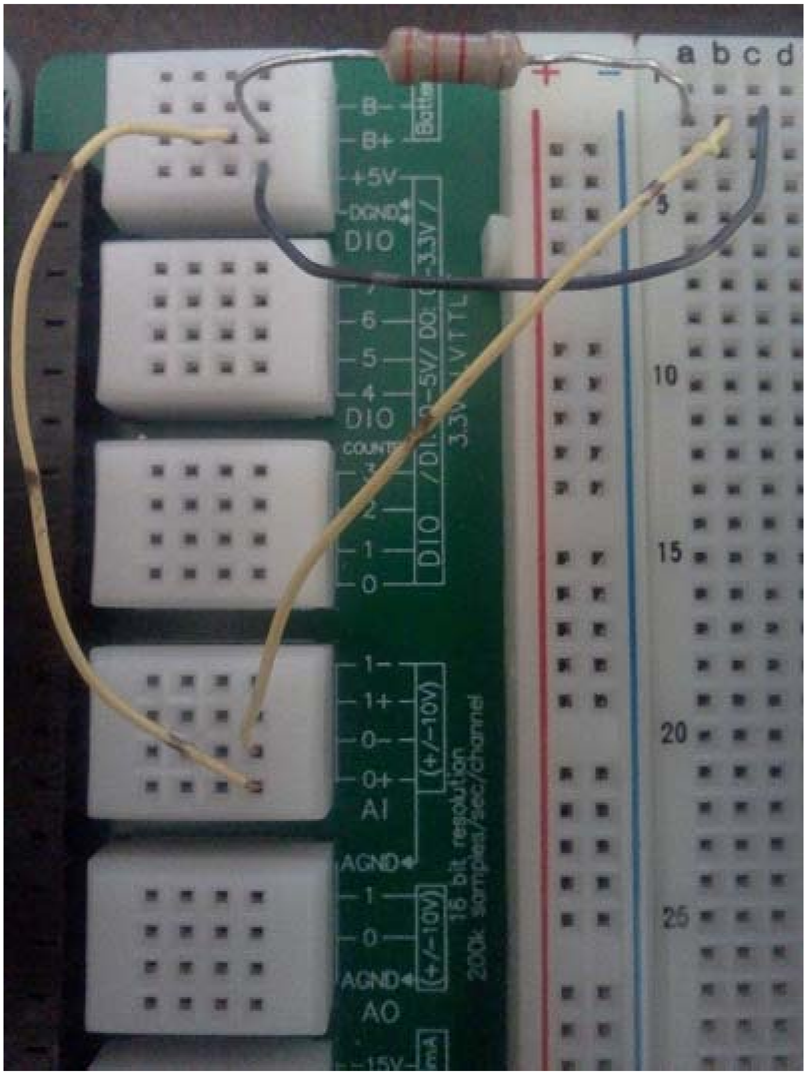
Set the Vertical Position to 0.

For this DC measurement, the Time/Div setting does not matter.

Set the Acquisition Mode to "Run Continuously."



Connect the "AI 0+" (signal) input on the myDAQ protoboard to the positive voltage side of the resistor and the "AI 0 -" (ground) input to the ground side of the resistor to make this measurement. See below.



Click on "Run."

A green line, representing the measured voltage, will appear across the screen 2.5 divisions above the center (0 V) graticule.

Read the voltage as 2.5 divisions * 2 V per division = 5 V.

Select the "CH 0" box under "Display Measurements" to display the RMS (DC equivalent) voltage under the oscilloscope display. Ignore the Freq and Vp-p readings for DC measurements.

More detailed instructions for doing this are in the myDAQ User Guide at http://courses.byui.edu/ECEN150/RLO/LabInstruments/NImyDAQ_UserGuide.pdf

16. Save the displayed screen to a file on your computer for inclusion in your laboratory report.

(This information will be *measured or actual data* in your formal laboratory report.)

Repeat steps 6 through 16 for each of the other two resistors.

17. Compare your *calculated data* to your *measured data*.

Discussion & Conclusions:

What conclusions can you make? Start with these:

Why are your expected data a little different from your actual data?

What are the advantages and disadvantages of the multi-meter and the oscilloscope?

How would you choose which one to use for future measurements?

Refer to the caution message at step 12; why does the fuse blow on a DMM when you do this?

(Record your conclusions in the *discussion & conclusion* section of your laboratory report.)

APPENDIX C

Laboratory 2 with Bench-Top Instruments

ECEN 150 Laboratory Experiment: Sinusoidal Waveforms

Purpose:

1. Learn how to make AC voltage measurements (both magnitude and frequency) with an oscilloscope**.**

2. Learn how to set the wave shape, magnitude, and frequency of a function generator.

3. Learn how to make AC voltage measurements with a DMM.

4. Become more familiar with reading instrument operating manuals.

Procedure:

Note: These instructions are for the Tektronix TDS 2022 digital storage oscilloscope and Tektronix CFG 250 function generator that are used in the Austin Building. Other makes and models have similar controls and menus, but the details may be slightly different from those shown.

1. Turn on the oscilloscope (Figure 1) and get it ready for making measurements.

The User Manual for the Tektronix TDS 2000 series oscilloscope can be found at http://courses.byui.edu/ECEN150/RLO/LabInstruments/TDSUserManual.pdf Loo k at "Functional Check" on page 5 and "Taking Simple Measurements" on page 42.

Instructions for the TDS 2000 Series Oscilloscope:

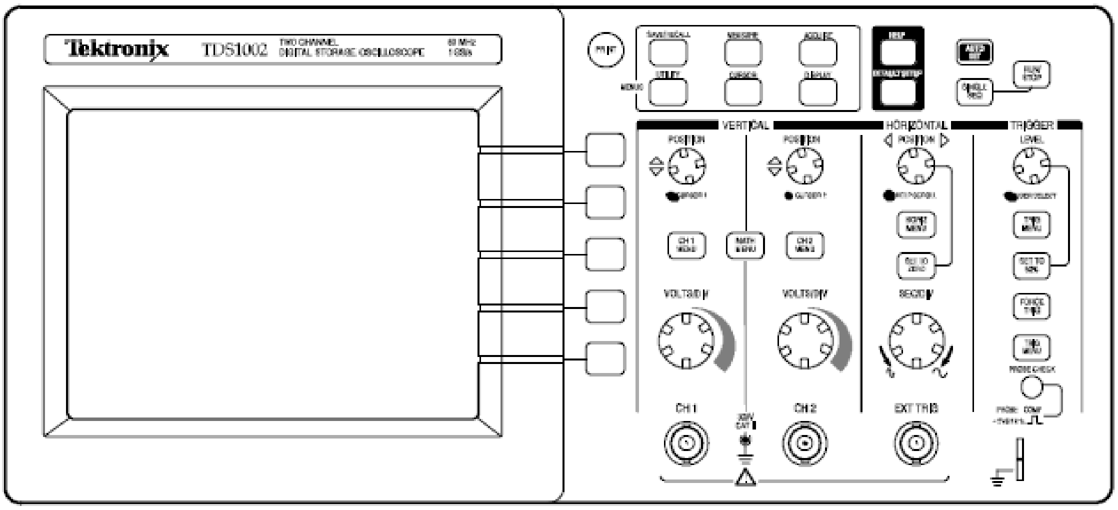
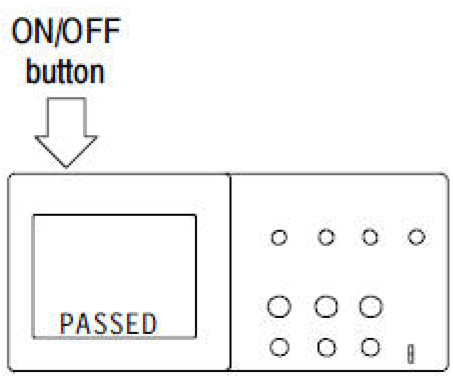
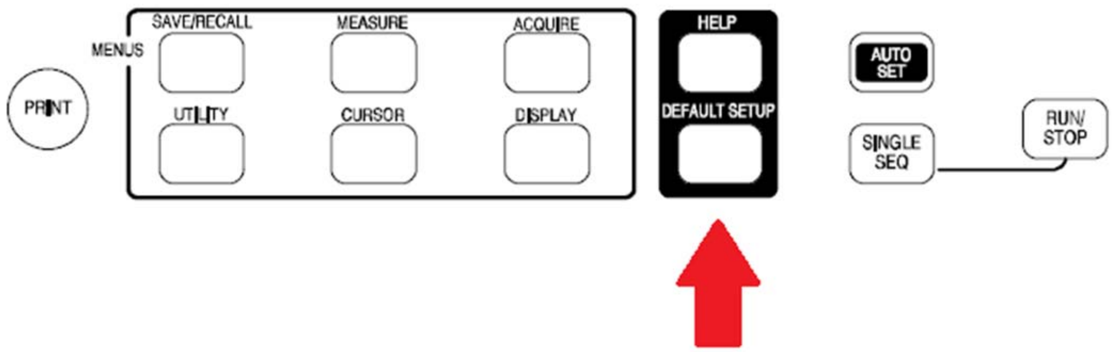


Figure 1: Digital Oscilloscope

(1a) Power on the oscilloscope. Wait until the display shows that all power-on tests passed.



(1b) Push the DEFAULT SETUP button.

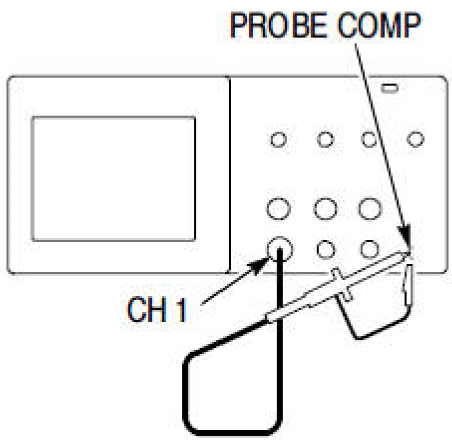


(1c) The default attenuation setting for the oscilloscope is 10X. Set the switch on the oscilloscope probe (Figure 2) to 10X.

Figure 2: Oscilloscope Probe

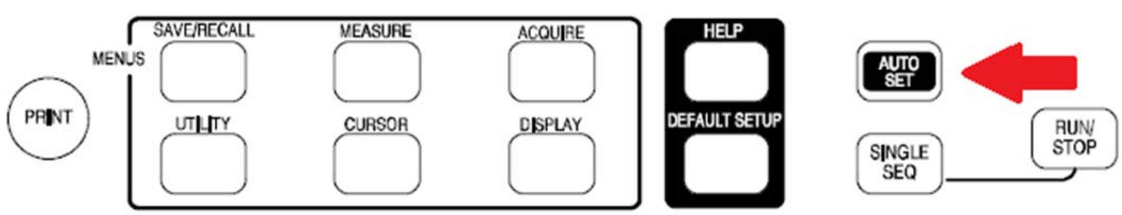
(1d) Connect the probe to the oscilloscope Do this by aligning the slot in the BNC connector with the key on the CH 1 BNC of the oscilloscope. Push to connect, and twist to the right to lock the probe in place.

(1e) Connect the probe tip to the 5V *PROBE COMP* connector and the ground clip (Figure 2) to the ground *PROBE COMP* connector on the oscilloscope.

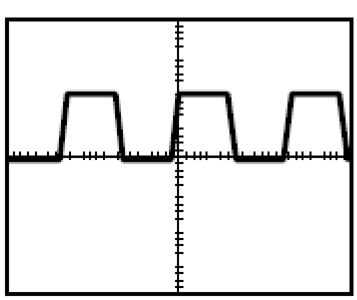


(1f) Push the *AUTOSET* button.

The Autoset function obtains a stable waveform display for you. It automatically adjusts the vertical scale, horizontal scale and trigger settings. Autoset also displays several automatic measurements in the graticule area, depending on the signal type.



Within a few seconds, you should see a square wave in the display of about 5 V peak-to-peak at 1 kHz.



The oscilloscope is functioning properly and is now ready to make a voltage measurement.

Additional Oscilloscope References:

A short video clip that demonstrates how to use a digital oscilloscope with an LCD display can be seen at http://courses.byui.edu/ECEN150/RLO/LabInstruments/Oscilloscope.html Most digital oscilloscopes have similar controls and menus, but the details may be slightly different from those shown.

A short video clip that shows the same controls and menus as the TDS 2000 Series digital oscilloscopes on the laboratory benches in the Austin Building can be seen at http://courses.byui.edu/ECEN150/RLO/LabInstruments/TekDigitalScope.html (N o audio.)

A short video clip that demonstrates how to use an analog oscilloscope with a CRT display can be seen http://courses.byui.edu/ECEN150/RLO/LabInstruments/TekAnalogScope.html M ost analog oscilloscopes have similar controls, but the layout may be slightly different from those shown.

2. Turn on the function generator (Figure 3).

The User Manual for the Tektronix CFG 250 Function Generator can be found at http://courses.byui.edu/ECEN150/RLO/LabInstruments/CFGUserManual.pdf Loo k at "Operation" in Section 2.

Instructions for the CFG 250 Function Generator:

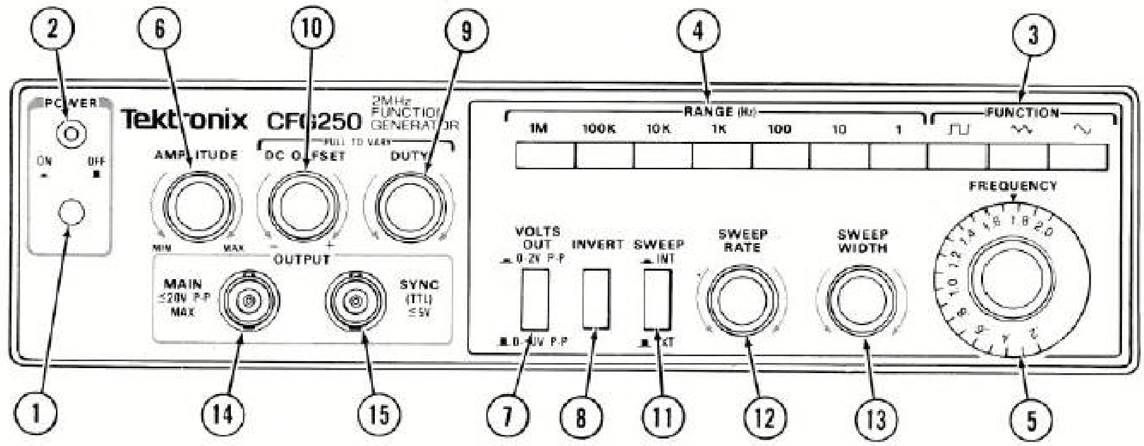


Figure 3: Function Generator

(2a) Power on the function generator by pushing the red button (#1 in Figure 3). The power indicator (#2) will illuminate.

(2b) Adjust the following control knobs to the approximate center of their range:

Amplitude (#6)

DC Offset (#10)

Duty Cycle (#9)

Sweep Rate (#12)

Sweep Width (#13)

(2c) Make sure the following buttons are NOT pushed in:

Volts Out (#7)

Invert (#8)

Sweep (#11)

3. Configure the function generator to output a 400 Hz sine wave.

(3a) Select the sine wave function (#3).

(3b) Set the frequency to 400 Hz by turning the frequency dial (#5) to 0.4 and pushing the 1 kHz Range button (#4).

4. Connect the BNC end of the function generator lead (Figure 4) to the output of the function generator (#14 in Figure 3).

Figure 4: Function Generator Lead

5. Connect the alligator clips of the function generator lead to an 8 ohm speaker. You will hear a tone.

6. Connect the oscilloscope probe tip to the same speaker connector as the signal (red) clip of the function generator clip, and connect the oscilloscope ground clip to the ground (black) clip of the function generator lead.

WARNING: It is very important to ALWAYS connect the oscilloscope ground clip to the function generator's ground clip. Both of these ground clips are connected together through the power cords and building wiring. If they are not connected to the same point, a short circuit will result.

7. Push the *AUTOSET* button on the oscilloscope.

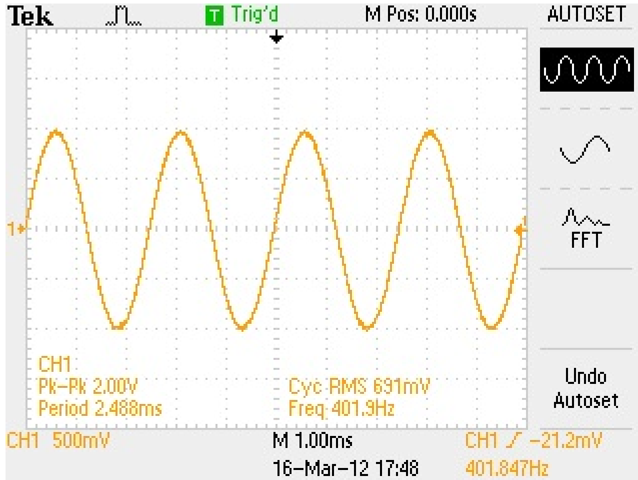
The oscilloscope sets the vertical, horizontal, and trigger controls automatically.

If you want to optimize the display of the waveform, you can manually adjust these controls.

The vertical size of the wave form is controlled with the VOLTS/DIV knob.

The horizontal size of the wave form is controlled with the SEC/DIV knob.

8. Adjust the amplitude knob on the function generator and notice the difference in speaker volume. Then use the oscilloscope to set the output voltage to about 2 Vpp. (The amplitude is not critical. If the volume of the tone is too loud, attenuate the amplitude as necessary to a comfortable level. Simply record the *actual* voltage.)



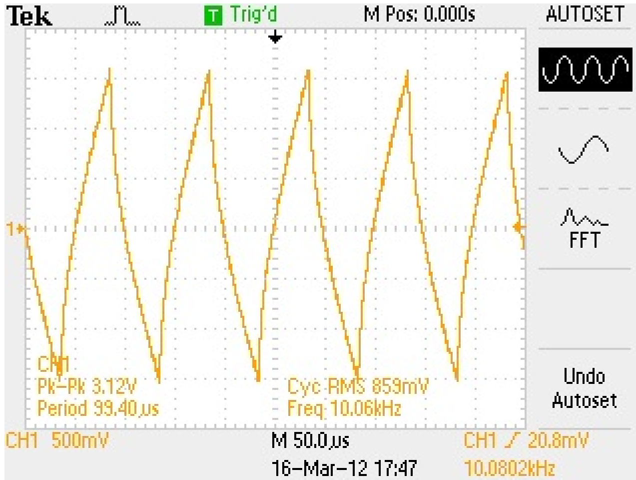
9. Adjust the frequency dial on the function generator to get an output frequency as close to 400 Hz as you can. Use the Tektronix "OpenChoice Desktop" software to record an image of the display or take a digital photo of the display for your lab report.

10. Reduce the frequency of the signal to 60 Hz. The speaker will sound like a motor boat. You may need to adjust the SEC/DIV knob for a good display. (If you cannot hear anything, use a slightly higher frequency, such as 100 Hz.)

11. Change the signal to a square wave. Why does the speaker sound different? Include your answer in your laboratory report.

12. Change the signal to a triangle wave. Why does the speaker again sound different? Include your answer in your laboratory report.

13. Increase the frequency of the triangle wave to 10 kHz. You may need to adjust the SEC/DIV knob for a good display. Use the Tektronix "OpenChoice Desktop" software to record an image of the display or take a digital photo of the display for your lab report. Why is it distorted? (Hint: A speaker is not a resistor -- the speaker coil is an inductor.)



14. Change the output back to a sine wave and increase its frequency to about 25 kHz. You may need to adjust the SEC/DIV knob for a good display. This is beyond the hearing range of nearly everyone.

15. Slowly decrease the frequency until you can hear it. Adjust the volume as necessary. You may need to adjust the SEC/DIV knob for a good display. This is the upper thresh hold of your hearing range. Record this frequency.

16. Continue decreasing the frequency until you cannot hear it anymore. Adjust the volume as necessary. You may need to adjust the SEC/DIV knob for a good display. This is the lower thresh hold of your hearing range. Record this frequency.

Discussion & Conclusions:

What conclusions can you make? Start with the questions asked in the procedure and then answer these:

How could you determine the voltage and frequency with an analog oscilloscope that does not directly display the voltage and frequency as a number?

Why did the sine wave, square wave, and triangle wave sound different through the speaker even though they were all the same frequency?

Why is the triangle wave in step 13 distorted?

The normal range of a young person's hearing is about 20 Hz to 20 kHz; how does your approximate hearing range on this simple test compare with the normal range?

APPENDIX D

Laboratory 2 with myDAQ Instruments

ECEN 150 Laboratory Experiment: Sinusoidal Waveforms (myDAQ)

Purpose:

1. Learn how to make AC voltage measurements (both magnitude and frequency) with an oscilloscope**.**

2. Learn how to set the wave shape, magnitude, and frequency of a function generator.

3. Learn how to make AC voltage measurements with a DMM.

4. Become more familiar with reading instrument operating manuals.

Notes: This version of the laboratory experiment is specifically for the myDAQ from National Instruments.

Detailed instructions for using the myDAQ are in the myDAQ User Guide at http://courses.byui.edu/ECEN150/RLO/LabInstruments/NImyDAQ_UserGuide.pdf

Setting up your myDAQ: http://zone.ni.com/devzone/cda/tut/p/id/11431

Using myDAQ instruments: http://zone.ni.com/devzone/cda/tut/p/id/11420

Using the myDAQ Function Generator:
http://zone.ni.com/devzone/cda/tut/p/id/11503

Using the myDAQ Oscilloscope: http://zone.ni.com/devzone/cda/tut/p/id/11502

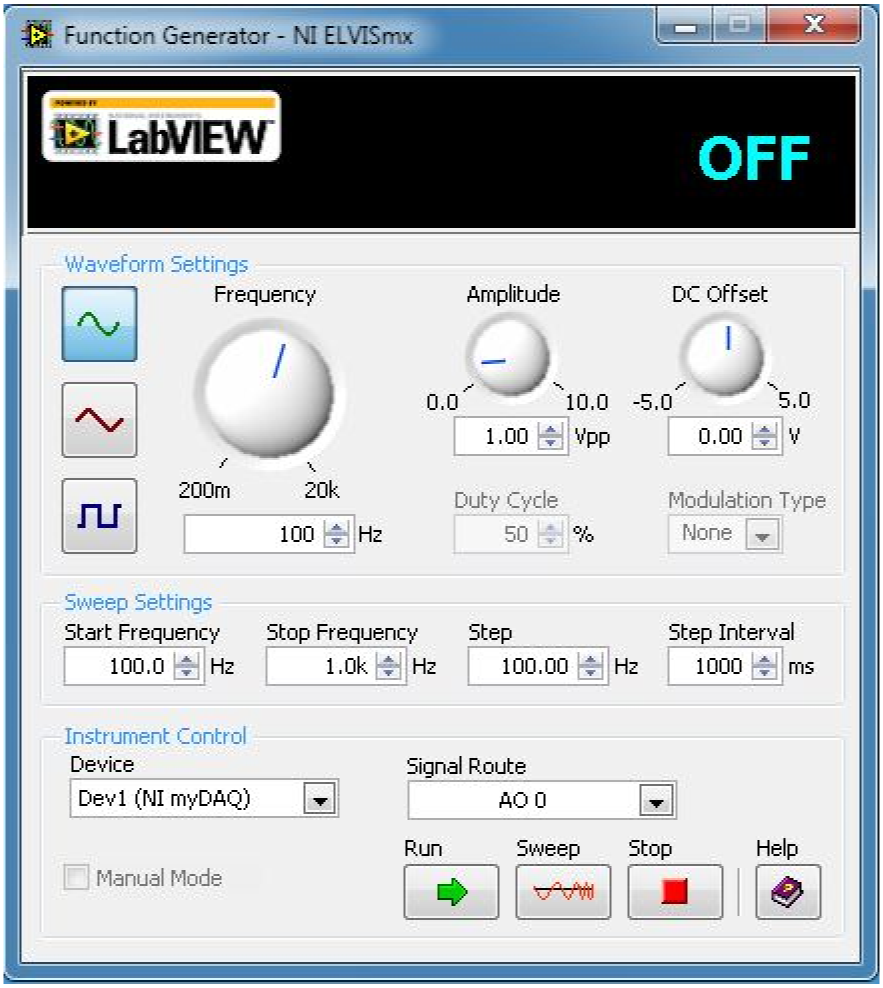
Each instrument also has a "Help" button in the lower right corner.

You should also watch the oscilloscope video clips, below, because they show how to operate the type of oscilloscope you will use most often on the job.

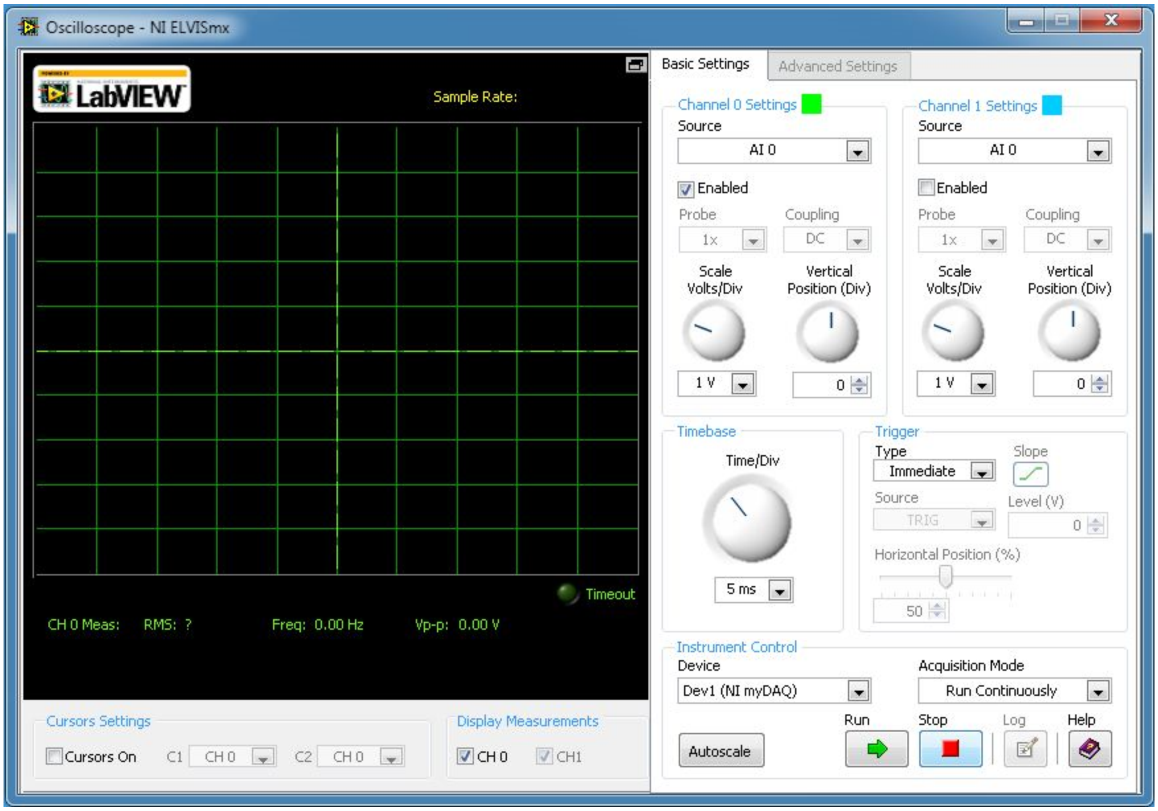
A short video clip that demonstrates how to use a digital oscilloscope with an LCD display can be seen at http://courses.byui.edu/ECEN150/RLO/LabInstruments/Oscilloscope.html Most digital oscilloscopes have similar controls and menus, but the details may be slightly different from those shown.

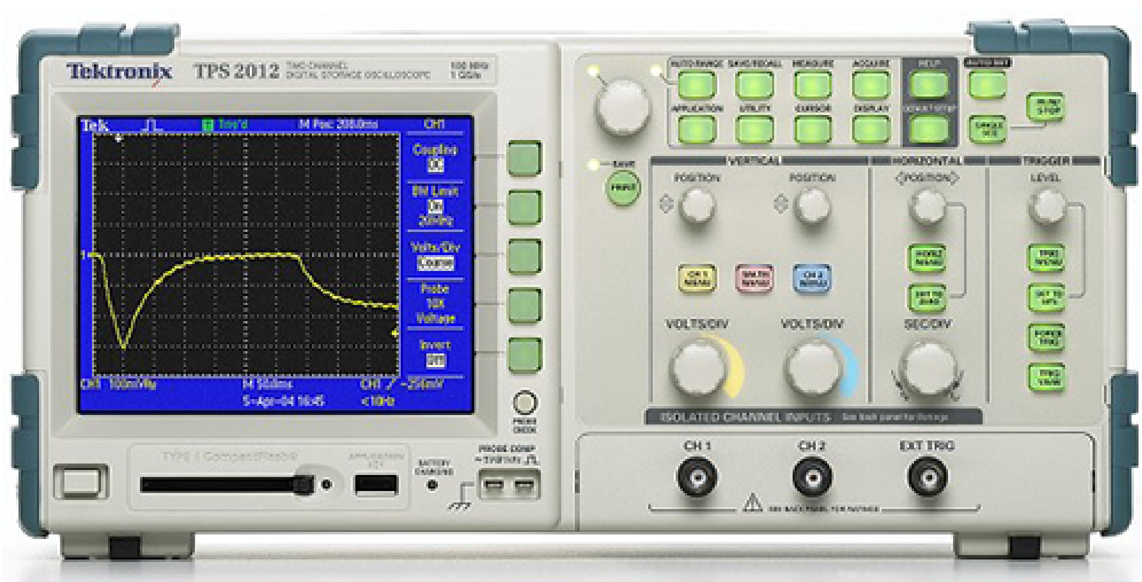
A short video clip that demonstrates how to use an analog oscilloscope with a CRT display can be seen http://courses.byui.edu/ECEN150/RLO/LabInstruments/TekAnalogScope.html M ost analog oscilloscopes have similar controls, but the layout may be slightly different from those shown.

Compare the controls of the myDAQ function generator with a typical bench-top function generator show below. Do you see the same adjustments (Frequency, Amplitude, DC Offset, Wave Shape, Sweep, etc.) on both?

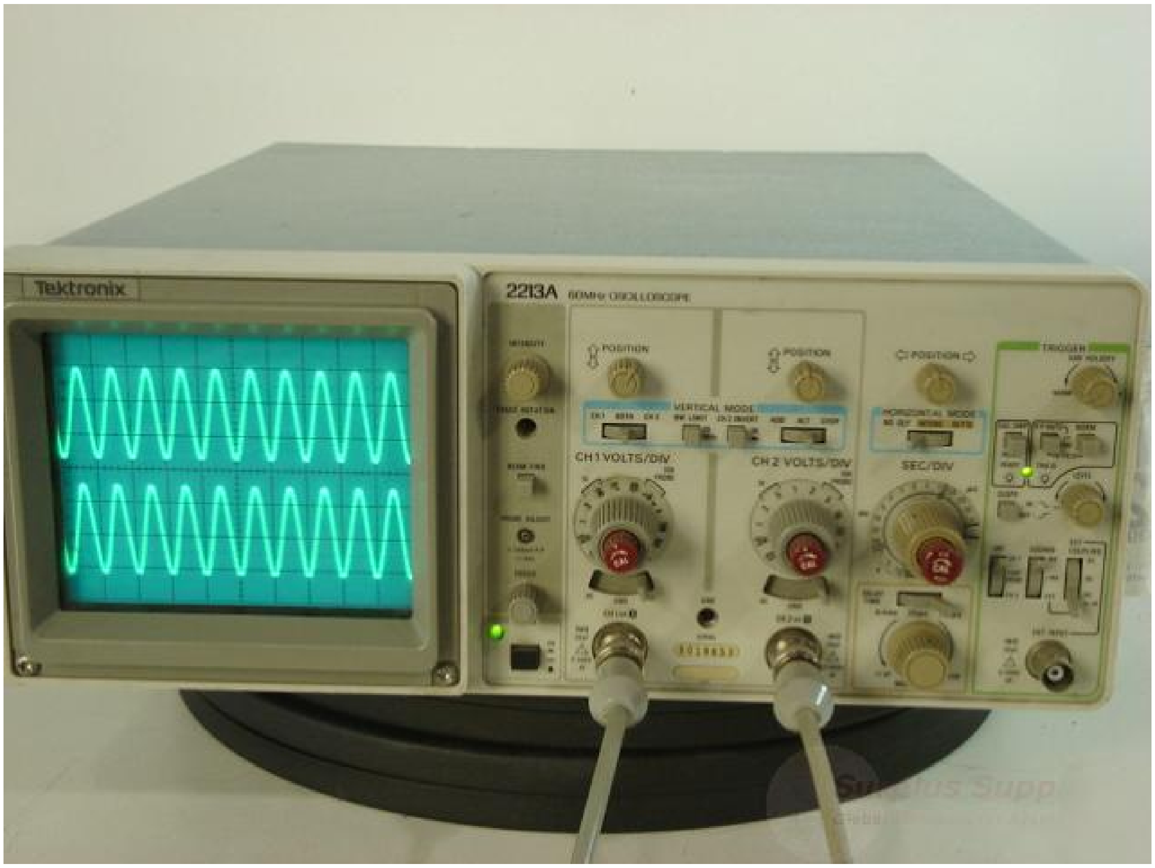


Compare the controls of the myDAQ oscilloscope with a typical bench-top oscilloscope. Can you find some of the same adjustments (VOLTS/DIV, TIME/DIV or SEC/DIV, Position, Trigger, etc.) on both?





Digital Oscilloscope



Analog Oscilloscope

Procedure:

1. Turn on, and configure, the myDAQ function generator (FGEN).

The myDAQ function generator produces standard sine, triangle, and square waves.

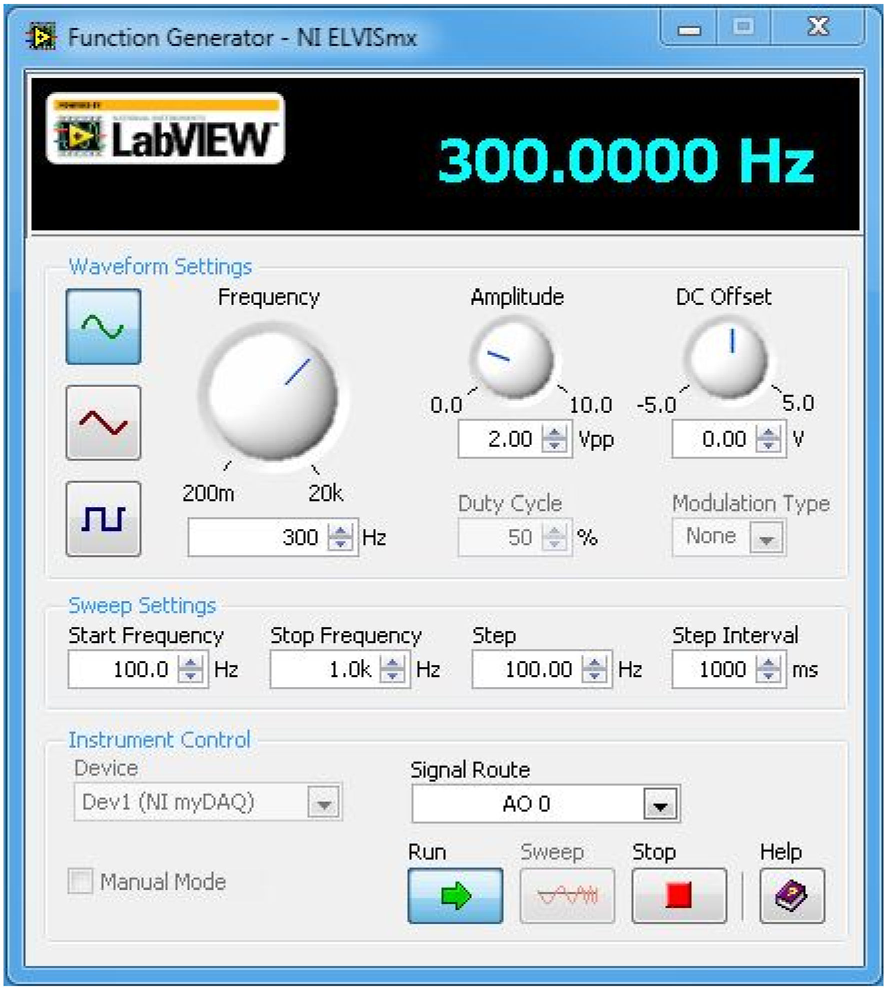
Click on the button that looks like a sine wave.

Set the Frequency to 300 Hz.

Set the Amplitude to 1 Vpp.

Set the DC offset to zero.

Ignore the other settings for now.



The output signal is terminal AO 0 on the protoboard. The AGND terminal is its ground reference.

Click on "Run."

2. Turn on, and configure, the myDAQ oscilloscope (Scope).

The myDAQ oscilloscope can display voltage measurements from two input channels simultaneously.

Set the Source of channel 0 to AI 0.

Select the "Enabled" box for channel 0.

Set the Volts/Div scale to 1 V.

Set the Vertical Position to zero.

Set the Time/Div scale to 1 ms.

Set the Trigger Type to "Edge."

Set the Trigger Source to "Chan 0 Source."

Set the Trigger Level to zero.

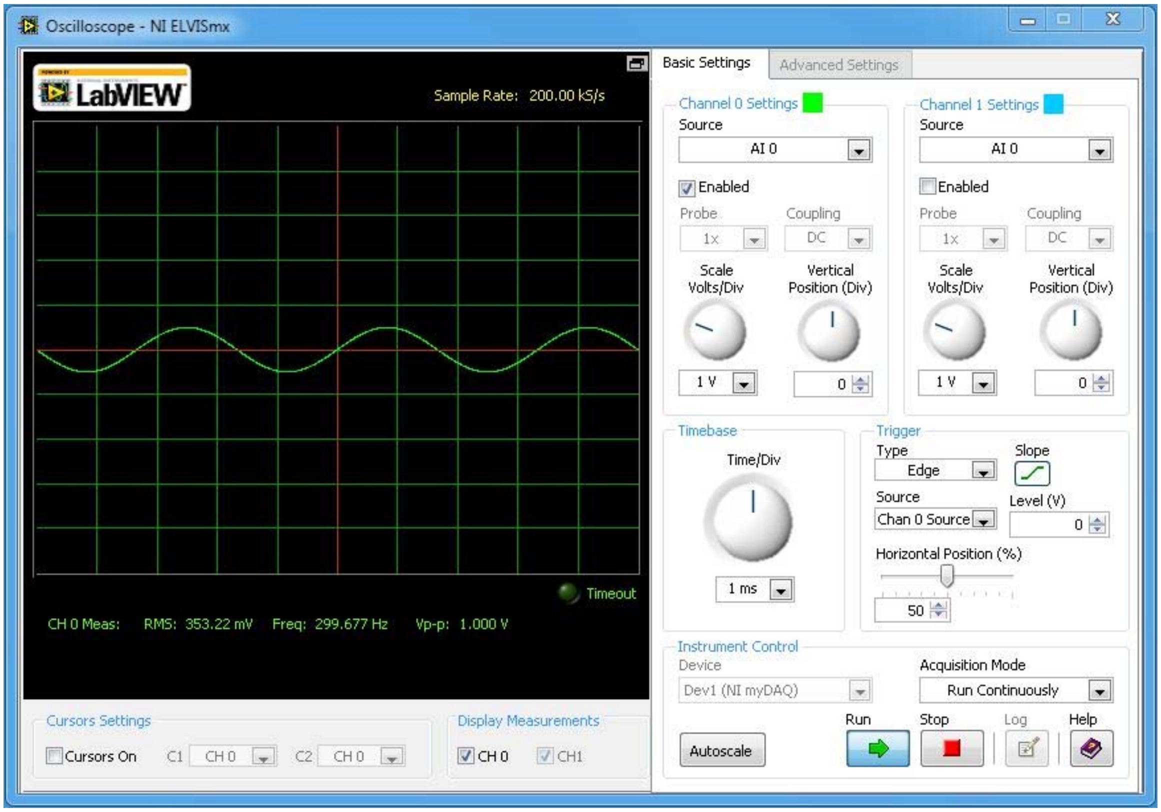
Set the Acquisition Mode to "Run Continuously."

Channel 0 uses the input terminal AI 0 on the protoboard or the left channel of the 3.5mm Audio Input jack on the side of the myDAQ. Channel 1 uses the input terminal AI 1 on the protoboard or the right channel of the Audio Input jack. You will only use Channel 0 (input AI 0) during this experiment.

Connect the AI 0 + oscilloscope (signal) input on the myDAQ protoboard to the AO 0 output of the function generator and the AI 0 - (ground) input to AGND.

Warning: It is very important to *ALWAYS* connect the oscilloscope ground lead to the function generator's ground lead as you did here. On bench-top instruments, both of these ground leads are connected together through the power cords and building wiring. If they are not connected to the same point on your circuit, a short circuit will result. Tuck this information away for the future. It will save you much grief, and possibly even embarrassment!

Click on "Run."



A green sine wave, representing the measured voltage, will appear across the screen.

3. Record the voltage measurements (Vp, Vpp, Vrms, frequency, and period).

Read the peak voltage as the number of divisions multiplied by the number of volts per division. (In this case, it is 0.5 divisions * 1 V per division = 0.5 Vp. If you adjusted your speaker volume to a different level, your voltage measurement will be different.)

Select the "CH 0" box under "Display Measurements" to show the RMS (DC equivalent) voltage, the frequency, and the peak-to-peak voltage under the oscilloscope display. (In this case, 0.5 Vp = 1 Vpp = 0.35 Vrms, and the frequency is very close to 300 Hz).

Read the period as the number of divisions multiplied by the time per division. For the display shown here, there are 3.3 divisions per period. Multiply that 3.3

divisions by the setting of 1 ms per division, and the result is 3.3 ms for the period. Frequency is the reciprocal of the period. The reciprocal of 3.3 ms is 303 Hz.

4. Listen to the tone.

Connect an 8 ohm speaker. (One terminal of a speaker goes to AO 0 and the other terminal goes to AGND.)

You will be able to hear the 300 Hz tone, but the oscilloscope will not work with the speaker connected.

5. Adjust the frequency dial on the function generator to get an output frequency of 60 Hz. The speaker will sound like a motor boat. (If you cannot hear anything, use a slightly higher frequency, such as 100 Hz.)

6. Measure and record the new frequency and period.

Disconnect the speaker to make these measurements. You may need to adjust the Time/Div setting on the oscilloscope for a good display.

7. Reconnect the speaker and increase the frequency 20 kHz. This is the maximum frequency of the myDAQ function generator and just beyond the hearing range of most people.

8. Measure and record the new frequency and period.

Disconnect the speaker to make these measurements. You may need to adjust the Time/Div setting on the oscilloscope for a good display.

9. Reconnect the speaker and slowly decrease the frequency until you can hear it. If you have a reasonably good speaker, this is the upper thresh hold of your hearing range. Otherwise, it is simply the upper thresh hold of your speaker's response!

10. Measure and record the new frequency and period.

Disconnect the speaker to make these measurements. You may need to adjust the Time/Div setting on the oscilloscope for a good display.

11. Reconnect the speaker and continue decreasing the frequency until you cannot here it anymore. This is the lower thresh hold of your hearing range.

12. Measure and record the new frequency and period.

Disconnect the speaker to make these measurements. You may need to adjust the Time/Div setting on the oscilloscope for a good display.

Discussion & Conclusions:

What conclusions can you make? Start with the questions asked in the procedure and then answer these:

How could you determine the voltage and frequency with an analog oscilloscope that does not directly display the voltage and frequency as a number?

The normal range of a young person's hearing is about 20 Hz to 20 kHz; how does your approximate hearing range on this simple test compare with the normal range?

APPENDIX E

Informed Consent for Participation

(See next page.)

Principal Investigator: Rex Fisher
(208) 496-7607
fisherr@byui.edu

1. **Purpose of the Study:** The purpose of this research study is to improve the effectiveness of the electrical engineering and computer engineering curricula. Your participation in this study is completely voluntary. Participation in this study is not a course requirement and does not affect your grade.

2. **Procedures to be followed:** For this study, you will:

   (1) Perform two laboratory experiments.

   (2) Take a written test.

   (3) Take a hands-on, laboratory test.

   (4) Take an anonymous, 50-question survey.

   (5) Refrain from discussing the tests with anyone until the study is completed. You will discuss the laboratory experiments only with your assigned laboratory partner. Please do this even if you do not participate in the study.

   Because these items are either a normal part of the course, or are part of the CSEE Department's continuous improvement activities, all students will be asked to complete them. However, you may choose to have your scores omitted from the study about improving the electrical engineering and computer engineering curricula.

3. **Duration:** It will take about three weeks during the semester to complete the laboratory experiments, tests, and survey.

4. **Statement of Confidentiality:** Your participation in this research is confidential. Only your instructor will have access to your individual laboratory and test scores. Scores used by the investigator will contain no personally identifiable information.

5. **Right to Ask Questions:** Please contact Rex Fisher at (208) 496-7607 or at fisherr@byui.edu with questions or concerns about this study.

6. **Voluntary Participation:** Your decision to be in this research is voluntary. You can stop having your scores included in the study at any time. This decision will not affect your course grade. If you are less than 18 years of age, you will automatically be removed from the study.

   Please indicate your decision to participate by marking the appropriate response below, and signing this form.

   Yes, I will participate _____ No, I will not participate _____

   ____ ______________________

   Signature Date

APPENDIX F

Summary of Treatment Design Using ADDIE

(Begins on next page.)

Analysis

This instructional design plan was used to analyze, design, develop, implement, and evaluate an alternative version of ECEN 150 and its laboratory component for use with online students who have no access to campus engineering laboratories. The analysis determines the requirements of the new ECEN 150 course. It examines the goals and objectives of the training, the needs and characteristics of the targeted learners, and the available resources.

Need for Instruction

Rational. The Computer Science and Electrical Engineering Department is investigating the feasibility of converting its on-campus courses for online delivery to students who cannot attend classes on campus. ECEN 150 is the first engineering course in the curriculum. The practicality of moving the laboratory exercises to a format useable by online students must be evaluated before offering the course entirely online.

Goals. Good instructional design methods will be used to ensure that the quality of the experience is high. This project will follow the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) model for instructional design. The goals for this course and its laboratories are based on the requirements of engineering accreditation organizations such as ABET (ABET, 2011) and engineering licensing exams such as the NCEES Fundamental of Engineering exam ("NCEES: Exams," 2011). The specific goals for the laboratory component of the course are that students will have the knowledge, skills, and attitudes necessary to:

1. Design, analyze, and troubleshoot DC circuits with batteries, resistors, capacitors, and inductors.

2. Design, analyze, and troubleshoot AC circuits with transformers, resistors, capacitors, and inductors.
3. Proto-type electric circuits using temporary and permanent construction methods.
4. Observe electric circuit operation with basic laboratory instruments.
5. Write technical reports.

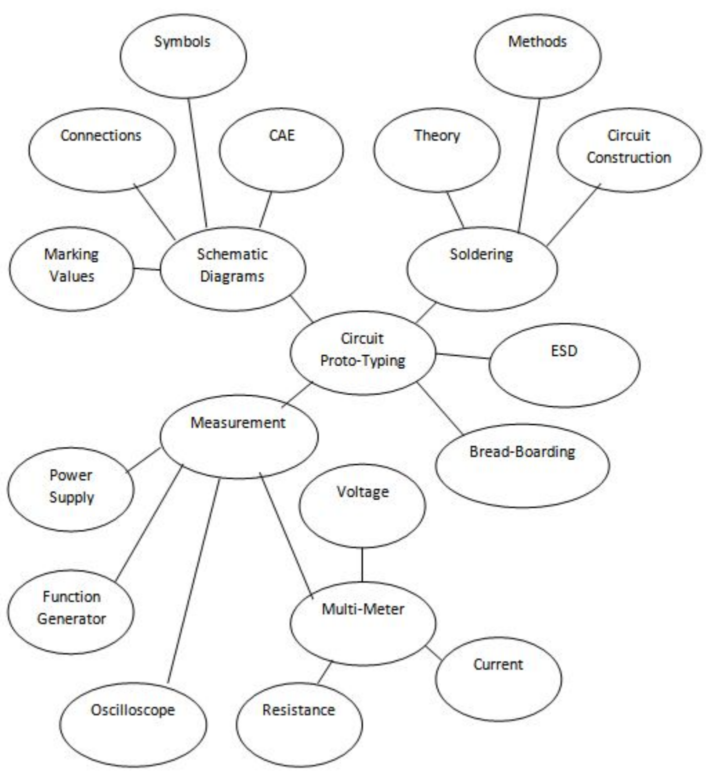
Task Analysis

What is to be learned. The knowledge, skills, and attitudes that each student must acquire to meet the laboratory goals are listed below. Although this process revealed some gaps in the on-campus laboratories, upon which these online laboratories are based, most of the tasks listed below were derived from that source. This analysis produced a more comprehensive and refined list than what previously existed.

- Identify basic schematic diagram symbols.
- Draw a simple circuit diagram.
- Correctly label voltages on a schematic diagram.
- Correctly label currents on a schematic diagram.
- Correctly label resistances on a schematic diagram.
- Demonstrate proper soldering techniques.
- Construct a simple circuit from its schematic diagram.
- Measure a DC voltage with a meter.
- Measure and AC voltage with a meter.
- Measure a DC current with a meter.
- Measure an AC current with a meter.

- Measure resistance with a meter.
- Use a DC power supply as a voltage source for a DC circuit.
- Use a function generator as a voltage source for an AC circuit.
- Measure a DC voltage with an oscilloscope.
- Measure an AC voltage with an oscilloscope.
- Determine the period of an AC waveform with an oscilloscope.
- Determine the frequency of an AC wave form with an oscilloscope.
- Write laboratory reports using the correct format.
- Write laboratory reports using professional language.
- Write a report about the assembly and operation of an electric circuit.

Concept map. The inter-relationships of the concepts to be learned in the laboratories can be seen in graphical form as a concept map.



Learner Analysis

Target audience. Students who will enroll in this course are typically males in their first semester of the electrical & computer engineering program. Most of them will be in their first semester of college as well. Women are historically under-represented in these engineering courses (Hill, Corbett, & Rose, 2010).

Prior Knowledge. Laboratory courses are the first practical experience that some students have (Montes. Castro, & Riveros, 2010). Clark, Flowers, Doolittle, Meehan, & Hendricks (2009) found that even though students used a plethora of electronic gadgets in their daily lives, “they had no experience in dealing with electronics from an experimental point of view” (p. 1). This was attributed to the decreasing interest in ham radio, assembling electronics kits, and rebuilding computers because technology has made components too small and difficult for hobbyists to work on (Clark, Flowers, Doolittle, Meehan, & Hendricks (2009). Feisel & Rosa (2005) came to the same conclusion “that fewer students come to the university with experience as ‘shade tree mechanics’ or amateur radio operators”, and that engineering laboratories are necessary to give them experience with physical systems (p. 123).

Learner characteristics. Because there are no special admission requirements for electrical and computer engineering at this university, students in these programs share some of the same characteristics as the general student body. The average student has an ACT score of about 24 or SAT score of 1090-1120, and a high school GPA of 3.4 (BYU-Idaho, 2010). Most of the students (80%) are between 18 and 23 years old. They are from every region in the U.S. and 57 other countries as well (BYU-Idaho, 2011). Some of them speak English as a second language. The heterogeneous student body makes it difficult to establish a shared context for some of the course material. Because of their average test scores, it is also safe to assume that not all of these engineering students took chemistry, physics, and advanced math in high school.

According to Kucukozer & Kocakulah (2007), it is very common for engineering students to have formed misconceptions about electricity during their previous exposure to the subject. These misconceptions are often firmly entrenched and can be difficult to correct. The reason for this may be that two-thirds of freshman engineering students would rather learn simple facts instead of the underlying concepts and theories (Kuri & Truzzi, 2002). A conscious effort to expose these misconceptions and replace them with correct concepts will be required.

Mina & Gerdes (2006) found fifteen characteristics to be typical of freshman electrical engineering students. Five of those characteristics are relevant to this project:

1. The students have an above-average understanding of computer tools. Using technology for a hybrid or online course should not be a barrier for them.
2. The students are generally unwilling to accept challenges. They have been among the top of their high school peers and are not accustomed to situations where learning is difficult. When challenged beyond their comfort level, many students drop the course or even switch to another major. It will be important to "ease them into" the level of expectation that comes with a college-level course.
3. The students are generally unwilling to maintain a committed interest unless the class is "fun." An attention span of only about ten minutes should be

expected otherwise. A variety of interesting learning activities will be required to keep them engaged.

4. The students lack formal verbal and written communication skills. They use, instead a “telegraphic-like” style similar to that used for texting, online chatting, and emailing. Those learners who dislike reading and writing may need additional motivation for completing assignments.
5. The students lack an understanding of the learning process. They attempt to learn theories and concepts simply by working through examples in the book. They do not seek understanding, only answers. This supports the findings of Kuri & Truzzi (2002) that many students avoid learning concepts and theories. Compelling reasons to learn the necessary concepts and theories must be included in the laboratories.

The topics selected to cover early in the curriculum should not require a significant amount of calculus and physics. They should also be designed to be interesting and relevant in order to “hook” the students and give them a reason for enduring some of the math and science that will prepare them for more advanced courses.

Instructional Analysis

Learning environment. The laboratories will normally be done either in a classroom, at home, or in one of the university’s many study centers. These classrooms and study centers typically provide high-speed Wi-Fi internet connections, power outlets and tables for students to use with their own laptop computers.

The laboratory exercises will be re-written for this course to use the myDAQ by National Instruments. The board has a circuit proto-typing area and several laboratory instruments built in. The instruments that will be used for this course are power supply, multi-meter, oscilloscope, and function generator. The board is connected to a computer via USB and the instruments are controlled by software.

Constraints. All courses at the university must use the university's learning model (BYU-Idaho, 2009). There is great flexibility in how its principles can be implemented, but they must all be present in some form.

At least 18 myDAQ units will be required for the feasibility study at a cost of $350 each. Students who are actually enrolled in the future online course will receive a $100 discount from National Instruments.

Design

The design section outlines the learning objectives, instructional strategy, course organization, and required instructional materials.

Learning Objectives

The knowledge, skills, and attitudes that each student must acquire to meet each of the course goals have been converted into measurable learning objectives. The learning objectives are descriptions of what students must be able to do in order to be competent. They describe the result of the instruction instead of the process. The learning objectives include an observable behavior, the conditions under which it will be evaluated, and the level of performance that is acceptable (Mager, 1984). The knowledge, skills, and abilities identified during the analysis phase have been transformed into observable and measureable objectives.

1. Given a description of a simple circuit with a voltage source and one or more resistors, and given no other reference materials, the student will draw a schematic diagram of the circuit with 100% accuracy.
2. Given the required values, and given no other reference materials, the student will correctly label voltages on a schematic diagram with 100% accuracy.
3. Given the required values, and given no other reference materials, the student will correctly label electric currents on a schematic diagram with 100% accuracy.
4. Given the required values, and given no other reference materials, the student will correctly label resistances on a schematic diagram with 100% accuracy.

5. Given the schematic symbol of any electric or electronic circuit component, and given access to reference materials, the student will correctly identify the component represented with 100% accuracy.
6. Given an actual electric or electronic circuit, and given access to reference materials, the student will correctly identify the component with 100% accuracy.
7. Given the necessary tools and materials, and given no other reference materials, the student will demonstrate proper soldering techniques by completing a joint
    a. That conforms to IPC-A-61D (Acceptability of Electronic Assemblies) physical standards 80% of the time.
    b. In less than 3 seconds 80% of the time.
8. Given the necessary tools and materials, and given access to reference materials, the student will construct a simple circuit from its schematic diagram with 100% accuracy.
9. Given a DC circuit, and given a digital multi-meter (DMM) with test leads, and given no other reference materials, the student will measure the DC voltage across any component with 90% accuracy.
10. Given an AC circuit, and given a digital multi-meter (DMM) with test leads, and given no other reference materials, the student will measure the AC voltage across any component with 90% accuracy.
11. Given a DC circuit, and given a digital multi-meter (DMM) with test leads, and given no other reference materials, the student will measure the DC current through any component with 90% accuracy.

12. Given an AC circuit, and given a digital multi-meter (DMM) with test leads, and given no other reference materials, the student will measure the AC current through any component with 90% accuracy.
13. Given a resistive component, and given a digital multi-meter (DMM) with test leads, and given no other reference materials, the student will measure resistance of the component with 90% accuracy.
14. Given an adjustable DC power supply with connection leads as a DC voltage source, and given a circuit requiring a specified DC voltage, and given no other instruments or reference materials, the student will apply the specified voltage to the circuit with 90% accuracy.
15. Given a function generator with connection leads as an AC voltage source, and given a circuit requiring a specified amplitude and frequency of AC voltage, and given an oscilloscope with probes, and given access to reference materials, the student will
    a. Apply the specified amplitude of voltage to the circuit with 90% accuracy.
    b. Apply the specified frequency of voltage to the circuit with 90% accuracy.
16. Given a DC circuit, and given an oscilloscope with probes, and given access to reference materials, the student will measure the DC voltage across any component with 90% accuracy.
17. Given an AC circuit, and given an oscilloscope with probes, and given access to reference materials, the student will measure the AC voltage across any component with 90% accuracy.

18. Given an AC circuit, and given an oscilloscope with probes, and given access to reference materials, the student will determine the period of an AC voltage source with 90% accuracy.
19. Given an AC circuit, and given an oscilloscope with probes, and given access to reference materials, the student will determine the frequency of an AC voltage source with 90% accuracy.
20. Given laboratory experiment results (calculations and measurements), and given the required report format, and given access to reference materials, the student will write a laboratory report that conforms to the required format with 100% accuracy.
21. Given laboratory experiment results (calculations and measurements), and given access to reference materials, the student will write a laboratory report using
    a. Correct spelling with 100% conformance.
    b. Correct sentence structure with 90% conformance.
    c. An appropriate tone of professionalism with 90% conformance.
22. Given an electric circuit, and given access to reference materials, and given at least one day to study the circuit, the student will write a technical report to an audience of peers (with schematics, theory of operation, and assembly photographs or drawings) that describes how the circuit operates and can how its assembly can be duplicated by those peers with 100% accuracy.

Instructional Strategy

Teaching methods. The theories of andragogy, behaviorism, cognitive information processing, social cognitivism, and constructivism have informed the teaching approaches used in this course and its laboratories.

Andragogy. The principles of andragogy address the characteristics of adult learners. College students have many of the same characteristics. They want to know why the new material is important to learn and how to apply it in real-life situations. Eduard Lindeman wrote, "[A learner] cannot begin by studying 'subjects' in the hope that some day [sic] this information will be useful. On the contrary, he begins by giving attention to situations in which he finds himself, to problems which include obstacles to his self-fulfillment" (Knowles, Holton, & Swanson, 1973/1998, p. 39). Students filter new learning though their personal experiences and want some control of the learning process. "[Educators must] make efforts to create learning experiences in which adults are helped to make the transition from dependent to self directing [sic] learners" Knowles, Holton, & Swanson, 1973/1998, p. 65). The ability to perform the laboratory exercises almost anywhere at almost any time supports the flexibility desired by adult learners.

Behaviorism. According to behaviorism, the teacher's role is to identify learning goals, determine contingencies of reinforcement, and implement a program of behavioral change (Driscoll, 2005). Rosenshine (1986) listed several teaching methods that are based on behaviorism, including reviews and practice with corrections and feedback. "You only really learn a principle by using it over and over again" (Eyring, 2003). Review quizzes and homework with feedback and numeric scores are reinforcements that help to improve performance. The curriculum is divided into blocks with reviews and practice. According to Rosenshine (1986), these are most useful in teaching subjects that are well-structured such as mathematics and science. Engineering clearly fits that category.

Cognitive information processing. This theory focuses on the inter-relationship of sensory input, short-term memory, and long-term memory. New information should be organized into manageable pieces and connected to existing knowledge. The teacher's role under cognitive information processing theory is to organize information, direct attention, enhance encoding and retrieval, and provide practice opportunities (Driscoll, 2005). Asking questions, providing advance organizers and elaborating on important concepts help accomplish this.

Because short-term memory is limited in capacity, it is important to keep the segments of new material small. One way to achieve this is chunking, which is a process of combining information in a meaningful way. Two factors that aid in the process of linking the new information to previous knowledge and encoding it for storage are organization and elaboration.

When items of new knowledge are logically organized, memory improves because they link together systematically. Ausubel (1978) advocated accomplishing this by teaching general ideas first, and then proceeding to specific points. These advance organizers, or general ideas presented at the beginning of a lesson, help associate new material with previous learning.

Elaboration has a similar goal. By expanding the new information with examples, details, or inferences it can be more easily associated with previous knowledge. Also, according to Ausubel & Youssef (1963), the failure to elaborate on how new information differs from what students already know will also cause them to ignore the new information and perpetuate their existing misconceptions. This has typically been a major problem in science and engineering courses (Sneider & Ohadi, 1998), (Stepans, 1994). Teachers can assist students by providing effective elaborations. Taking notes, writing reports, and performing lab experiments are forms of elaboration.

Social cognitivism. This highlights the benefits of modeling. Albert Bandura concluded, "Most human behavior is learned observationally through modeling: from observing others, one forms an idea of how new behaviors are performed, and on later occasions this coded information serves as a guide for action" (Learning Theories Knowledgebase, 2008). This vicarious learning allows people to learn much faster than if they were required to perform every learning activity themselves. Learning complex skills usually requires practice after observing the modeled skill.

It is important to structure the curriculum so that it enhances learners' self-efficacy. Learners with a high level of self-efficacy display more motivation and persistence when encountering difficulties. It is also a significant predictor of student achievement (Schunk, 1991/2008). With social cognitivism, the teacher's role is to provide models of appropriate practices with an eye toward enhancing learners' self-efficacy.

Constructivism. Also called constructivist theory, this ties all of the preceding ideas together in a personally meaningful way for learners. They must construct their own understanding. They are not containers that we simply fill with knowledge. Professors are not the principal sources of all important knowledge, as is often the perception. "[The teacher] is no longer the oracle who speaks from the platform of authority, but rather the guide, the pointer-out who participates in learning" (Gessner, 1956, p.160).

Constructivism concentrates on constructing knowledge in the mind instead of simply acquiring and storing it. In contrast to the teacher-centered learning dominant in the previous theories, this one is learner-centered. That means the teacher does not simply dispense information. Instead, the learner must assimilate it and construct personal meaning from it. The emphasis is on understanding – not rote memorization. According to Bain (2004), "When we can successfully stimulate our students to ask their own questions, we are laying the foundation for learning" (p. 31). Students are engaged in authentic, real-world problem solving. Design projects and lab exercises, as well as some homework problems, fall into this category.

Vygotsky (1978) believed that the social environment was a major factor in learning. He stressed personal interaction. An application of this principle is students teaching one another, often called reciprocal teaching (Palinscar & Brown, 1984). Peer collaboration on laboratory exercises is another technique based on Vygotsky's ideas (Fawcett & Garton, 2005).

Bruner (1966) identified various ways of representing knowledge. Although his specific categories may not apply to engineering students, the idea of them certainly does. Students exhibit true understanding of a science or engineering principle only by describing it at two levels: quantitatively and qualitatively (Forbus & Falenhainer, 1990). Simply obtaining the correct calculated value or only being able to describe something intuitively does not demonstrate complete "understanding." Presenting and assessing instruction in a variety of ways is, therefore, is required. Gardner (1983), who proposed a theory of multiple intelligences, also validated this concept. Most people excel within one or two intelligences, so teachers must include several of them in the curriculum in order for students to learn through their individual strengths.

As students become more proficient at engineering, the approach should change from telling them what they should know, to helping them decide and discover it themselves. Fostering this by creating practical, real-world situations in which students can experience problems and explore their own solutions, is superior to using only the traditional [lecture] in a classroom setting. "Lectures must be replaced with class exercises in which there is a large share of student participation. 'Let the class do the work' should be the adopted motto" (Knowles et al., 1973/1998, p. 44).

BYU-Idaho learning model. The overall structure of the course conforms to the official university learning model. The learning model is designed to "deepen the learning experiences of students" (BYU-Idaho, 2009) and it "enables students to take greater responsibility for their own learning and for teaching one another" (BYU-Idaho, 2009). There are three steps in the learning model:

1. Prepare
2. Teach One Another
3. Ponder & Prove

Prepare. Preparation enables students to achieve deep learning. Although responsibility for preparation is on the student, the instructor guides the student by providing context, objectives, and study materials. The introductory material is studied before class. Class time is "used for activities that deepen the level of understanding from simple recall to comprehension and application" (BYU-Idaho, 2009).

Teach one another. This phase of instruction typically occupies most of the class time and allows students to share the responsibility for their learning in a collaborative setting. Students learn more when they teach. They also build their own knowledge, which aids in retaining and applying their learning. The instructor's role is to design the interaction, select engaging problems to solve, provide feedback, and intervene when necessary to correct and clarify.

Ponder & prove. Ponder and prove activities are designed around learning outcomes. Pondering helps students reflect and organize their thoughts. Pondering is a form of elaboration, which combines new learning with prior knowledge to enhance meaning and recall. By expanding the new information with examples, details, or inferences it can be more easily associated with previous knowledge. Reviewing notes, writing reports, working homework problems, and performing lab experiments are forms of pondering (elaboration). Pondering should actually take place during the first two phases of the learning model as well, not just at the end. An example of this is the study guide, which is part of the preparation phase. It sometimes challenges students' preconceived ideas and causes them to ponder the truth of what they think they know.

Proving involves trying out ideas, verifying that new learning fits with prior knowledge, and demonstrating competence. "Prove" activities assess competence, develop confidence, and motivate. When students internalize the learning through pondering and then externalize it through proving, they obtain more insight and understand more deeply.

Assessment

Assessment of students' progress in reaching the learning objectives will be divided among several different instruments: course examinations, a laboratory performance test, and a survey. This provides a mix of written and hands-on methods to assess knowledge, skills, and attitudes.

Required Course Material

The following course materials must be created, purchased, or substantially modified from their original form in the current on-campus course:

1. Video clip(s) that demonstrate the operation of a multi-meter;
2. Video clip(s) that demonstrate the operation of an oscilloscope;
3. myDAQ from National Instruments
4. Laboratory parts kit
5. Re-write laboratory experiments to use the myDAQ instead of traditional equipment.

Templates for New Course Material

Documents that must be created or revised require a template to ensure a consistent look and that all of the required information is contained within. Templates are located in the appendix.

LMS learner interface. The course will be hosted on the university's LMS system.

Laboratory experiment template. These are served up as web pages and may include hyperlinks to additional information required to perform the experiment.

Video clip template. The primary purpose for embedding video clips in these custom web pages is to prevent students from becoming distracted when being sent to external web sites, such as YouTube. Also, because some video clips will be created specifically for this course, the web page template maintains a common look and feel for all video clips.

Development

Development of the online laboratories into their final form was complete before the treatment in this study began. The actual laboratories are shown in Appendices A, B, C, and D.

Implementation

Implementation was performed during the treatment for this study and is described in the body of the main document.

Evaluation

Evaluation was performed at the conclusion of the treatment for this study and is described in the main body of this document.

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APPENDIX G

Knowledge Test

Subject Matter to be Covered:

Reading Schematics

Identifying Electronic Components

Circuit Proto-Typing

Basic Concepts of DC Electricity

    Engineering Notation

    E, I, R

Electrical DC Calculations

    Ohm's Law

    Electrical Power & Energy

Electrical DC Measurements

    Measuring Voltage

    Measuring Resistance

    Measuring Current

Basic Concepts of AC Electricity

    Sine Waves

    $v(t)$, $i(t)$

Electrical AC Calculations

Peak, Average, RMS Values

Frequency and Period

Electrical AC Measurements

Measuring Voltage

Measuring Current

Measuring Frequency and Period

Taxonomy Used:

Three levels suggested in *Measurement and Assessment in Schools* by Worthen:

1. Knowledge: Students are required only to recall facts. Without an adequate knowledge base, it is impossible to acquire higher-level cognitive skills.
2. Comprehension & Application: Students must be able to rephrase information using their own statements and translate knowledge into new context. Students are also required to identify the relevant information and rules to arrive at a solution and solve problems using known algorithms.
3. Analysis, Synthesis & Evaluation: Students must demonstrate their ability to reason with their knowledge and use it to solve problems, exercise judgment, make rational decisions, and communicate effectively.

Objectives:

This test will assess a student's ability to:

1. Analyze electric circuits. (weight = approx. 65%)

   A. Explain what voltage is.

   B. Explain what electric current is.

C. Explain what electric resistance is.

D. Identify the units of potential difference (electromotive force).

E. Identify the units of electric current.

F. Identify the units of electric resistance.

G. Correctly label voltages on a schematic diagram.

H. Correctly label currents on a schematic diagram.

I. Calculate voltage.

J. Calculate current.

K. Calculate voltage.

L. Explain the difference between direct current and alternating current.

M. Identify basic schematic diagram symbols.

N. Explain electric power.

O. Calculate resistive power consumption.

P. Identify the peak amplitude of an AC voltage shown in trigonometric form.

Q. Identify the angular frequency (rad/sec) of an AC voltage shown in trigonometric form.

R. Calculate the frequency in Hertz of an AC voltage shown in trigonometric form.

S. Calculate the period of an AC voltage shown in trigonometric form.

T. Calculate peak-to-peak amplitude of an AC voltage shown in trigonometric form.

U. Calculate the RMS amplitude of an AC voltage shown in trigonometric form.

2. Design electric circuits. (weight = approx. 5%)

A. Select resistors with appropriate power ratings.

3. Construct electric circuits. (weight = approx. 10%)

A. Identify basic electrical and electronic components.

B. Prevent ESD damage.

C. Apply the correct DC voltage to an electric circuit with a variable power supply.

4. Observe electric circuit operation with basic laboratory instruments. (weight = approx. 20%)

A. Measure voltage with a meter.

B. Measure current with a meter.

C. Measure voltage amplitude with an oscilloscope.

D. Measure the period of an AC voltage with an oscilloscope.

E. Measure the frequency of an AC voltage with an oscilloscope.

Test Blueprint:

Content Area	**Knowledge**	**Comprehension and Application**	**Analysis, Synthesis and Evaluation**	**Total**
Analyze electric circuits	11	7	2	20
Design electric circuits			1	1
Construct electric circuits	1		1	2
Observe Circuits with Basic Laboratory Instruments	1	3	3	7
Total	13	10	7	30

Mapping of Test Questions to Objectives:

Question	Objective	Level
1	1B	1
2	1C	1
3	1G	1
4	1H	1
5	1I	3
6	1D	1
7	1E	1
8	1F	1
9	1L	1
10	1J	2
11	1K	2
12	1M	1
13	1P	3
14	1O	2
15	1P	1
16	1Q	1
17	1R	2
18	1S	2
19	1T	2
20	1U	2
21	2A	3
22	3A	1
23	3B	3
24	3C	3
25	4A	3
26	4A	3
27	4B	1
28	4C	2
29	4D	2
30	4E	2

(1 = Knowledge, 2 = Comprehension/Application, 3 = Analysis/Synthesis/Evaluation)

Actual Test:

Knowledge Test **Name: ____**

You will have 120 minutes to complete this 30-question, closed-book test. Most of the questions are multiple-choice. Select the best answer.

1. The movement of electric charge is called

A. voltage.

B. current.

C. resistance.

D. power.

2. The movement of electric charge is inversely proportional to the

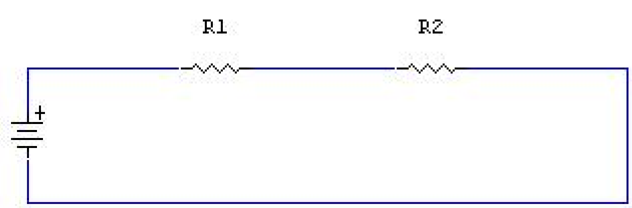
A. voltage across the conductive path.

B. current through the conductive path.

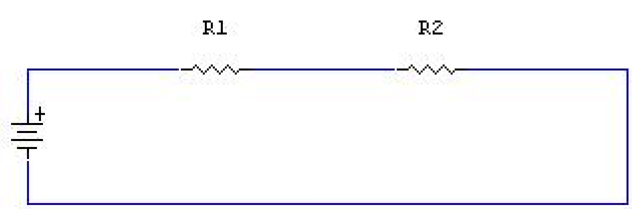
C. resistance of the conductive path.

D. power consumed in the conductive path.

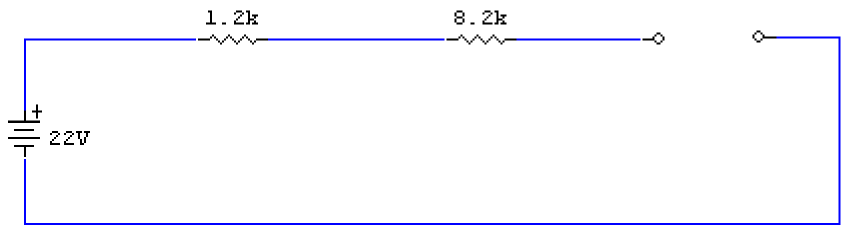
3. The voltage across R1 is 10 V and the current through R2 is 5 mA. Correctly mark the voltage across R1 on the schematic diagram below:



4. The voltage across R1 is 10 V and the current through R2 is 5 mA. Correctly mark the current through R2 on the schematic diagram below:



5. What is the indicated voltage (V)? **+ V -**



A. V = 0 V

B. V = 2.8 V

C. V = 19.2 V

D. V = 22 V

6. Electric potential difference is measured in

A. volts.

B. amps.

C. ohms.

D. watts.

7. Electric current is measured in amps, which is equal to

A. joules per coulomb.

B. coulombs per second.

C. volts squared per watt.

D. volts squared per ohm.

8. The symbol for ohms is

A. k

B. O

C. R

D. Ω

9. The difference between DC and AC is

A. DC current always comes from a battery, AC current always comes from a generator.

B. DC current never changes, AC current is always changing.

C. DC current always flows in the same direction, AC current periodically reverses direction.

D. DC current is better for low voltages, AC current is better for high voltages.

10. A 4.7 ohm resistor has 2 volts across it. How much current is flowing through the resistor?

A. 0.426 A

B. 2.35 A

C. 4.26 A

D. 9.40 A

11. A 40 volt battery is providing 2 amps of current to an electric circuit. How much resistance is in the circuit?

A. 80 ohms

B. 2 ohms

C. 40 ohms

D. 20 ohms

12. What does the schematic symbol shown below represent?

A. inductor

B. fuse

C. antenna

D. resistor

13. A light bulb is connected to an AC voltage supply of 100 RMS volts. If the same light bulb is then connected to a 100 volt battery, it will be

A. brighter with the battery voltage.

B. dimmer with the battery voltage.

C. the same brightness with either voltage source.

D. It depends on the power rating (Wattage) of the light bulb.

14. A soldering iron intended for electronics work has 480 ohms of resistance and operates on 120 volts. What is its power rating?

A. 12 watts

B. 25 watts

C. 30 watts

D. 48 watts

15. An AC voltage is expressed as 240 cos(2765t)V. What is its peak voltage?

A. 0 volts

B. 240 volts

C. 170 volts

D. 480 volts

16. An AC voltage is expressed as 240 cos(2765t)V. What is its angular velocity (frequency in radians/second)?

A. 240 r/s

B. 2765 r/s

C. 440 r/s

D. 377 r/s

17. An AC voltage is expressed as 240 cos(2765t)V. What is its frequency (in Hz)?

A. 60 Hz

B. 2765 Hz

C. 440 Hz

D. 377 Hz

18. An AC voltage is expressed as 240 cos(2765t)V. What is its period?

A. 16.7 ms

B. 406 µs

C. 2.27 ms

D. 2.65 ms

19. An AC voltage is expressed as 240 cos(2765t)V. What is its peak-to-peak voltage?

A. 0 volts

B. 240 volts

C. 170 volts

D. 480 volts

20. An AC voltage is expressed as 240 cos(2765t)V. What is its RMS voltage?

A. 0 volts

B. 240 volts

C. 170 volts

D. 480 volts

21. Two milli-amps of current flow through a 2700 ohm resistor. What is the minimum recommended power rating for the resistor?

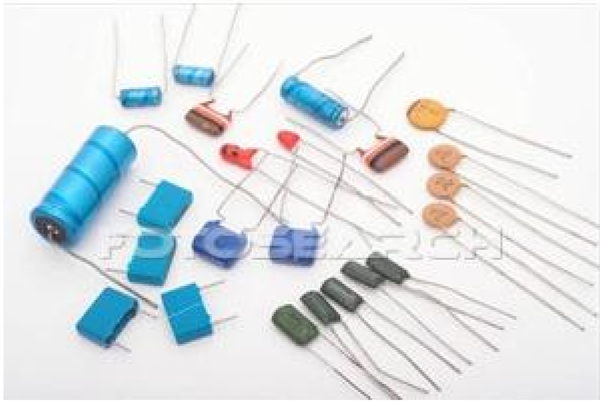
A. 1/8 watt

B. 1/4 watt

C. 1/2 watt

D. 1 watt

22. What type of component is pictured below?



A. transistor

B. capacitor

C. diode

D. inductor

23. Which one of these items can best reduce the possibility of ESD damage?

A. low wattage soldering iron

B. air ionizer

C. insulated tools

D. white noise machine

24. The output voltage of an adjustable power supply is measured most accurately by

A. measuring it with a DMM before connecting it to the intended circuit.

B. measuring it with a DMM after connecting it to the intended circuit.

C. reading the supply's built-in meter before connecting it to the intended circuit.

D. reading the supply's built-in meter after connecting it to the intended circuit.

25. If a DC voltage of 170 volts is measured with an AC voltmeter, the voltage displayed is

A. 170 volts.

B. 120 volts.

C. 0 volts.

D. an error message.

26. If an AC voltage of 170 peak volts is measured with a DC voltmeter, the voltage displayed will be

A. 170 volts.

B. 120 volts.

C. 0 volts.

D. an error message.

27. The current in a resistor is measured by connecting the ammeter

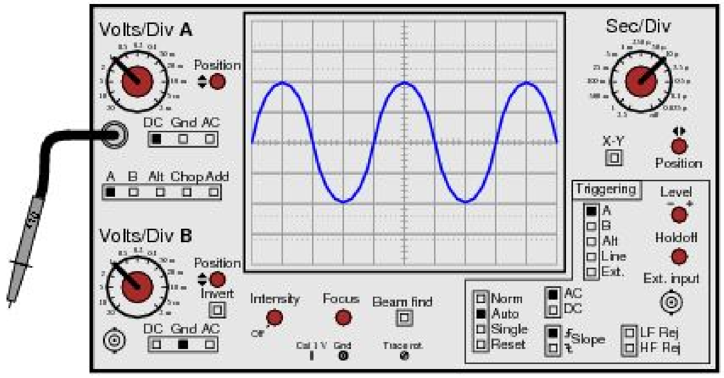
A. across the resistor.

B. in parallel with the resistor.

C. in series with the resistor.

D. across the battery.

28.



The VOLTS/DIV knob on this oscilloscope is set at 1 V. The peak voltage of the displayed signal is

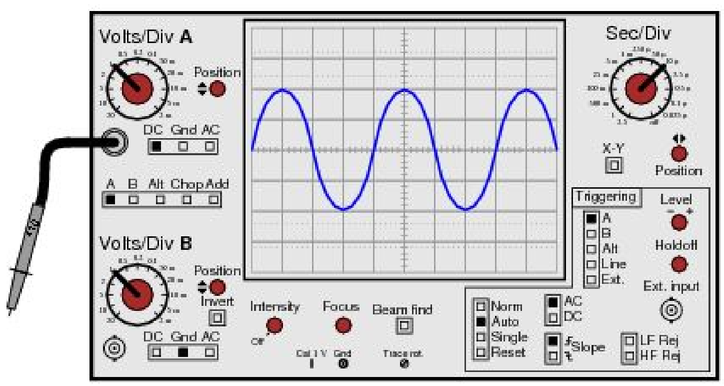
A. 2.83 volts

B. 1 volt

C. 4 volts

D. 2 volt

29.



The SEC/DIV knob on this oscilloscope is set at 10 µs. The period of the displayed signal is

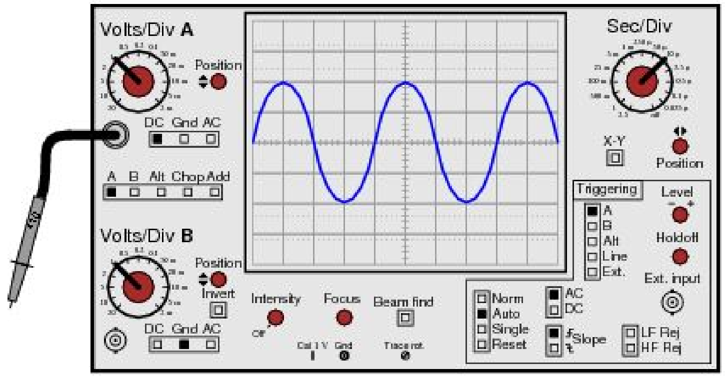
A. 10 µs

B. 100 µs

C. 40 µs

D. 80 µs

30.



The SEC/DIV knob on this oscilloscope is set at 10 µs. The frequency of the displayed signal is

A. 25 kHz

B. 100 kHz

C. 10 kHz

D. 12.5 kHz

APPENDIX H

Performance Test

ECEN 150 Laboratory Test: Laboratory Instruments

Name: ____

Useful Equations:

$1 / f = T$	$360^{o} = 2\pi$ radians
$1 / T = f$	$V_{RMS} = 0.7071\ V_{p}$
$\omega = 2\pi f$	

Procedure:

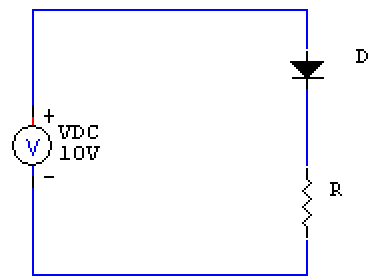
Notes: (1) Record all DMM measurements using 3 digits of precision.

(2) Record all oscilloscope measurements using 2 digits of precision.

(3) Perform all measurements in the order listed.

(4) Replacement fuses are available if you need one. The time required to change it will be included in your measurement time.

Circuit # 1: This circuit has already been constructed for you. It has diode (D) and a resistor (R) connected in series to a 10 V DC voltage source.



Circuit # 1

1-1. Record the time shown on the wall clock (hours:minutes:seconds): ___ : ___ : ___

1-2. Measure the resistance of R with a DMM. R = _______________ Ω

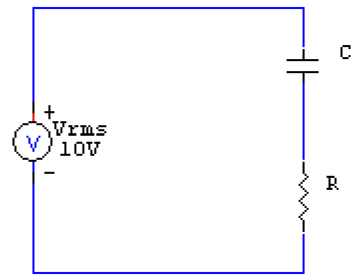
1-3. Measure the voltage across R with a DMM. V_R = _______________ V

1-4. Measure the current through R with a DMM. I_R = _______________ mA

1-5. Record the time shown on the wall clock (hours:minutes:seconds): ___ : ___ : ___

If this section takes longer than 15 minutes, notify the proctor.

Circuit # 2: You must construct this circuit yourself before making any measurements. It has a 10 µF (C) and a 330 Ω resistor (R) connected in series to a 10 V_{RMS} AC voltage source with a frequency (f) of 60 Hz.



Circuit # 2

2-1. Record the time shown on the wall clock (hours:minutes:seconds): ___ : ___ : ___

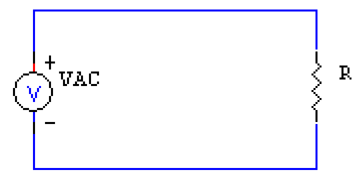
2-2. Measure the RMS voltage across R with a DMM. V_R = _______________ V

2-3. Measure the RMS current through R with a DMM. I_R = _______________ mA

2-4. Record the time shown on the wall clock (hours:minutes:seconds): ___ : ___ : ___

If this section takes longer than 15 minutes, notify the proctor.

Circuit # 3: This circuit has already been constructed for you. A resistor (R) is connected to an AC voltage source.



Circuit # 3

3-1. Record the time shown on the wall clock (hours:minutes:seconds): ___ : ___ : ___

3-2. Measure the peak amplitude of the AC voltage across R with an oscilloscope.

V_R = ________________ V

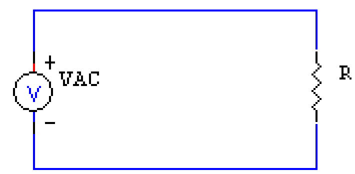
3-3. Measure the period of the AC voltage across R with an oscilloscope.

T= ________________ V

3-4. Record the time shown on the wall clock (hours:minutes:seconds): ___ : ___ : ___

If this section takes longer than 15 minutes, notify the proctor.

Circuit # 4: This circuit has already been constructed for you. A resistor (R) is connected to a function generator as the AC voltage source.



Circuit # 4

4-1. Record the time shown on the wall clock (hours:minutes:seconds): ___ : ___ : ___

4-2. Adjust the function generator for sine wave output with a peak voltage of 2.00 V and a frequency of 440 kHz. Veneer scales, as on this function generator, are often not very accurate. Verify the voltage and frequency with the oscilloscope. Leave it at that setting for the proctor to verify later.

Proctor's Measurement of V_P = __________ V, Proctor's Initials: __________

Proctor's Measurement of f = __________ Hz, Proctor's Initials: __________

4-3. Record the time shown on the wall clock (hours:minutes:seconds): ___ : ___ : ___

If this section takes longer than 15 minutes, notify the proctor.

APPENDIX I

Pittsburgh Freshman Engineering Attitudes Survey

This is a survey to elicit first-year engineering students' opinions and feelings about engineering. Please do not spend more than 15 minutes to complete this questionnaire, so work as quickly as you can. **Your responses will remain anonymous!**

Are you an engineering major or planning to become one?

Yes _____ No _____

If yes, why did you choose to become an engineering major?

For each statement, please circle the word(s) that correspond(s) to how strongly you disagree or agree with the statement.

1. I expect that engineering will be a rewarding career.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

2. I expect that studying engineering will be rewarding.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

3. The advantages of studying engineering outweigh the disadvantages.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

4. I don't care for this career.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

5. The future benefits of studying engineering are worth the effort.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

6. I can think of several other majors that would be more rewarding than engineering.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

7. I have no desire to change to another major.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

8. The rewards of getting an engineering degree are not worth the effort.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

9. From what I know, engineering is boring.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

10. Engineers are well paid.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

11. Engineers contribute more to making the world a better place than people in most occupations do to contribute.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

12. Engineers are innovative.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

13. I enjoy the subjects of science and mathematics the most.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

14. I will have no problem finding a job when I have obtained and engineering degree.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

15. Engineering is an exact science.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

16. My parents are making me study engineering.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

17. Engineering is an occupation that is respected by other people.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

18. I like the professionalism that goes with being an engineer.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

19. I enjoy taking liberal arts courses more than math and science courses.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

20. Engineering is more concerned with improving the welfare of society than most other professions.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

21. I am studying engineering because it will provide me with a lot of money; and I cannot do this in other professions.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

22. Engineers have contributed greatly to fixing problems in the world.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

23. An engineering degree will guarantee me a job when I graduate.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

24. My parents want me to be an engineer.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

25. Engineers are creative.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

26. Engineering involves finding precise answers to problems.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

27. I am studying engineering because I enjoy figuring out how things work.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

28. Technology plays an important role in solving society's problems.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

For the following subjects and skills, please circle the word(s) that correspond(s) to how confident you are of your abilities in the subject or skill.

29. Chemistry

Not Strongly Confident	Not Confident	Neutral	Confident	Strongly Confident

30. Physics

Not Strongly Confident	Not Confident	Neutral	Confident	Strongly Confident

31. Calculus

Not Strongly Confident	Not Confident	Neutral	Confident	Strongly Confident

32. Engineering

Not Strongly Confident	Not Confident	Neutral	Confident	Strongly Confident

33. Writing

Not Strongly Confident	Not Confident	Neutral	Confident	Strongly Confident

34. Speaking

Not Strongly Confident	Not Confident	Neutral	Confident	Strongly Confident

35. Computer Skills

Not Strongly Confident	Not Confident	Neutral	Confident	Strongly Confident

For the following statements about studying, working in groups, and personal abilities, please circle the word(s) that correspond(s) to how strongly you disagree or agree with the statement.

36. I feel I know what an engineer does.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

37. Studying in a group is better than studying by myself.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

38. Creative thinking is one of my strengths.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

39. I need to spend more time studying than I currently do.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

40. I have strong problem solving skills.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

41. Most of my friends that I “hang out” with are studying engineering.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

42. I feel confident in my ability to succeed in engineering.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

43. I prefer studying/working alone.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

44. I am good at designing things.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

45. In the past, I have not enjoyed working in assigned groups.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

46. I am confident about my current study habits or routine.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

47. I consider myself mechanically inclined.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

48. I consider myself technically inclined.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

49. I enjoy solving open-ended problems.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

50. I enjoy problems that can be solved in different ways.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Created by Mary Besterfield-Sacre (mbsacre@pitt.edu): 1040 Benedum Hall, University of Pittsburgh, Pittsburgh, PA 15261.

APPENDIX J

SPSS Data Sets

(See next page.)

Table 13

Pair Scores for All Groups

Pair	EquipmentType[1]	PairingType[2]	Knowledge	Skill		Attitude
				Time	Error	
LD1	LIAB	HL	19.0	44.5	104.4	14.5
LD2	LIAB	HL	20.0	44.5	120.2	11.0
LD3	LIAB	HL	17.5	43.9	82.7	6.5
LD4	LIAB	HL	16.5	43.1	167.8	12.5
LD5	LIAB	HL	21.0	44.7	178.9	15.0
LD6	LIAB	HL	22.0	37.0	80.0	13.0
LD7	LIAB	HL	23.0	55.7	78.2	6.5
LD8	LIAB	HL	20.5	44.7	116.1	9.5
LD9	LIAB	HL	21.5	50.7	158.4	8.0
LS1	LIAB	MM	23.0	53.4	96.2	14.0
LS2	LIAB	MM	20.0	40.4	114.2	13.0
LS3	LIAB	MM	22.0	45.7	158.5	12.5
LS4	LIAB	MM	19.0	36.0	155.5	6.0
LS5	LIAB	MM	23.0	31.9	116.5	8.0
LS6	LIAB	MM	15.5	40.1	157.0	8.5
LS7	LIAB	MM	18.0	48.2	185.9	3.0
LS8	LIAB	MM	21.0	42.2	140.5	5.5
LS9	LIAB	MM	20.0	48.4	165.4	12.0
TD1	TRAD	HL	20.5	38.3	35.6	6.5
TD2	TRAD	HL	18.5	58.8	134.8	8.5
TD3	TRAD	HL	24.5	35.7	121.1	5.5
TD4	TRAD	HL	21.0	31.7	130.8	12.5
TD5	TRAD	HL	20.0	33.4	118.3	5.0
TD6	TRAD	HL	18.0	44.1	170.9	11.5
TD7	TRAD	HL	17.0	38.0	188.0	8.0
TD8	TRAD	HL	17.5	40.0	128.5	5.5
TD9	TRAD	HL	22.5	53.8	167.5	9.0
TS1	TRAD	MM	17.0	30.6	78.2	11.5
TS2	TRAD	MM	21.5	40.7	210.9	11.5
TS3	TRAD	MM	21.5	37.1	97.8	12.0
TS4	TRAD	MM	24.5	27.0	159.7	13.0
TS5	TRAD	MM	20.0	29.7	154.3	7.5
TS6	TRAD	MM	17.0	31.1	104.0	9.0
TS7	TRAD	MM	15.5	48.9	199.3	2.0
TS8	TRAD	MM	22.0	35.1	143.5	5.5
TS9	TRAD	MM	19.5	43.9	178.8	11.5

Note: Knowledge score is test points (higher is better, 30 max); Time score is sum of minutes for all measurements (lower is better, 60 max); Error score is sum of errors for all measurements (lower is better, 400 max). [1] Type of Laboratory. [2] Type of Pairing.

Table 14

Individual Scores for HL Groups

	Speed-Skill		Accuracy-Skill	
Group	TimeH	TimeL	ErrorH	ErrorL
HL1	48.0	41.00	89.3	120.3
HL2	60.0	28.90	113.2	113.2
HL3	46.1	41.60	53.3	111.2
HL4	44.2	42.00	35.9	299.7
HL5	44.6	44.60	205.1	152.6
HL6	39.0	35.00	56.3	103.5
HL7	46.3	55.10	9.6	146.7
HL8	35.2	54.20	121.6	110.6
HL9	46.7	54.70	170.1	146.7
HL10	40.6	34.70	87.4	51.4
HL11	60.0	57.50	111.2	158.3
HL12	51.1	20.30	99.3	144.1
HL13	39.4	23.90	120.3	141.2
HL14	57.6	22.60	133.3	103.2
HL15	43.8	44.40	210.2	131.3
HL16	21.6	54.30	113.8	262.1
HL17	47.6	60.00	136.4	198.6
HL18	44.1	35.90	110.7	73.7

Note: TimeH = measurement time for H student within pair, TimeL = measurement time for L student within pair, ErrorH = measurement error for H student within pair, ErrorL = measurement error for L student within pair

APPENDIX K

SPSS Results

(See next page.)

```
UNIANOVA Knowledge BY EquipmentType PairingType
  /METHOD=SSTYPE (3)
  /INTERCEPT=INCLUDE
  /PLOT=PROFILE (EquipmentType*PairingType PairingType*EquipmentType)
  /EMMEANS=TABLES (OVERALL)
  /EMMEANS=TABLES (EquipmentType)  COMPARE ADJ(LSD)
  /EMMEANS=TABLES (PairingType)  COMPARE ADJ(LSD)
  /EMMEANS=TABLES (EquipmentType*PairingType)
  /PRINT=HOMOGENEITY DESCRIPTIVE  ETASQ
  /CRITERIA=ALPHA (0.05)
  /DESIGN=EquipmentType PairingType EquipmentType*PairingType.
```

Between-Subjects Factors

		N
EquipmentType	LIAB	18
	TRAD	18
PairingType	HL	18
	MM	18

Descriptive Statistics

Dependent Variable: Knowledge

EquipmentType	PairingType	Mean	Std. Deviation	N
LIAB	HL	20.056	2.1131	9
	MM	20.167	2.4495	9
	Total	20.111	2.2199	18
TRAD	HL	19.944	2.4805	9
	MM	19.833	2.8940	9
	Total	19.889	2.6153	18
Total	HL	20.000	2.2361	18
	MM	20.000	2.6066	18
	Total	20.000	2.3934	36

Levene's Test of Equality of Error Variances[a]

Dependent Variable: Knowledge

F	df1	df2	Sig.
.359	3	32	.783

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + EquipmentType + PairingType + EquipmentType * PairingType

Tests of Between-Subjects Effects

Dependent Variable: Knowledge

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	.556[a]	3	.185	.030	.993	.003
Intercept	14400.000	1	14400.000	2304.640	.000	.986
EquipmentType	.444	1	.444	.071	.791	.002
PairingType	.000	1	.000	.000	1.000	.000
EquipmentType * PairingType	.111	1	.111	.018	.895	.001
Error	199.944	32	6.248			
Total	14600.500	36				
Corrected Total	200.500	35				

a. R Squared = .003 (Adjusted R Squared = -.091)

1. Grand Mean

Dependent Variable: Knowledge

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
20.000	.417	19.151	20.849

2. Estimates

Dependent Variable: Knowledge

EquipmentType	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
LIAB	20.111	.589	18.911	21.311
TRAD	19.889	.589	18.689	21.089

Pairwise Comparisons

Dependent Variable: Knowledge

(I) EquipmentType	(J) EquipmentType	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
LIAB	TRAD	.222	.833	.791	-1.475	1.919
TRAD	LIAB	-.222	.833	.791	-1.919	1.475

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Univariate Tests

Dependent Variable: Knowledge

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	.444	1	.444	.071	.791	.002
Error	199.944	32	6.248			

The F tests the effect of EquipmentType. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

3. Estimates

Dependent Variable: Knowledge

PairingType	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
HL	20.000	.589	18.800	21.200
MM	20.000	.589	18.800	21.200

Pairwise Comparisons

Dependent Variable: Knowledge

(I) PairingType	(J) PairingType	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
HL	MM	.000	.833	1.000	-1.697	1.697
MM	HL	.000	.833	1.000	-1.697	1.697

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Univariate Tests

Dependent Variable: Knowledge

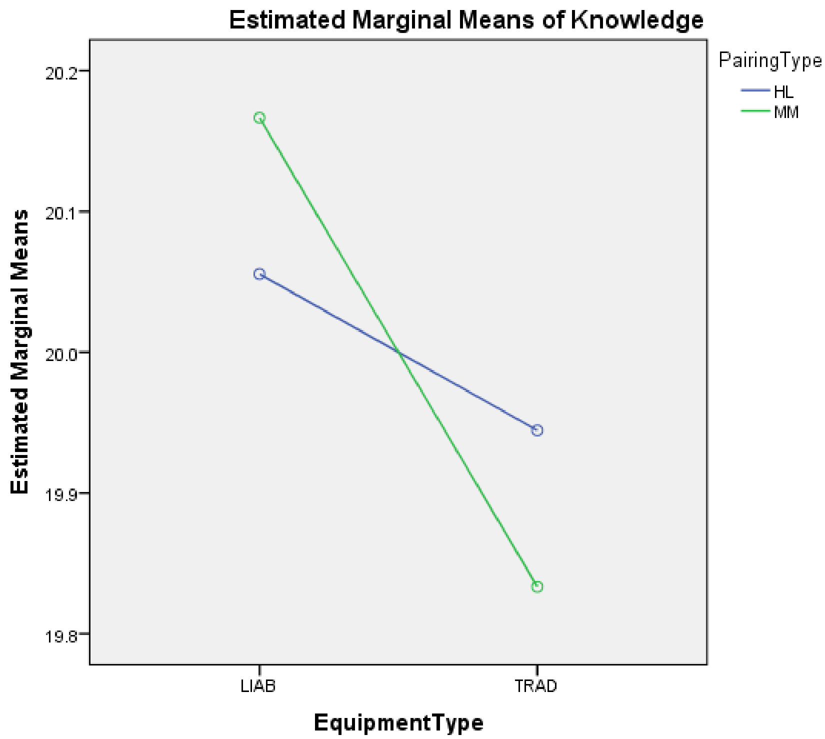
	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	.000	1	.000	.000	1.000	.000
Error	199.944	32	6.248			

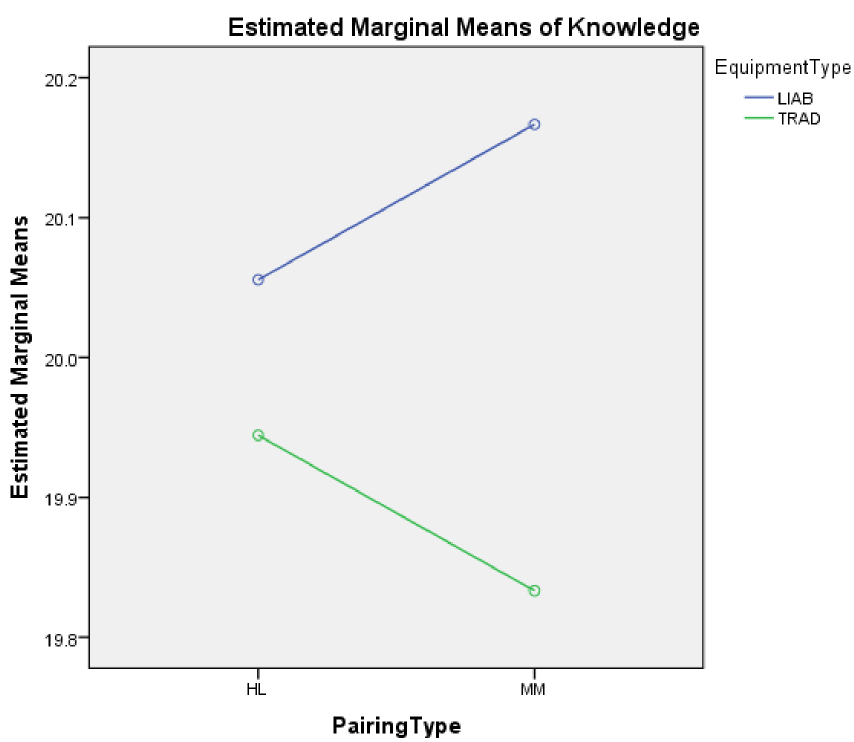
The F tests the effect of PairingType. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

4. EquipmentType * PairingType

Dependent Variable: Knowledge

EquipmentType	PairingType	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
LIAB	HL	20.056	.833	18.358	21.753
	MM	20.167	.833	18.469	21.864
TRAD	HL	19.944	.833	18.247	21.642
	MM	19.833	.833	18.136	21.531


Estimated Marginal Means of Knowledge
PairingType
HL
MM
Estimated Marginal Means
20.2
20.1
20.0
19.9
19.8
LIAB
TRAD
EquipmentType


Estimated Marginal Means of Knowledge
EquipmentType
LIAB
TRAD
Estimated Marginal Means
20.2
20.1
20.0
19.9
19.8
HL
MM
PairingType

```
UNIANOVA Time BY EquipmentType PairingType
  /METHOD=SSTYPE (3)
  /INTERCEPT=INCLUDE
  /PLOT=PROFILE (EquipmentType*PairingType PairingType*EquipmentType)
  /EMMEANS=TABLES (OVERALL)
  /EMMEANS=TABLES (EquipmentType)  COMPARE ADJ(LSD)
  /EMMEANS=TABLES (PairingType)  COMPARE ADJ(LSD)
  /EMMEANS=TABLES (EquipmentType*PairingType)
  /PRINT=HOMOGENEITY DESCRIPTIVE  ETASQ
  /CRITERIA=ALPHA (0.05)
  /DESIGN=EquipmentType PairingType EquipmentType*PairingType.
```

Between-Subjects Factors

		N
EquipmentType	LIAB	18
	TRAD	18
PairingType	HL	18
	MM	18

Descriptive Statistics

Dependent Variable: Time

EquipmentType	PairingType	Mean	Std. Deviation	N
LIAB	HL	45.422	5.1826	9
	MM	42.922	6.7046	9
	Total	44.172	5.9538	18
TRAD	HL	41.533	9.2016	9
	MM	36.011	7.3040	9
	Total	38.772	8.5453	18
Total	HL	43.478	7.5158	18
	MM	39.467	7.6748	18
	Total	41.472	7.7578	36

Levene's Test of Equality of Error Variances[a]

Dependent Variable: Time

F	df1	df2	Sig.
1.241	3	32	.311

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + EquipmentType + PairingType + EquipmentType * PairingType

Tests of Between-Subjects Effects

Dependent Variable: Time

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	427.792[a]	3	142.597	2.718	.061	.203
Intercept	61918.028	1	61918.028	1180.347	.000	.974
EquipmentType	262.440	1	262.440	5.003	.032	.135
PairingType	144.801	1	144.801	2.760	.106	.079
EquipmentType * PairingType	20.551	1	20.551	.392	.536	.012
Error	1678.640	32	52.458			
Total	64024.460	36				
Corrected Total	2106.432	35				

a. R Squared = .203 (Adjusted R Squared = .128)

1. Grand Mean

Dependent Variable: Time

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
41.472	1.207	39.013	43.931

2. Estimates

Dependent Variable: Time

EquipmentType	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
LIAB	44.172	1.707	40.695	47.650
TRAD	38.772	1.707	35.295	42.250

Pairwise Comparisons

Dependent Variable: Time

(I) EquipmentType	(J) EquipmentType	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
LIAB	TRAD	5.400*	2.414	.032	.482	10.318
TRAD	LIAB	-5.400*	2.414	.032	-10.318	-.482

Based on estimated marginal means

*. The mean difference is significant at the 0.05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Univariate Tests

Dependent Variable: Time

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	262.440	1	262.440	5.003	.032	.135
Error	1678.640	32	52.458			

The F tests the effect of EquipmentType. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

3. Estimates

Dependent Variable: Time

PairingType	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
HL	43.478	1.707	40.000	46.955
MM	39.467	1.707	35.989	42.944

Pairwise Comparisons

Dependent Variable: Time

(I) PairingType	(J) PairingType	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
HL	MM	4.011	2.414	.106	-.907	8.929
MM	HL	-4.011	2.414	.106	-8.929	.907

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Univariate Tests

Dependent Variable: Time

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	144.801	1	144.801	2.760	.106	.079
Error	1678.640	32	52.458			

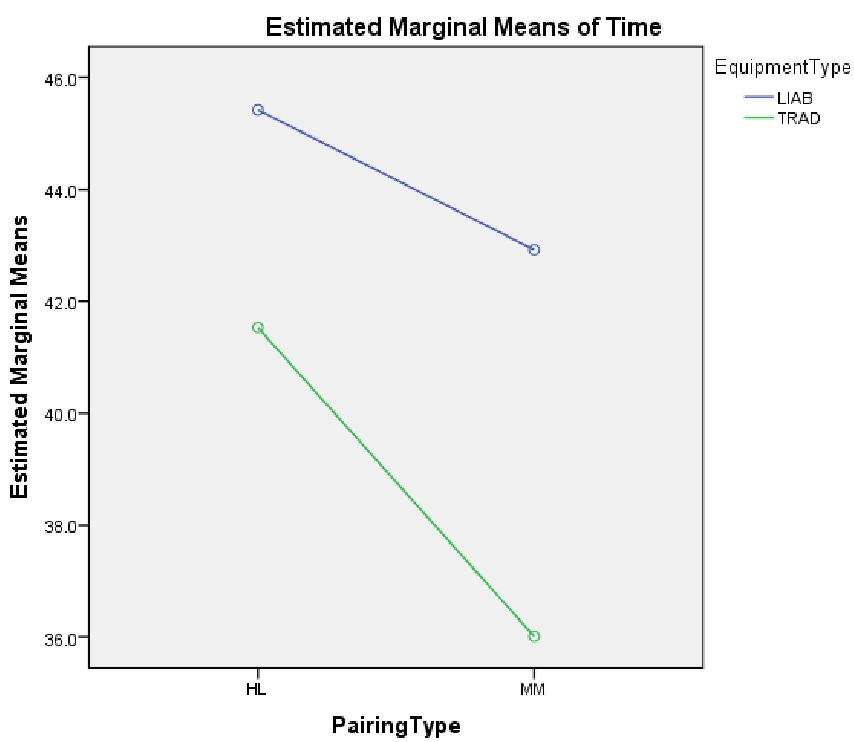
The F tests the effect of PairingType. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

4. EquipmentType * PairingType

Dependent Variable: Time

EquipmentType	PairingType	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
LIAB	HL	45.422	2.414	40.505	50.340
	MM	42.922	2.414	38.005	47.840
TRAD	HL	41.533	2.414	36.616	46.451
	MM	36.011	2.414	31.093	40.929


Estimated Marginal Means of Time
PairingType
HL
MM
46.0
44.0
42.0
40.0
38.0
36.0
Estimated Marginal Means
LIAB
TRAD
EquipmentType


Estimated Marginal Means of Time
EquipmentType
LIAB
TRAD
46.0
44.0
42.0
40.0
38.0
36.0
Estimated Marginal Means
HL
MM
PairingType

```
UNIANOVA Error BY EquipmentType PairingType
  /METHOD=SSTYPE (3)
  /INTERCEPT=INCLUDE
  /PLOT=PROFILE (EquipmentType*PairingType PairingType*EquipmentType)
  /EMMEANS=TABLES (OVERALL)
  /EMMEANS=TABLES (EquipmentType)  COMPARE ADJ(LSD)
  /EMMEANS=TABLES (PairingType)  COMPARE ADJ(LSD)
  /EMMEANS=TABLES (EquipmentType*PairingType)
  /PRINT=HOMOGENEITY DESCRIPTIVE  ETASQ
  /CRITERIA=ALPHA (0.05)
  /DESIGN=EquipmentType PairingType EquipmentType*PairingType.
```

Between-Subjects Factors

		N
EquipmentType	LIAB	18
	TRAD	18
PairingType	HL	18
	MM	18

Descriptive Statistics

Dependent Variable: Error

EquipmentType	PairingType	Mean	Std. Deviation	N
LIAB	HL	120.744	39.0845	9
	MM	143.300	28.8575	9
	Total	132.022	35.2906	18
TRAD	HL	132.833	44.0514	9
	MM	147.389	46.1767	9
	Total	140.111	44.4151	18
Total	HL	126.789	40.8747	18
	MM	145.344	37.4131	18
	Total	136.067	39.7481	36

Levene's Test of Equality of Error Variances[a]

Dependent Variable: Error

F	df1	df2	Sig.
.510	3	32	.678

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + EquipmentType + PairingType + EquipmentType * PairingType

Tests of Between-Subjects Effects

Dependent Variable: Error

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	3831.649[a]	3	1277.216	.794	.506	.069
Intercept	666508.960	1	666508.960	414.421	.000	.928
EquipmentType	588.871	1	588.871	.366	.549	.011
PairingType	3098.778	1	3098.778	1.927	.175	.057
EquipmentType * PairingType	144.000	1	144.000	.090	.767	.003
Error	51465.291	32	1608.290			
Total	721805.900	36				
Corrected Total	55296.940	35				

a. R Squared = .069 (Adjusted R Squared = -.018)

1. Grand Mean

Dependent Variable: Error

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
136.067	6.684	122.452	149.681

2. Estimates

Dependent Variable: Error

EquipmentType	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
LIAB	132.022	9.452	112.768	151.276
TRAD	140.111	9.452	120.857	159.365

Pairwise Comparisons

Dependent Variable: Error

(I) EquipmentType	(J) EquipmentType	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
LIAB	TRAD	-8.089	13.368	.549	-35.318	19.140
TRAD	LIAB	8.089	13.368	.549	-19.140	35.318

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Univariate Tests

Dependent Variable: Error

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	588.871	1	588.871	.366	.549	.011
Error	51465.291	32	1608.290			

The F tests the effect of EquipmentType. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

3. Estimates

Dependent Variable: Error

PairingType	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
HL	126.789	9.452	107.535	146.043
MM	145.344	9.452	126.090	164.599

Pairwise Comparisons

Dependent Variable: Error

(I) PairingType	(J) PairingType	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
HL	MM	-18.556	13.368	.175	-45.785	8.674
MM	HL	18.556	13.368	.175	-8.674	45.785

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Univariate Tests

Dependent Variable: Error

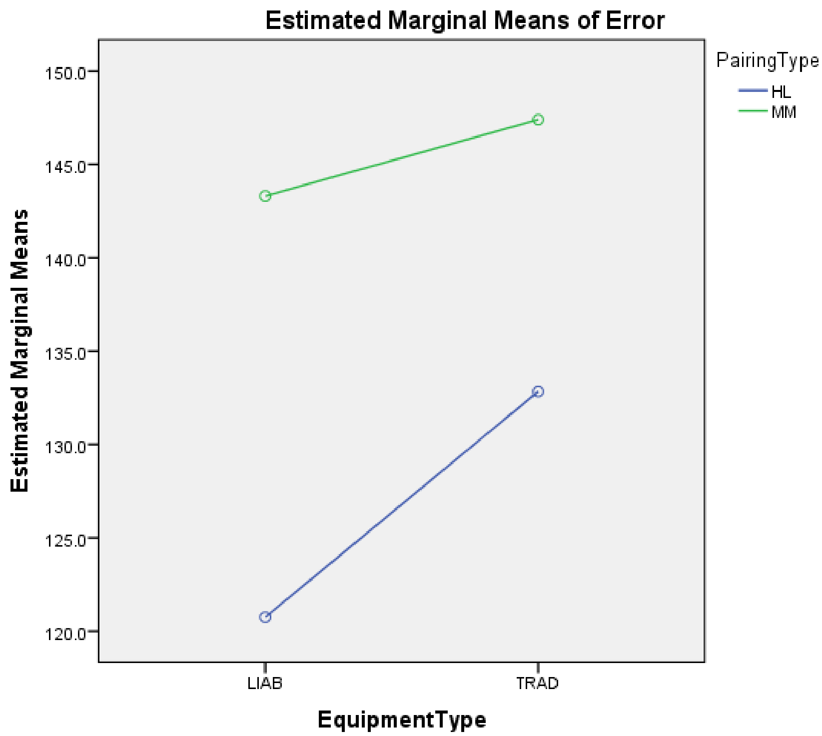
	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	3098.778	1	3098.778	1.927	.175	.057
Error	51465.291	32	1608.290			

The F tests the effect of PairingType. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

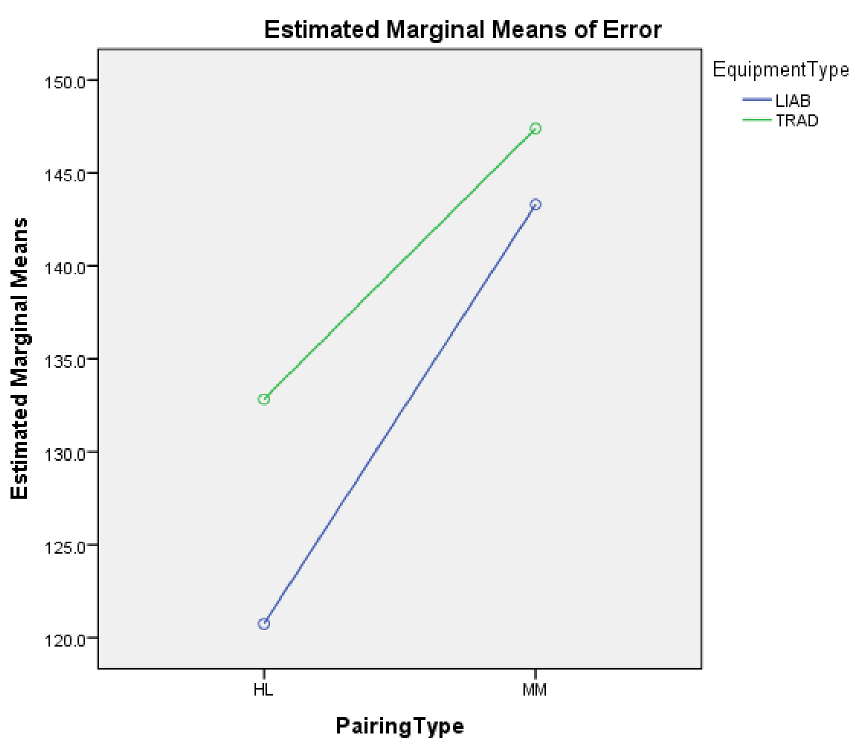
4. EquipmentType * PairingType

Dependent Variable: Error

EquipmentType	PairingType	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
LIAB	HL	120.744	13.368	93.515	147.974
	MM	143.300	13.368	116.071	170.529
TRAD	HL	132.833	13.368	105.604	160.063
	MM	147.389	13.368	120.160	174.618



Estimated Marginal Means of Error
PairingType
HL
MM
150.0
145.0
140.0
135.0
130.0
125.0
120.0
Estimated Marginal Means
LIAB
TRAD
EquipmentType



Estimated Marginal Means of Error
EquipmentType
LIAB
TRAD
150.0
145.0
140.0
135.0
130.0
125.0
120.0
Estimated Marginal Means
HL
MM
PairingType

```
UNIANOVA Attitude BY EquipmentType PairingType
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  /INTERCEPT=INCLUDE
  /PLOT=PROFILE (EquipmentType*PairingType PairingType*EquipmentType)
  /EMMEANS=TABLES (OVERALL)
  /EMMEANS=TABLES (EquipmentType)  COMPARE ADJ(LSD)
  /EMMEANS=TABLES (PairingType)  COMPARE ADJ(LSD)
  /EMMEANS=TABLES (EquipmentType*PairingType)
  /PRINT=HOMOGENEITY DESCRIPTIVE  ETASQ
  /CRITERIA=ALPHA (0.05)
  /DESIGN=EquipmentType PairingType EquipmentType*PairingType.
```

Between-Subjects Factors

		N
EquipmentType	LIAB	18
	TRAD	18
PairingType	HL	18
	MM	18

Descriptive Statistics

Dependent Variable: Attitude

EquipmentType	PairingType	Mean	Std. Deviation	N
LIAB	HL	10.722	3.2702	9
	MM	9.167	3.8810	9
	Total	9.944	3.5723	18
TRAD	HL	8.000	2.6810	9
	MM	9.278	3.6496	9
	Total	8.639	3.1753	18
Total	HL	9.361	3.2213	18
	MM	9.222	3.6551	18
	Total	9.292	3.3962	36

Levene's Test of Equality of Error Variances[a]

Dependent Variable: Attitude

F	df1	df2	Sig.
.802	3	32	.502

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + EquipmentType + PairingType + EquipmentType * PairingType

Tests of Between-Subjects Effects

Dependent Variable: Attitude

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	33.576[a]	3	11.192	.968	.420	.083
Intercept	3108.063	1	3108.063	268.725	.000	.894
EquipmentType	15.340	1	15.340	1.326	.258	.040
PairingType	.174	1	.174	.015	.903	.000
EquipmentType * PairingType	18.063	1	18.063	1.562	.220	.047
Error	370.111	32	11.566			
Total	3511.750	36				
Corrected Total	403.688	35				

a. R Squared = .083 (Adjusted R Squared = -.003)

1. Grand Mean

Dependent Variable: Attitude

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
9.292	.567	8.137	10.446

2. Estimates

Dependent Variable: Attitude

EquipmentType	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
LIAB	9.944	.802	8.312	11.577
TRAD	8.639	.802	7.006	10.272

Pairwise Comparisons

Dependent Variable: Attitude

(I) EquipmentType	(J) EquipmentType	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
LIAB	TRAD	1.306	1.134	.258	-1.004	3.615
TRAD	LIAB	-1.306	1.134	.258	-3.615	1.004

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Univariate Tests

Dependent Variable: Attitude

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	15.340	1	15.340	1.326	.258	.040
Error	370.111	32	11.566			

The F tests the effect of EquipmentType. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

3. Estimates

Dependent Variable: Attitude

PairingType	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
HL	9.361	.802	7.728	10.994
MM	9.222	.802	7.589	10.855

Pairwise Comparisons

Dependent Variable: Attitude

(I) PairingType	(J) PairingType	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
HL	MM	.139	1.134	.903	-2.170	2.448
MM	HL	-.139	1.134	.903	-2.448	2.170

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Univariate Tests

Dependent Variable: Attitude

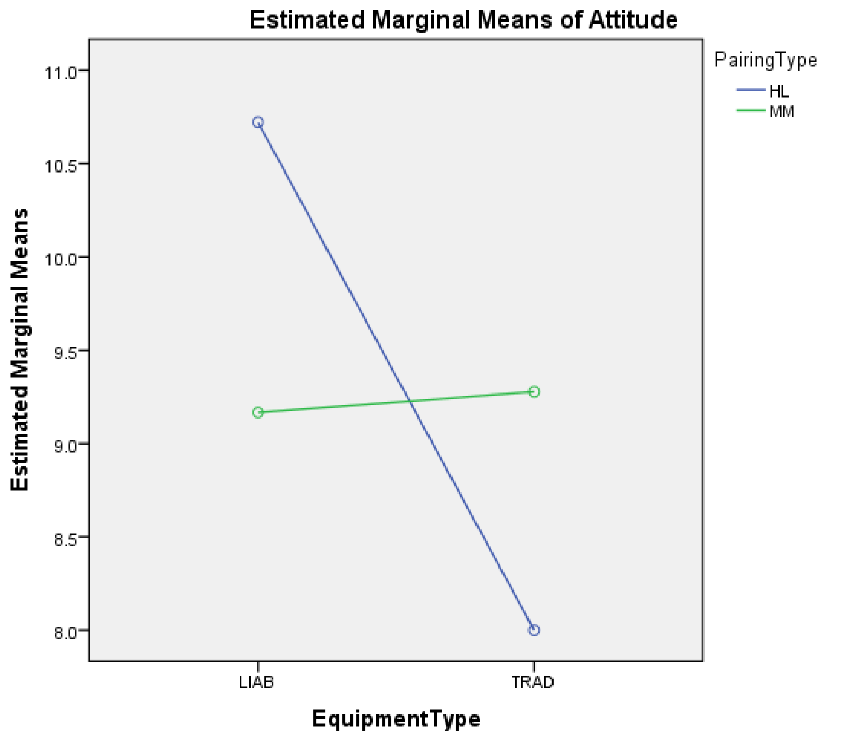
	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	.174	1	.174	.015	.903	.000
Error	370.111	32	11.566			

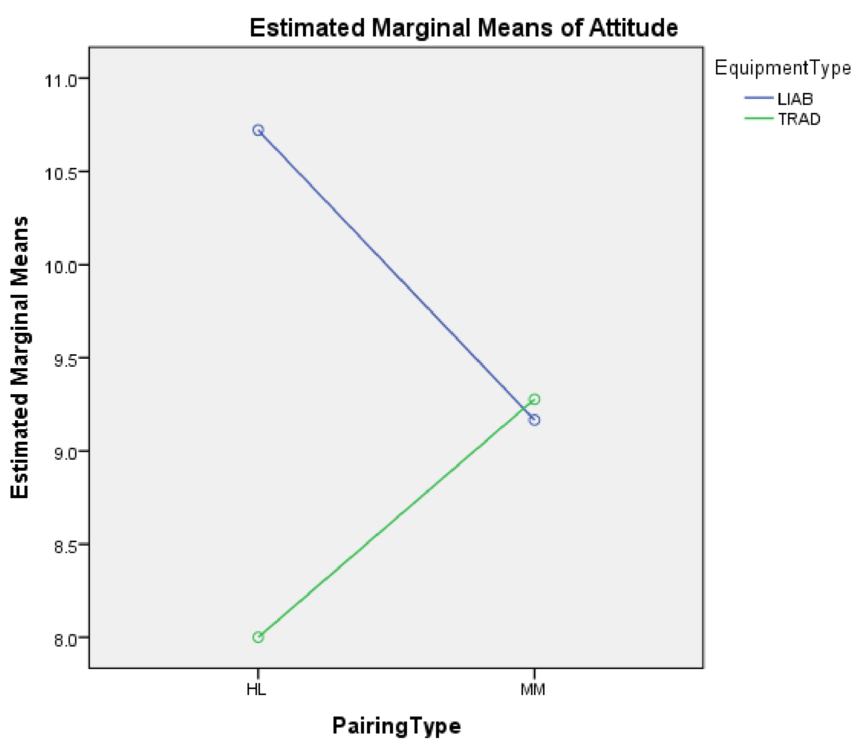
The F tests the effect of PairingType. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

4. EquipmentType * PairingType

Dependent Variable: Attitude

EquipmentType	PairingType	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
LIAB	HL	10.722	1.134	8.413	13.031
	MM	9.167	1.134	6.858	11.476
TRAD	HL	8.000	1.134	5.691	10.309
	MM	9.278	1.134	6.969	11.587


Estimated Marginal Means of Attitude
PairingType
HL
MM
Estimated Marginal Means
11.0
10.5
10.0
9.5
9.0
8.5
8.0
LIAB
TRAD
EquipmentType


Estimated Marginal Means of Attitude
EquipmentType
LIAB
TRAD
Estimated Marginal Means
11.0
10.5
10.0
9.5
9.0
8.5
8.0
HL
MM
PairingType

```
T-TEST PAIRS=TimeH WITH TimeL (PAIRED)
  /CRITERIA=CI(.9500)
  /MISSING=ANALYSIS.
```

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	TimeH	45.328	18	9.0715	2.1382
	TimeL	41.7056	18	12.59171	2.96789

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
TimeH - TimeL	3.62222	17.26808	4.07013	-4.96499	12.20944	.890	17	.386

```
T-TEST PAIRS=ErrorH WITH ErrorL (PAIRED)
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  /MISSING=ANALYSIS.
```

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ErrorH	109.833	18	52.5390	12.3836
	ErrorL	142.689	18	60.4522	14.2487

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
ErrorH - ErrorL	-32.8556	83.7512	19.7403	-74.5040	8.7929	-1.664	17	.114