Relationships Among Personal Characteristics, Self-Efficacy, and Conceptual

Knowledge of Circuit Analysis of Community College Engineering Students

by

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ABSTRACT

Conceptual knowledge and self-efficacy are two research topics that are well-established at universities, however very little has been investigated about these at the community college. A sample of thirty-seven students enrolled in three introductory circuit analysis classes at a large southwestern community college was used to answer questions about conceptual knowledge and self-efficacy of community college engineering students. Measures included a demographic survey and a pre/post three-tiered concept inventory to evaluate student conceptual knowledge of basic DC circuit analysis and self-efficacy for circuit analysis.

A group effect was present in the data, so descriptive statistics were used to investigate the relationships among students' personal and academic characteristics and conceptual knowledge of circuit analysis. The a priori attribute approach was used to qualitatively investigate misconceptions students have for circuit analysis. The results suggest that students who take more credit hours score higher on a test of conceptual knowledge of circuit analysis, however additional research is required to confirm this, due to the group effect. No new misconceptions were identified. In addition to these, one group of students received more time to practice using the concepts. Consequently, that group scored higher on the concept inventory, possibly indicating that students who have extra practice time may score higher on a test of conceptual knowledge of circuit analysis.

Correlation analysis was used to identify relationships among students' personal and academic characteristics and self-efficacy for circuit analysis, as well as to

investigate the relationship between self-efficacy for circuit analysis and conceptual knowledge of circuit analysis. Subject's father's education level was found to be inversely correlated with self-efficacy for circuit analysis, and subject's age was found to be directly correlated with self-efficacy for circuit analysis. Finally, self-efficacy for circuit analysis was found to be positively correlated with conceptual knowledge of circuit analysis.

This dissertation is dedicated to my wife, Madeline Boyle-Whitesel.

You encouraged me from the community college to now.

I am a better man because of you.

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INTRODUCTION

**Background of the Study**

America is not producing and keeping enough engineers and scientists to meet

changing industry needs (Carnevale, Smith, & Strohl, 2010).  The science and

engineering job sectors are fast-growing, yet fewer college students are choosing to study

science and engineering.  Of those who start an engineering program, 40% change their

major (Carnevale, Smith, & Strohl, 2010).  The reason for concern is rooted in the fear

that companies will relocate from the U.S. for other countries, in search of the skilled

workforce needed for their industries.  As American need for engineers increases, the

number of college graduates is only slightly increasing.  Many of those students who do

graduate are foreign nationals who return to their home countries, leaving a shortage of

their skills in the United States (Carnevale, Smith, & Strohl, 2010).  This inability to

produce enough engineers to meet industry demand would eventually remove the U.S

from its position as a global leader (Hagedorn & Purnamasari, 2012). This phenomenon

has been called a "creeping crisis" by leaders in the National Academies (Wulf, 2005)

and the "quiet crisis" by economist Thomas Friedman (Friedman, 2006).  It is predicted

that there will continue to be a shortfall in skilled Science, Technology, Engineering and

Math (STEM) labor (Packard, Gagnon, & Senas, 2012).

Many assume that the majority of STEM careers require a bachelor's degree.  In

fact, most shortages are in jobs that require less than a bachelor's degree but more than a

high school diploma (Hagedorn & Purnamasari, 2012).  Community colleges are the

primary providers of this skilled training, and are defined as "Any institution accredited

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to award the associate degree as its highest degree" (Cohen & Brawer, 2008). There is a wealth of research studying STEM students in 4-year universities, but far less on community college students and virtually no research on community college engineering students. This is a major issue that needs to be addressed given the role community colleges play in educating a skilled engineering workforce. This study adds to the body of knowledge by focusing on the overlooked community college engineering student population.

**Statement of Problem/Rationale**

There would be no shortage of skilled workers if the current needs in STEM fields were filled with qualified minorities in the same proportions as their percentages in the general population (May & Chubin, 2003). Community colleges are the primary entry point for minorities in STEM fields (Starobin & Laanan, 2008), yet research on minorities pursuing STEM degrees has focused mainly on university engineering students.

Community college students are different from university students. The little research available on community college engineering students has focused on retention and transfer students. Unfortunately, few community college students complete an Associate's (AAS) degree in engineering, and even less transfer and graduate from a four-year engineering program within eight years (Packard, Gagnon, & Senas, 2012). This is a problem because those students whose only goals are to complete an AAS or certificate of completion (CCL) are overlooked by the results of research on university students. Those overlooked students are the technicians and maintenance workers who make up the skilled workforce that is so desired.

Within engineering education, at both universities and community colleges, DC circuit analysis is considered to be a difficult course for many engineering students to understand (Streveler, Litzinger, Miller, & Steif, 2008). This is important because correct conceptual knowledge may help students gain expertise in their performance, yet there have been no studies of this topic involving the community college student population. Of the few studies on community college engineering students, there is a common link with research on the university population. That link is the use of self-efficacy as the theoretical basis (Jones, Paretti, Hein, & Knott, 2010). This is rooted in the fact that many of the strategies intended to increase student interest, achievement and persistence in engineering are based on increasing self-efficacy, which is a better predictor of those outcomes than value-based, achievement based, or career based approaches (Schull & Weiner, 2002; Jones, Paretti, Hein, & Knott, 2010).

Solutions that match the characteristics of the community college population have to be created in order to reverse the downward trend in graduating skilled engineering technicians. In order to ascertain who comprises that population and their needs, more research has to be conducted on engineering education at the community college level. A logical starting point is to examine the relationships between conceptual knowledge of a traditionally difficult subject – DC circuit analysis – with self-efficacy for circuit analysis and the characteristics that identify community college engineering students.

**Purpose of the Study**

The purpose of this study is to examine the relationships between 1) personal and academic characteristics and conceptual knowledge of DC circuit analysis, 2) personal and academic characteristics and self-efficacy for circuit analysis, and 3) self-efficacy for

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and conceptual knowledge of circuit analysis, for community college engineering students. In this study, conceptual knowledge, self-efficacy, and predictors of both were used to gain insight into the relationships being investigated.

To accomplish this objective, 37 community college engineering students enrolled in two introductory circuit analysis courses were studied. At the start of the semester, students in each class were given a three-tiered concept inventory to assess their knowledge of basic DC circuit analysis and self-efficacy for circuit analysis. Students were also given a survey to determine their personal and academic characteristics as part of the same instrument. The concept inventory was re-administered to each class after the material measured by the concept inventory had been taught by their instructors. A group effect was present for the pre- and post-test characteristics and conceptual knowledge analysis. The data set was subsequently analyzed using quantitative and qualitative methods to look for evidence that might explain the differences among the classes. There was no difference between the classes' pre- and post-test self-efficacy scores, so the data set was analyzed to look for correlations among the demographic and academic characteristics of the students. Finally, the self-efficacy data and the conceptual knowledge data sets were analyzed for correlations between them.

Due to the lack of distinction in the literature between engineering and engineering technology, for the purpose and context of this study, the term *engineering student(s)* is used to represent students enrolled in engineering or engineering technology programs. This is supported in the literature by the Grinter Report (Grinter, 1955; Grinter, 1984) and the more recent work of Land (2012).

**Research Questions**

  To investigate the relationships between community college engineering students' personal and academic characteristics, conceptual knowledge of DC circuit analysis, and self-efficacy for circuit analysis, several research questions were identified:

  *Research Question One: What demographic or academic characteristics are correlated with conceptual knowledge of circuit analysis?*

  *Research Question Two: What demographic or academic characteristics are correlated with self-efficacy for circuit analysis?*

  *Research Question Three: Does self-efficacy for circuit analysis correlate with conceptual knowledge of circuit analysis?*

  These questions will provide the needed insight into the relationships between personal characteristics, conceptual knowledge of DC circuit analysis, and self-efficacy for circuit analysis of this group of community college students that is very different from their university cohorts.

Chapter 2

REVIEW OF RELEVANT LITERATURE

**Introduction**

Within the literature, self-efficacy is a common theoretical framework for

research in engineering education. Self-efficacy is a context-specific predictor of

performance (Bong, 2001), and has also been shown to be an influence on the

development of interests, values and goals (Kantas, 1997). Self-efficacy has been shown

in the literature to be correlated with several key personal and academic characteristics,

as outlined in Table 1. Because of its common usage in engineering education research,

its correlation with personal and academic characteristics, and the fact that the present

study assesses performance, makes self-efficacy the appropriate theoretical framework.

Table 1

*Characteristics Correlated with Self-Efficacy*

| Characteristics | | |
|---|---|---|
| Hours worked each week *(a)* | Total time in program *(b, c)* | Number of college chemistry courses *(d)* |
| Gender *(d, e)* | Taken remedial Math *(f)* | Taken remedial English *(f)* |
| Race/Ethnicity *(a)* | Highest high-school Math course *(d, g, h)* | Marital status *(f)* |
| Percentage of tuition paid by financial aid (i) | Dependent children *(j)* | |

Sources: *(a)* Kane, Beals, Valeau, & Johnson, 2004. *(b)* Spellman, 2007. *(c)* Pajares, 2009. *(d)* Buchanan, 2006. *(e)* Besterfield-Sacre, Moreno, Shuman, & Atman, 2001 *(f)* Chatman, 2007. *(g)* Adleman, 1998. *(h)* Tyson, 2011. *(i)* Hayden & Holloway. *(j)* Packard, Gagnon & Senas, 2012.

The assessment used in this study is a concept inventory, which measures conceptual knowledge of voltage, current and the physical characteristics of DC circuit analysis. Concepts are the organizers that sort our prior knowledge so we have an idea of what to expect when we encounter something new (Perkins, 2006). Conceptual knowledge is the understanding or interpretation one may have about concepts. This can then be carried into future situations, providing the holder with an idea of what to expect in that situation (Demirci, 2010). Academic characteristics tend to be associated with the concepts of voltage, current and the physical characteristics of DC circuit analysis since conceptual knowledge is based on prior knowledge (Antimirova, Noack, & Milner-Bolotin, 2009). However, any prior knowledge that provides insight into the basis of electricity or electronics can help to shape conceptual knowledge of DC circuit analysis before a student even takes a circuit analysis course. This prior knowledge tends to come from high school and college math, physics and chemistry courses (Antimirova, Noack, & Milner-Bolotin, 2009).

The particular concepts of voltage, current and the physical characteristics of DC circuit analysis were chosen for the present study because they have been identified in the literature as being particularly difficult for students to learn (Engelhardt & Beichner, 2004; Streveler, et al., 2006; Peşman & Eryilmaz, 2010). Prior research has not been extended to the community college population, which has been shown to be very different from the university student population. Community college students, in general, have different educational goals and academic backgrounds than their university cohorts; the principal role of the community college is to be the provider of workplace and skill training. Most community colleges attract students who are under-represented minorities,

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older, female, and those in search of education for a career change. Many of these students are ill-prepared for college (Hagedorn & Purnamasari, 2012). Compared to their university counterparts, community college students generally arrive on campus with issues related to academics, family, finances, and personal issues. Specific demographic and personal characteristics related to these issues are highlighted in Table 2.

Table 2

*Unique Characteristics of Community College Students*

| Category | Characteristics | |
|---|---|---|
| Academics | Require remedial Math *(a,b)* | Require remedial English *(a,b)* |
| | Less Chemistry, Physics & Math courses in high school *(c)* | Less Chemistry, Physics & Math courses in college *(d)* |
| | Lower high-school GPA *(e)* | Longer time working toward degree *(a)* |
| Family | Married *(f)* | Have dependent children *(f)* |
| | Less parental education *(g)* | |
| Finances | Dependent on Financial Aid *(f)* | Work full, or more than part-time *(h)* |
| Personal | Under-represented Minority *(a)* | Older than university students *(a)* |
| | Take time off from studies *(h)* | First-generation college student *(g)* |

Sources: *(a)* Cohen & Brawer, 2008. *(b)* Chatman, 2007. *(c)* Tyson, 2011. *(d)* Adleman, 1998. *(e)* Kane, Beals, Valeau, & Johnson, 2004. *(f)* Packard, Gagnon, & Senas, 2012. *(g)* Cassidy, 2004. *(h)* Alfonso, 2006.

Clearly there is some overlap indicating that self-efficacy and conceptual knowledge are related. Additionally, there are other characteristics that may be correlated with each. What is not known is how the characteristics that define a community college engineering student population are related to their self-efficacy for circuit analysis and conceptual knowledge of voltage, current and the physical

characteristics of DC circuits. The present study extends the work of others by applying prior research on self-efficacy and conceptual knowledge of voltage, current and the physical characteristics of DC circuits to a community college engineering student population.

**Theoretical Framework.** Self-Efficacy is based on confidence about one's capabilities to organize and implement actions necessary to attain desired performance (Bandura, 1997). People have little incentive to persevere with a project if they lack high self-efficacy (Pajares, 2009). Self-efficacy is context and domain-related (Vogt, Hocevar, & Hagedorn, 2007); the more specific a domain is, the more specific one can determine self-efficacy. Self-Efficacy is not the same as outcome expectation or self-concept. Outcome expectation is the judgment of consequences that may result from behavior, while self-concept is a much more broad evaluation that includes self-efficacy in addition to worth and esteem in relation to a task, thus self-concept can be domain-specific, but is not based on context. Self-efficacy, is an evaluation of one's confidence to succeed at a task in the context of a domain (Pajares, 2009).

Self-efficacy is also a significant contributor to motivation and performance in terms of choices of activities to pursue and those to avoid, as well as behavior for people who have different levels of self-efficacy, and behavior as ones' self-efficacy changes (Bandura & Locke, 2003). This has been observed in many domains, including work environments (Wood & Bandura, 1989), children (Bandura, 1993), academic achievement and persistence (Pajares, 1996; Vogt, Hocevar, & Hagedorn, 2007), health improvement (Holden, 1991), athletics (Moritz, Feltz, Fahrbach, & Mack, 2000), group environments (Sanderson, Rapee, & Barlow, 1989), treating phobias (Bandura & Locke,

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2003), career choices (Bandura & Locke, 2003; DiLisi, McMillin, & Virstek, 2011), goal setting (Bandura, 1993; Liem, Lau, & Nie, 2008), and more.

Academic self-efficacy has also been shown to be a powerful contributor to academic attainment that is independent of knowledge and skills. Ultimately it is an individual assessment that can be influenced by current mood and observing others (Pajares, 2009). Research on self-efficacy in education has often been focused on the links between self-efficacy and college major choices and the relationships between self-efficacy and motivation, achievement and attributes of each. High self-efficacy of college science and engineering students has been shown to influence those students to persist in maintaining high academic achievement (Pajares, 1996). Self-efficacy impacts self-regulated learning in that students who understand an academic task tend to utilize cognitive and metacognitive strategies to persist at that task (Pajares, 1996). In regard to educational goals and goal setting, self-efficacy has been shown to be a strong predictor of achievement goals, and a weak predictor of mastery goals (Liem, Lau, & Nie, 2008).

Experience allows people to assess their capabilities to perform. People must have some prior knowledge of the task they are considering in order to be self-efficacious. Prior knowledge provides familiarity with the task and the actions required to perform that task. For a new task, or one in which there is a lack of understanding of required actions, one must infer based on what they believe are similar actions. In this instance they are not judging their capabilities on what they know, but on what they think may be equivalent (Pajares, 1996).

A person's self-efficacy can vary in three areas, including estimation of task difficulty, how strongly one believes they can perform a task at a particular level of

difficulty, and the extent that task difficulty and capability beliefs are influenced by generalizing from prior experiences in other domains (Bandura, 1997). Self-efficacy is a rather fragile characteristic related to capability. If people do not believe that their actions will produce a desired outcome, then there is little incentive to begin, or persevere in, an activity when faced with obstacles and difficulties. Lack of progress toward a goal that is attributed to a lack of ability can also cause doubt in one's ability to perform a task, and belief in ones' own capability is essential for success in academic endeavors (Pajares, 2009). The academic characteristic, grade point average (GPA), is most influenced by self-efficacy (Vogt, Hocevar, & Hagedorn, 2007), and conception of ability has a significant impact on the mechanisms that govern performance. Belief that ability can be acquired improves resilience in the face of a challenge, while belief that ability is a static reflection of personal capability amplifies the negative effects of failure (Wood & Bandura, 1989). Those who lack confidence in their abilities are more likely to interpret difficulties as being insurmountable and will refrain from full participation, or will outright quit an activity (Bandura, 1993).

*Confidence as a measure of self-efficacy.* Confidence is freedom from doubt of an outcome. It is the strength of one's belief without requiring specification of what they are confident about (Bandura, 1997). Self-efficacy includes confidence as well as one's perceived capabilities to organize and implement actions necessary to attain desired performance (Bandura, 1997). Thus, self-efficacy is a reflection of one's confidence to succeed at a task in the context of a domain (Pajares, 2009). Likewise, confidence can be a measure of self-efficacy, as the more confident one is in a domain, the more certain they are in their responses to questions about that domain (Peşman & Eryilmaz, 2010).

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***Sources of self-efficacy.*** Bandura (1977) identified four core sources of self-efficacy. These include performance accomplishments, which are often called mastery experiences, vicarious experiences, verbal persuasion, and emotional arousal or physiological response. Each of these sources, as listed, has a decreasing level of impact on self-efficacy (Bandura, 1982).

*Mastery experiences.* Mastery experiences are the most influential source of self-efficacy since they are based on an individual's success and personal mastery of a task (Bandura, 1982). Success raises one's self-efficacy, and repeated failure tends to reduce it, particularly if those failures occur early when learning or attempting something new (Bandura, 1977). If people experience much failure before a solid sense of self-efficacy is formed, it may be very difficult, if not impossible, to form positive feelings of self-efficacy (Hodges & Murphy, 2009). Introduction to mastery experiences comes from participant modeling, performance desensitization, performance exposure and self-instructed performance (Bandura, 1977). Learning environments that present abilities as skills that are able to be learned, and progress as a personal accomplishment that should not be compared to others, also build academic self-efficacy (Bandura, 1993).

*Vicarious experiences.* Vicarious experience is an important influence on self-efficacy, though it is highly subjective. A vicarious experience is one in which the subject observes or infers their capability based on the performance of someone else. This can be from directly observing another, hearing about someone else, or any other report that offers a model for comparison (Bandura, 1977). The issue with subjectivity comes from the choice of the model, in that a performance that is perceived as being better than the model raises self-efficacy, while a lower level of performance will reduce

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self-efficacy, thus the model for comparison is crucial when trying to build self-efficacy (Hodges & Murphy, 2009).

*Verbal persuasion.* Verbal persuasion is also referred to as social persuasion (Hodges & Murphy, 2009). Bandura identified verbal persuasion as originating from suggestion, exhortation, self-instruction and interpretation (Bandura, 1977), and found that people can be steered into believing in their capabilities by the suggestion of others. Verbal persuasion has limitations on the level of self-efficacy that endures because verbal persuasion is so easily dispensed. The impact of the persuasion is affected by how the persuader is viewed by the recipient and how the message was delivered by the persuader. If the persuader is viewed as being competent and credible by the recipient, the message will have greater impact. Persuasion that is given in an unrealistic or dismissive manner will have less impact on the recipient (Hodges & Murphy, 2009). Regardless of the verbal persuasion type and delivery, if the recipient continually experiences performance that does not meet their level of self-efficacy due to verbal persuasion, eventually the recipient's mastery expectations, and thus their self-efficacy, will be reduced (Bandura, 1977).

Perceived self-efficacy is not simply a reflection of prior experience, but is an independent contributor to performance (Bandura & Locke, 2003). Feedback on prior performance impacts self-efficacy, particularly when considering prior effort. Pajares (1996) found that positive feedback on prior efforts raised self-efficacy, which increased persistence. This also shows that self-efficacy impacts performance on multiple levels, and in the case of this example, both directly, and via its impact on persistence (Pajares, 1996). Students' belief in their own ability to learn and master an academic

accomplishment determines their goals, motivation to achieve those goals and ultimately, their achievements (Bandura, 1993). Encouragement and guidance from teachers can also help to increase students' self-efficacy (Vogt, Hocevar, & Hagedorn, 2007).

*Emotional arousal.* Physiological and affective states can be interpreted by a subject as supportive or aversive, depending on the situation. These interpretations can have an influence on self-efficacy, but there is disagreement in the literature regarding the strength of this influence, due to inconsistencies in the findings of various studies (Hodges & Murphy, 2009). Bandura identified sources of emotional arousal as originating from attribution, relaxation, biofeedback, symbolic desensitization and symbolic exposure (Bandura, 1977). In general, emotional states that are supportive of performance tend to influence successful outcomes and states that are of aversive arousal tend to influence performance negatively (Hodges & Murphy, 2009). States of high arousal and anxiety tend to reduce performance, and fear tends to exacerbate this reduced performance, which is particularly acute when those fears are greater or more intense than the actual action that is feared (Bandura, 1977). Behavioral control such as modeling and desensitization may increase self-efficacy, which can help to overcome the debilitating effects of aversive emotional arousal, though it is important to consider that the environment in which the emotions are experienced is also a key influence on performance (Bandura, 1977). Finally, because of the relationship between emotion and self-efficacy, it should be noted that self-efficacy can also affect emotional states as well, particularly when one has low self-efficacy for an action, yet is expected to perform that action (Bandura, 1977). This can possibly result in anger or despair when a subject has

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low self-efficacy and cannot see himself successfully performing a task. This emotional response may cause performance to deteriorate.

*Self-efficacy in practice.* In practice, a major problem with self-efficacy is determining causality. Self-efficacy influences motivation, and motivation influences self-efficacy, thus there is always a question of whether one caused the other. Because of this relationship between self-efficacy and motivation, it is impossible to determine influence, however, models can be created and tested to see the influences each has on the other in that particular model and context (Pajares, 1996).

There is also some disagreement as to whether self-efficacy helps to improve performance. This is based on the idea that, if a person truly believes they can succeed at an activity, they may set goals that are too difficult, or they may be likely to reduce their level of performance in achieving their goals simply because they believe success is guaranteed (Bandura, 1993), regardless of the task. There are other situations when self-efficacy does not influence performance, such as when no amount of skill and self-efficacy will bring about a desired outcome because that outcome is impossible, or when a subject simply does not want to do the task (Pajares, 1996).

A weakness with self-efficacy has to do with the fact that it is based on self-observations. Most people are overly harsh on themselves when assessing their abilities, as they tend to rely on vicarious experiences to make this assessment. This indicates that social comparisons are crucial to motivation as well (Bandura, 1993). Regardless of the issues with self-efficacy, it is still a common framework in education-based research.

***Self-efficacy and STEM education.*** Self-efficacy is a common theoretical framework for studying Science, Technology, Engineering and Math (STEM) education. The vast majority of research on STEM education has been on university or four-year college student populations. Self-efficacy has been used in studies as a measure of engineering design (Carberry, Lee, & Ohland, 2010), persistence (Concannon & Barrow, 2010; Brown, Lent, & Larkin, 1989), success in Mathematics (Khezri azar, Lavasani, Malahmadi, & Amani, 2010; Bonham & Boylan, 2011), gender in engineering education (Concannon & Barrow, 2009; Marra, Rodgers, Shen, & Bogue, 2009), career choice (DiLisi, McMillin, & Virstek, 2011), and more.

Within STEM education, studies have also been performed to identify influences of self-efficacy. Studies have found that social interactions influence the self-efficacy of women who major in science, math and engineering (Seymour E. , 1999), and that gender does not predict self-efficacy for engineering graduate students (Santiago & Einarson, 1998). Other examples of research to identify influences of self-efficacy include formal reasoning ability as a positive predictor of self-efficacy for college biology students (Lawson, Banks, & Logvin, 2007), academic progress increasing self-efficacy in engineering students, and Mexican-American students not displaying improved self-efficacy as they begin their engineering studies (Hackett, Casas, Betz, & Rocha-Singh, 1992).

***Self-efficacy and the community college.*** Self-efficacy has been used as the theoretical framework across a range of domains within the realm of community college-based research. It has been used as a way of measuring metacognitive skills (Akturk & Sahin, 2010), student perceptions of themselves fitting in with their cohorts (Edman &

Brazil, 2007), relationships between goals and GPA (Nakajima, Dembo, & Mossler, 2012), effects of student-faculty interaction (Chang, 2005) and stress (Zajacova, Lynch, & Espenshade, 2005). Other studies have found that participation in a gardening program can increase self-efficacy for completing long-term projects (Hoffman, Thompson, & Cruz, 2004), and that non-traditional students take longer to develop self-efficacy in their majors (Spellman, 2007).

There have also been studies that found various characteristics that influence self-efficacy, including perception of college environment (Morris & Daniel, 2008), mentoring (Reyes, 2011), being a first generation student (Inman & Mayes, 1999), immigration status (Teranishi, Suarez-Orozco, & Suarez-Orozco, 2011), working in groups (Thompson, 2001; Sandoval-Lucero, Blasius, Klingsmith, & Waite, 2012), and prior education (Muse, 2003).

**Prior knowledge bridging self-efficacy and conceptual knowledge**. As discussed previously, high self-efficacy has been shown to influence persistence and high academic achievement, which implies knowledge has been acquired and learning has occurred. Likewise, there are academic and personal characteristics that influence self-efficacy as well. The primary intersection lies with prior knowledge. Prior knowledge not only provides a foundation for the introduction of new concepts, but the potential for high self-efficacy in that particular domain. In other words, prior knowledge is the link between self-efficacy and conceptual knowledge.

**Conceptual Knowledge**

Knowledge is central to the practice of engineering, and conceptual knowledge is a key component of what engineers need to know (Sheppard, Macatangay, Colby, & Sullivan, 2009). Concepts are mental symbols used to classify things in our prior knowledge. These symbols and classifications allow us to make inferences about new things we encounter in our lives, thus concepts are the link between prior knowledge and things that may lead to new or expanded knowledge (Murphy, 2004; Carey, 2009). Concepts are basic principles that are applicable in every domain (Navigli & Velardi, 2004). Concepts are the organizers that sort our prior knowledge so we have an idea of what to expect when we encounter something new (Perkins, 2006). Concepts are related to language, as they allow us to understand the meaning of information in different domains. Concepts and the ability to identify classes within categories can be considered as units of knowledge that are accumulated, refined, and then combined with other concepts to create mental images that are even more vivid and clear than we were previously able to create (Sfard, 1998). Assessment of conceptual understanding might include measures of vocabulary, including the appropriate terms and observations of patterns that might indicate if a concept is unclear (Meyer & Land, 2005).

**Knowledge and conceptual knowledge.** Conceptual knowledge is the understanding or interpretation one may have about concepts, which can then be carried into future situations, providing the holder with an idea of what to expect in that situation. It builds on the work of Piaget (Matthews, 1998), and can be related to the "Understanding" level of Bloom's Taxonomy. While this level is not often considered to be difficult for students, it is one of the foundations of higher learning, and if that

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foundation is weak, unclear, or misunderstood, then higher thought is likely to be clouded as well (Demirci, 2010). Conceptual knowledge is often thought of as a set of mental structures that can be rearranged, and rearranging to accommodate new knowledge is when meaningful learning occurs (Ausubel, 1960; Leach & Scott, 2003). Learning results in changes to the learner's mental structures and representations, and is dependent on prior knowledge and the learner's ability to evaluate and remember what they learned (VanLehn, 1996). Prior research has shown that students who are presented data that conflicts with prior knowledge will struggle when trying to assimilate that conflicting information with concepts they already know, but when they are able to overcome that conflict, their conceptual knowledge increases (Koretsky, Kelly, & Gummer, 2011).

Conceptual knowledge has been extensively studied, particularly in the field of Physics Education (Wieman, 2006). Physics is a set of general concepts that have been established by experimentation, and uses problem-solving which is based on conceptual knowledge to describe nature. It is usually taught, however, as a set of isolated bits of knowledge that are neither related to each other nor applicable to "the real world", thus most students miss that connection to conceptual knowledge and instead focus on memorizing facts and procedures (Wieman & Perkins, 2005). Conceptual understanding is the basis of understanding physics, yet it is possible for students to correctly answer questions about topics without actually understanding the concepts that are the basis of those topics. Expert competence can only come from active involvement and solid understanding of concepts (Wieman & Perkins, 2005).

**Procedural and conceptual knowledge.** Conceptual knowledge is used for problem solving, by identifying a problem, creating a mental representation of the initial

state and the desired end state, then identifying the operations that will help us to attain that end state (Ross, Taylor, Middleton, & Nokes, 2008). Problem solving is a key component of engineering and requires procedural knowledge (VanLehn, 1996). Procedural knowledge is the knowledge of how to do something (Dekeyser, 1998), or knowledge of the actions needed to perform a procedure (Friege & Lind, 2006). Procedural knowledge is different from conceptual knowledge, yet the two are related. Before one can perform a procedure, they must first have conceptual knowledge in order to identify the key factors and concepts necessary to begin down the best procedural path. As students grow in conceptual knowledge, their ability to perform procedures grows as well, and vise-versa. When concepts are well-understood, students are often able to explain related problems, make inferences from the problem, integrate other ideas, predict outcomes and apply conceptual knowledge to other areas (Taraban, DeFinis, Brown, Anderson, & Sharma, 2007). Learning is about changing conceptions, thus conceptual change is a hallmark of learning and education, not just acquisition of information (Biggs, 1999).

**Conceptual Knowledge and Motivation.** Leach and Scott (2003) also argue that conceptual knowledge is reinforced through social interaction, thus social processes influence the learning of conceptual knowledge. This idea of social influences on conceptual learning was also identified by Dole and Sinatra (1998), who thought that people may be influenced to process information based on peer interest or messages. In the case of students, a message will be received differently, based on the messenger. They are more likely to give credence to the message if it is delivered by someone they admire and respect, as opposed to someone they do not know. Dole and Sinatra's work

introduces motivation into the picture as well, with the thought that there has to be some form of cognitive conflict or dissonance that arises from seeing anomalies, or from holding beliefs that contradict their existing conceptions. Motivation can come from simple dissatisfaction with concepts that can be easily disproven by observation, personal relevance, or the fact that some people are simply motivated by their desire to learn, which drives them to process information in order to achieve that which they desire. This driving force can help to focus effort and persistence when considering and learning new ideas (Dole & Sinatra, 1998).This is a link between self-efficacy and conceptual knowledge, as identified by Bandura and Locke (Bandura & Locke, 2003).

**Categories, concepts, and conceptions.** Recent work has identified threshold concepts as being a more primitive form of conceptual knowledge, in that they are considered to be "conceptual gateways" (Meyer & Land, 2005) that introduce a new understanding, interpretation or way of thinking about something that is transformative, irreversible, integrative and possibly even troublesome to the learner (Cousin, 2010). Concepts such as the Central Limit Theorem in Statistics, or entropy in Physics, would be considered threshold concepts. Development of these concepts is troublesome for students because they often conflict with prior knowledge or everyday observations, yet mastery of them is a new understanding which leads to new ways of thinking about and interpreting those subject areas (Meyer & Land, 2005). Because of the difficulties that are often encountered when learning these basic concepts, students often need continued exposure, scaffolding and other support as they learn this information.

*Concepts and categories.* Concepts are different from categories, though they are often used interchangeably, however, concepts refer to ideas that define a class of entities

within a category (Ross, Taylor, Middleton, & Nokes, 2008). A category can contain many entities, all of which may be individually different, but the entire group can still be considered as practically the same. Within that category are classes which contain individual sub-grouped entities, yet a class is still representative of the category (Ross, Taylor, Middleton, & Nokes, 2008). Because of this ability to classify, we can utilize prior knowledge to make inferences about a concept, which helps us to understand and explain not just what is happening, but why it is happening (Ross, Taylor, Middleton, & Nokes, 2008). The ability to understand that a concept such as "voltage", is a class within the category "energy", allows us to make inferences about how voltage may behave when we encounter it, provided that we have sufficient prior knowledge about energy. When we do encounter it, we observe if it did behave the way we predicted. If not, we learn, and change our conceptions, our understanding of those concepts.

*Conceptions and misconceptions.* Conceptions are beliefs that are held about concepts, thus a misconception is an incorrect belief about a concept (Carey, 2009). Conceptions can be right, wrong, incomplete, or otherwise unclear. This may lead to confusion, and there is no debate in the literature that misconceptions can be extremely difficult to correct (Streveler, Litzinger, Miller, & Steif, 2008). Even if prior knowledge conflicts with current information, many people will hold misconceptions because they simply believe so strongly in them (Dole & Sinatra, 1998), and misconceptions that are attributed to phenomena that can readily and easily be observed are the most difficult to overcome (Martin-Blas, Seidel, & Serrano-Fernandez, 2010).

One of the most common misconceptions of electricity is the "substance-based" model, which presents electricity as equivalent to fluid that flows through conductors that

are analogous to plumbing pipes (Streveler, Litzinger, Miller, & Steif, 2008). This is

classified as an "emergent" phenomena, which is the most difficult misconception to

correct because the causes and forces behind electricity are not directly or readily

observable, leaving the individual to misattribute its causes to something they are able to

observe (Chi, 2005). Regardless of their origin, misconceptions can make it extremely

difficult for students to accept and learn new information, which is why identification of

those misconceptions is so important (Martin-Blas, Seidel, & Serrano-Fernandez, 2010).

**Measuring conceptual knowledge.** Students often get numerical problems

correct, yet cannot connect the relationship between those problems and the underlying

concepts. This begs the question of whether they know the underlying meaning, and if

they can take that knowledge outside the domain in which the information was taught

(Lopez, 2008). The ability to measure conceptions can help the engineering educator to

address misconceptions instead of assuming that concepts are understood, or worse,

leaving those misconceptions in place, to possibly influence future learning in a negative

way (Taraban, DeFinis, Brown, Anderson, & Sharma, 2007). One way to measure

conceptual knowledge is through the use of concept inventories.

*Concept inventories.* Concept inventories are standardized exams designed to

identify common misconceptions students may hold about concepts within a specific

domain (Simoni, Herniter, & Ferguson, 2004). Since the development of the Force

Concept Inventory (FCI) (Hestenes, Wells, & Swackhamer, 1992), which has been used

to measure prior knowledge and effectiveness of instruction, other concept inventories

have been developed for many different domains.

Concept inventories allow rapid assessment of conceptual knowledge, as compared to qualitative methods that take much longer, but may provide detailed information on the concepts, or misconceptions, that people may hold (Streveler, Litzinger, Miller, & Steif, 2008). Because of what they are measuring, concept inventories are created in a manner that allows them to be used in assessing both novices and those who have more advanced knowledge (Hake R. , 2011), and they allow assessment of conceptual understanding, as opposed to assessing the ability to work a math problem correctly (Hake R. , 2007). Results from concept inventories are accepted by the Accreditation Board for Engineering and Technology (ABET) as proof of student learning and achievement (Simoni, Herniter, & Ferguson, 2004).

Most typical assessments do not draw out students' true understanding of conceptual knowledge, or the origins of any misconceptions. When assessment items are unfamiliar to students, they will rely on their prior knowledge from other contexts to provide an answer, which means misconceptions can often be their guide. For this reason, poor performance on typical assessments may not be representative of lack of knowledge of a concept, but lack of knowledge of the context and terminology used on the assessment. Likewise, a correct answer on a typical assessment may not necessarily indicate mastery of the concepts (Harlow & Jones, 2004). Most assessments tend to focus on whether students get the "right" or "wrong" answers. A typical multiple choice concept inventory can help teachers to focus on how students arrived at their answers. This approach accomplishes this focus because the distractor responses are usually common misconceptions. A lingering issue is that this approach does not account for false positives arising from guessing.

*Applications of concept inventories*.  At its most basic, a concept inventory is a multiple choice test designed to measure understanding of conceptual categories (Savinainen & Scott, 2002).  More specifically, they are designed to identify common misconceptions students may hold about concepts within a specific domain (Simoni, Herniter, & Ferguson, 2004; Martin, Mitchell, & Newell, 2003)**.**

Concept inventories are useful tools because the links between individual items and their tested concepts are explicit and offer insight into student thinking because it can identify understanding of concepts and patterns of misconceptions.  This helps the teacher to be aware of specific issues, as opposed to the more generalized misunderstandings (Savinainen & Scott, 2002).

Concept inventories are particularly effective when trying to gauge students' pre-instructional knowledge.  In this application, they do not measure structural change, but are a measure of prior knowledge, which can then help the teacher to tailor lessons to address particular weaknesses (Leach & Scott, 2003).  The use of concept inventories for this purpose is well-established in the literature, and is used in many domains (D'Avanzo, 2008), including Statics, Dynamics, Fluid Mechanics, Heat and Energy, Heat Transfer, Thermodynamics, Materials, Circuit Analysis, Electricity, Electricity and Magnetism and Statistics (Purdue University, 2011).  They have been used to examine the effects of gender on conceptual knowledge (Noack, Antimirova, & Milner-Bolotin, 2009), identify characteristics that influence conceptual knowledge in university physics courses (Antimirova, Noack, & Milner-Bolotin, 2009), and to measure the effects of different teaching methods (Savinainen & Viiri, 2003; Cummings, Marx, Thornton, & Kuhl, 1999; Demirci, 2010).  In addition to these applications, they have also been used as part of

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overall student assessments, in terms of midterm and final exam questions (Bonham S. , 2007), and have been shown to be useful for identifying dominant, systematic, common misconceptions among large groups (Martin-Blas, Seidel, & Serrano-Fernandez, 2010).

*Criticism of concept inventories***.** There is some debate as to whether concept inventories are truly effective measures of knowledge and understanding. In addition to the expectation that concept inventories should be well-written to remove any ambiguity for the test taker and in evaluating the results, there is also the expectation that they are reliable and valid. There is also disagreement on the most basic question of how they are used, in regard to issues with pre- and post-testing, and if a multiple choice test is even capable of being a reliable and valid way to measure conceptual knowledge.

*Improving concept inventories***.** One way to improve basic concept inventories is to create multi-tiered instruments. The most basic concept inventories are a single tier of multiple choice questions. Adding a second tier allows for the identification of false-positive responses, in that a correct response to a single-tiered question may not be a representation of correct conceptual knowledge, but that the subject relied on misconceptions and still got the correct answer, or was simply a lucky guesser (Peşman & Eryilmaz, 2010). The second tier questions are multiple choice, and typically consist of one correct concept, and two to four misconceptions. If the response to the first tier is correct, and the response to the second tier is correct, then the answer for that entire question is scored as correct because the subject got the right answer using the correct conceptual knowledge. If the response to the first tier is wrong, then the answer for the entire question is scored as incorrect due to a wrong answer, regardless of the response to

the second tier.  If the second tier response is wrong, then the conceptual knowledge is incorrect, thus the answer for the entire question is also scored as incorrect.

In addition to including common misconceptions as distractor responses for the second tier, further improvement can be made to the two-tiered design.  This can be done by including in the second tier an open-ended answer choice for subjects to respond with their own reasoning, in their own words, as to why they chose a particular response on the first tier.  This is beneficial because it provides a qualitative opportunity to learn of new misconceptions subjects may have (Osborne & Gilbert, 1980), which were not previously identified or offered as distractors in the second tier by the instrument authors. This application is much like how an interview would be used to determine these misconceptions.  This is a key strength of the present study, but does introduce a practical limitation.  Qualitative research requires time consuming analysis that hampers a primary goal - rapid assessment from concept inventories.

Further improvement to a concept inventory can be attained by adding a third tier to each question.  The third tier measures the confidence the subject has in their responses to the first two tiers.  Measuring confidence provides verification in that, if a subject answers the first two tiers correctly, and has high confidence, then we can expect that the subject does not have any misconceptions.  If the subject answers the first two tiers incorrectly, and has high confidence, then we can expect that the subject clearly has misconceptions (Peşman & Eryilmaz, 2010).  This third tier can also serve a second purpose.  Since confidence can be used as a measure of self-efficacy, the third tier can also be used to gauge subjects' self-efficacy for the material being assessed.  It is for this purpose a third tier is included in the present study.

Improvements do not change the notion that one single test is incapable of being a stand-alone assessment. Thus concept inventories, by themselves, are invalid measures of conceptual knowledge. Hake (Hake R. , 2007) rebuffed this by saying that there is no way to account for every single thing that occurs during treatment which may influence learning, and this is the case for any assessment. He also argued that other issues, such as performance ceiling effects, can be mitigated by using the average normalized gain as a measure of treatment effectiveness as long as the assessment tool does not have instrument ceiling effects (Hake R. , 2007)

Conceptual knowledge and learning are important because we are exposed to anomalies and data every day, which conflict with concepts we hold. With the continued availability of access to the Internet, humans will only encounter those contradictions and anomalies more frequently (Dole & Sinatra, 1998), thus the ability to measure conceptual knowledge will continue to be a useful educational tool.

**Conceptual knowledge and engineering education.** Conceptual knowledge in engineering education is important because there are differences between experts and novices, and much of it is based on conceptual knowledge. Experts tend to be able to identify problems based on conceptual knowledge of a domain, while novices tend to identify problems based on characteristics of the questions being asked (Ross, Taylor, Middleton, & Nokes, 2008). A lack of conceptual knowledge may not mean students fail to understand course material, it could instead be a sign that students have passed the course material, but are unable to take those lessons and apply them outside the context in which they were learned. In this instance, students have simply learned the process of getting to the answer, not the larger implications of what that process and subsequent

answer represent (Wieman, 2006).  The ability to identify student understanding of concepts and misconceptions can be helpful because it allows instructors to address and correct them as necessary (Harlow & Jones, 2004).

Understanding conceptual knowledge in engineering education may also help to enhance procedural knowledge, which could improve performance.  Conceptual knowledge helps students identify key features of problems which may suggest better approaches to solutions, thus students to become more expert in their performance.  It may also help students recognize flaws in their own approaches to problem-solving or possibly even lead students toward novel solutions by guiding them through the evaluation of a problem, at a conceptual level, and addressing issues from that perspective (Streveler, Litzinger, Miller, & Steif, 2008).

*Electrical Concept Inventories.*  Using concept inventories to assess conceptual knowledge of voltage, current and the physical characteristics of DC circuits is a common approach in engineering education.  There are at least thirteen published concept inventories used to measure various concepts within electrical engineering.  They have been used as a pre/post measure of the effects of an instructional module on circuit analysis (Sangam & Jesick, 2012), as well as determining the effects of using simulation to teach circuit analysis (Baser, 2006).  They have also been used to compare the effects of hands-on lab experiments, virtual lab experiments, and combinations of the two (Farrokhnia & Esmailpour, 2010).  Parts of concept inventories have been used to test the understanding of specific concepts (Rosenthal & Henderson, 2006), and have also been incorporated into other assessments that include measures of student confidence in their responses (Peşman & Eryilmaz, 2010).  They have been combined with semi-structured

interviews to gauge conceptual knowledge of electricity (Findlay, 2010), and to simply

identify pre-existing misconceptions (O'Dwyer, 2009).

*Voltage, Current and the Physical Characteristics of DC Circuits*.  Within the

literature, there is agreement on some of the most common misconceptions students have

about electricity.  Leach and Scott (2003) previously identified that energy is a topic that

students tend to misconceive.  Working with content experts, Streveler, et. al (2006) have

done much work to identify the most common misconceptions, including charge, voltage,

current, power, energy, and Kirchoff's Laws.  Working with students, Streveler, et. al

(2006) also identified charge, voltage and current as the most common misconceptions.

The concepts identified by Streveler's work are fundamental in circuit analysis.  Building

on their previous work, Streveler, et. al (2008) also found other common misconceptions,

including batteries as a source of constant current, batteries maintaining constant

potential energy between their terminals, the idea that current is consumed, the difference

between potential and potential difference, and complete circuits.  This finding of

misconceptions about complete circuits was confirmed by Findlay, who found that

resistance, as related to the physical connections of a circuit, is also a common

misconception about electricity and circuit analysis (Findlay, 2010).

**Conceptual knowledge, self-efficacy and a unique population**.  Much research

has been done to identify characteristics that are related to self-efficacy and conceptual

knowledge, and self-efficacy has been shown to be correlated with conceptual knowledge

(Peşman, 2005).  There has also been research focused on identifying the characteristics

that may be used to define the community college student population, and the subset of

engineering students at those institutions.  This is important because this particular

population has been shown to be significantly different from students who attend universities and four-year colleges. What is unknown in the literature is if any of the other characteristics used to define community college students can be shown to correlate with self-efficacy and conceptual knowledge of DC circuit analysis. The following section discusses those characteristics that have been found in the literature to define this unique population, with emphasis on the characteristics that have also been shown to influence self-efficacy and conceptual knowledge.

**Academic and Personal Characteristics of Community College Engineering Students**

Within the literature few resources differentiate between students in engineering programs with intent to transfer to a four-year program, and students in terminal engineering technology Associate in Applied Science (AAS) and certificate programs. Because of the few references available and the lack of differentiation between programs, for this study, all references within the literature to engineering at the community college are considered as "engineering". This approach has support in the literature. In 1955, Grinter suggested creating and keeping separate engineering and engineering technology programs as a way to differentiate between engineers who had a background in design, and those who had a background in applications. His rationale was that industry does not differentiate between new hires based on their degree title, and that all new hires would be considered engineers by their employers, based on their ability to do "engineering" work. Most colleges and universities with undergraduate engineering programs implemented this idea by either maintaining dual paths or choosing a single path toward an undergraduate engineering degree (Grinter, 1984; Kelnhofer, Strangeway, Chandler, & Petersen, 2010). Most companies do not differentiate between those with a BSE and a

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BSET (Land, 2012), indicating that for the most part, companies consider their newly hired engineers to be interchangeable in the jobs they perform.

**Academic characteristics.** For this study, academic characteristics are considered to be those that are directly related to prior or current education, such as high school coursework, college coursework, lesson context and collegiate institutional student support.

*High school coursework.* Among community college engineering students, there appears to be a general lack of preparedness for college studies (Daempfle, 2003; Chatman, 2007). Students are often unprepared for college coursework and require remediation which can take several semesters and has been shown as a reason for attrition from those programs. Students who are not prepared, yet enroll in college math and science gatekeeper courses are severely disadvantaged, and struggle. Finding help to continue in those courses can be difficult, and often students fail, or they somehow complete the course, yet do not understand the material, moving the problem farther down the road (Chatman, 2007). In addition to this, students often have unrealistic expectations of their own performance in their coursework, and that can have a negative effect on performance and retention (Hayden & Holloway, 1985). College professors indicate that they prefer students who have good study skills, are creative and imaginative, yet in high school, students are often just being taught facts, definitions and skills (Daempfle, 2003) with little analysis or critical thought about what exactly they are doing.

As for specific academic characteristics from high school, there does seem to be agreement that high school math and science courses influence retention in engineering. In general, the higher the level of high school math, physics and chemistry, the more likely students are to complete any engineering degree (Adleman, 1998; Buchanan, 2006; Tyson, 2011). Male students who enter engineering programs with Algebra 2 as the highest math they've completed have a difficult time completing any engineering program, and this is even more pronounced for students within the lowest SES. Just under 50% of all engineering students enter their engineering programs having completed either Algebra 2 or Trigonometry as their highest level of high school math (Adleman, 1998). While engineering students do tend to come to the community college having completed higher levels of math and science courses than their non-engineering cohorts, that does not guarantee their persistence in an engineering program because performance in college Calculus and Physics are also indicators of retention in engineering programs (Tyson, 2011).

As for high school science courses, most engineering students begin their programs having completed three science courses in high school. Students who earned an "A" in any high school physics course were more likely to earn higher grades in college Calculus and Physics courses than students who earned a "B" in any high school physics course (Tyson, 2011). Engineering majors have a more solid background in the most influential prior coursework, compared to non-engineering majors, but the higher the level of prior coursework, the more likely students are to succeed in their engineering majors at all levels (Adleman, 1998).

***College coursework.***  Once students begin taking classes on their college campus, their coursework and GPA impact self-efficacy (Veenstra, Dey, & Herrin, 2008). Students who persist in their community college engineering programs tend to have a higher self-efficacy for gatekeeper Calculus and Physics courses, which is important because success in engineering is often based on understanding the fundamental concepts from those courses.  Community college students who are forced to take remedial courses have lower self-efficacy for necessary higher college math classes (Chatman, 2007).

***Context.***  One of the most common reasons cited by students for changing from engineering into a different major is the abstract way calculus and physics are presented (Chatman, 2007).  Without learning concepts in the context which they will be applied, many engineering students have a difficult time seeing the significance and utility of prior courses to their engineering studies.  This can create a weak foundation in early coursework, particularly math (Umeno, 2001).  Engineering students who have a weak foundation of early math courses have more difficulty understanding complex mathematical content, and are not likely to go back and pick it up.  For a typical community college engineering student, this may even be impossible, due to their other commitments and obligations.  They then move on, and forget the concepts they did not understand.  By the time they reach the later courses where they are expected to apply their prior knowledge, they have a very difficult time doing so (Umeno, 2001).

Learning math in an engineering context is helpful for seeing its utility, but putting too much emphasis on applications, versus theory, can be problematic too. Because many community college engineering programs focus on preparing technicians

for the workforce, there is often an emphasis on applications, which can dilute concepts that are necessary for solving problems in other domains (Umeno, 2001).

*Institutional Support.*  Within engineering programs, students who drop out or change majors consistently cite a lack of support by their professors, and this is especially true of Hispanic students (Hayden & Holloway, 1985).  When students feel intimidated by faculty because their instructors are perceived as non-supportive, students may struggle because they will not approach faculty for help (Seymour & Hewitt, 1997).

Community college engineering students also indicate that scheduling issues are a major deterrent to retention, especially for course work that is sequential (Packard, Gagnon, & Senas, 2012). Offering other amenities and support resources for engineering programs, as well as additional course sections can be especially difficult for college administration to justify, since community college engineering programs tend to be smaller than other programs.  Limited resources were noted as a deterrent to retention by 13% of the students surveyed by Packard, et. al. (2012), but like the general community college student body, general tutoring and support programs rarely work because those efforts do not focus on individual issues and characteristics (Hayden & Holloway, 1985).

Finally, poor advisement was noted as a deterrent to retention and transfer by 47% of students surveyed by Packard, et. al (2012), who found that in many cases, student advisors have general knowledge about college requirements, but not enough specialized knowledge of engineering programs, let alone engineering transfer requirements.  These "informational setbacks" (Packard, Gagnon, & Senas, 2012) can be crucial for community college STEM students, especially those who plan to transfer.  Having a clear

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pathway is important in keeping students focused on their coursework instead of the potential pitfalls that may arise later on. This is especially true for female students, who prefer to know what is expected of them and what they can look forward to (Starobin & Laanan, 2008). Misinformation ranges from not knowing answers and passing students to other advisors who do not know the answers, failure to tell students that they can take placement exams in place of lower-level math courses, advising students to take non-transferable courses, and even the difference between "full-time" status for financial aid, versus for completing a program in a timely manner (Packard, Gagnon, & Senas, 2012).

**Personal characteristics.** Personal characteristics are considered to be those that are not based on prior or current education, and for the present study, include gender, race, family impact, social issues, finances, goals and motivation, and personal issues.

*Gender.* The characteristic that has seen much research focus is gender. One of the primary factors attributable to academic gender differences is the perception that STEM fields are "difficult" and "masculine". Many female students dislike environments in which students compete for grades from an emotionally distant or remote professor. The perception of the sciences being masculine fields is usually entrenched long before female students reach the community college, and tends to decrease the self-confidence of female students (Buchanan, 2006). While female engineering students are more confident in their study habits, male students consistently give higher self-ratings on practically every other characteristic (Besterfield-Sacre, Moreno, Shuman, & Atman, 2001).

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The challenge to keeping female students in engineering programs is most significant in the early courses. Female students tend to drop gatekeeper courses, such as chemistry, earlier than male students (Buchanan, 2006). The fact that many have false impressions of those courses and their own abilities, can be attributed to a lack of guidance and support for those students, and which is crucial for success in their chosen engineering major (Starobin & Laanan, 2008). Persistence of adult female students in community college math and science programs is directly related to their future goals, financial aid and support, and GPA (Buchanan, 2006).

*Race.* Minority students that have family support and access to supplemental programs do better in science and math courses (Buchanan, 2006). Compared to Caucasian students, however, they still tend to underperform in gatekeeper courses such as Analytic Geometry, Calculus, Physics and early engineering course sequences (Kane, Beals, Valeau, & Johnson, 2004). Minority students are more likely to believe that manual skills are not needed to major in hands-on, lab-intensive engineering courses (Hayden & Holloway, 1985).

African-American engineering students consistently self-rate themselves at a significantly higher level of writing, speaking and computer skills than the majority of other students, indicating confidence in their abilities (Besterfield-Sacre, Moreno, Shuman, & Atman, 2001). They are cognitively equivalent to their Caucasian cohorts, but they tend to have lower measures of self-efficacy, motivation, commitment and persistence in their engineering courses (Buchanan, 2006).

***Family Impact.*** In general, students who have a family member who is familiar with engineering, or is an engineer, tend to have more realistic expectations of their community college engineering programs, and are more likely to persist in them (Hayden & Holloway, 1985). Families that are not supportive of engineering students are often the cause of strife. Students who change their majors out of engineering often indicate they were encouraged to do so by family members (Chatman, 2007). Students who have their own families also reported influence by their spouses and children, and women are more likely to delay their education than men, primarily to care for children or other family members (Packard, Gagnon, & Senas, 2012). This is crucial because community college engineering students tend to be married or have other familial obligations.

***Social Issues.*** Engineering students tend to be focused on preparing for their careers, thus a learning environment that models the workplace and provides professional development and engagement in their field, and with their professors, is helpful in preparing students for their careers (Craft & Mack, 2001; Anderson-Rowland, 2012). It is student perceptions of social isolation that is the key to success. A perception of social isolation negatively affects retention, but students who do persist in engineering tend to see social isolation as a temporary necessity (Hayden & Holloway, 1985).

The environment of a community college is not conducive to establishing a sense of community. Most community college students are commuters, workers and parents, none of which aid in keeping students on campus. This then forces a reliance on the engineering classroom environment as the primary way community college engineering students establish social ties, especially since the classes are smaller (Strawn & Livelybrooks, 2012). This environment provides an opportunity for interaction with

peers and professors, (Cejda, 1997; Craft & Mack, 2001), however, most engineering

faculty are often perceived as lacking in the professional skills necessary to effectively

interact as mentors to their students, as most engineering faculty were themselves trained

to be researchers or practitioners, not educators (Chatman, 2007).

In addition to these, female engineering students are also likely to leave

engineering due to other social issues, including perceptions of the program culture,

career aspects and contributions to society (Besterfield-Sacre, Moreno, Shuman, &

Atman, 2001), which is in line with other research (Buchanan, 2006; Starobin & Laanan,

2008). This would indicate that female engineering students are different from their male

classmates, in regard to social needs and issues as well (Daempfle, 2003). Female

students tend to need more social support than their male classmates, and not having it

can impede their progress. Female STEM students who do well in the community

college classroom tend to take a leadership role among their peers, which helps to build

their confidence. As their confidence increases, so does their self-efficacy for current and

future coursework (Starobin & Laanan, 2008; Brandt & Hayes, 2012).

*Finances.* A large percentage of engineering students at the community college

work full or part-time as they progress in their education (Anderson-Rowland, 2012).

Work and inability to pay for classes are the top two reasons cited for delays or switching

majors for engineering students at the community college (Chatman, 2007; Packard,

Gagnon, & Senas, 2012). Funding is crucial for all students, and for engineering majors

at the community college, it is just as critical, yet at the community college, students are

also more likely to have family responsibilities which they must continue to support. .

Community college students who are unemployed, but seeking employment, have the

lowest GPAs (Kane, Beals, Valeau, & Johnson, 2004).  Those who are unemployed and

not seeking a job tend to have the highest GPAs (Buchanan, 2006).  Students who work

14 hours or more per week are more likely to drop out of school all together (Kane,

Beals, Valeau, & Johnson, 2004)

Not only do students have to worry about short term issues with employment, but

socioeconomic status (SES) and outside work affect time to complete a degree, as well as

how far students want to go in their educational goals.  Because of their financial and

work issues, low income students need more time to complete AAS programs (Kane,

Beals, Valeau, & Johnson, 2004).  Simple mistakes or problems with financial aid can

result in delays in receiving funds, causing students to reduce or delay their continued

enrollment.  If courses are sequential, like many engineering courses are, this can spell

disaster for retention (Packard, Gagnon, & Senas, 2012).  Students who receive less

financial aid are less likely to persist (Hayden & Holloway, 1985).  Kane, et. al. (2004)

identified the two biggest obstacles to enrollment, retention, and success in engineering

and math, as finances and outside employment.  Low SES is a barrier to degree

attainment, and finances affect living conditions, nutrition, and health.  All of these affect

academic persistence and success (Kane, Beals, Valeau, & Johnson, 2004).  Financial

problems tend to be more difficult for Latino students, who are the largest minority on

community college campuses, and are also more likely to drop out of college or change

majors than all other student groups, since they need a larger percentage of their tuition

and fees from financial aid, and they receive the least amount of any student group from

their families (Kane, Beals, Valeau, & Johnson, 2004).

*Personal Issues.* Personal issues are those characteristics that are not necessarily related to the previous categories, but may be influenced by them. The issues most frequently cited in the literature range from simple boredom with the curriculum (Hayden & Holloway, 1985; Seymour & Hewitt, 1997) to the practical, such as a desire to minimize time in school (Chatman, 2007). Another personal issue that causes students to leave engineering is that many decide engineering is not as socially oriented, or "compassionate" as they would like (Chatman, 2007). This is especially true for minorities (Hayden & Holloway, 1985) and women, who are usually more concerned that education, career goals and personal priorities are aligned, as opposed to men, who are more likely to place career goals above personal satisfaction (Seymour & Hewitt, 1997).

**Summary**

Studies involving conceptual knowledge and self-efficacy are common and well-developed in engineering education research. While much of this research has been limited to university student populations, there is a smaller body of work that has focused on the general community college population. There has been practically no research, however, on the engineering student population at community colleges. In general, the community college population is very different from the university population, and this is also true for the differences between engineering student populations at both types of institutions. This makes the study of engineering education in the community college ripe for further research. In addition to the characteristics which have been shown to be related to self-efficacy and conceptual knowledge, these differences present an opportunity to identify the unique personal and academic characteristics of community

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college engineering students.  These characteristics may also be correlated with self-efficacy and conceptual knowledge of DC circuit analysis.

The present study extends prior research on self-efficacy and conceptual knowledge by applying what was learned in the literature to a different population of interest.  The upcoming chapters describe the personal and academic characteristics of a group of circuit analysis students at a large community college.  Those characteristics are compared using the results of a concept inventory and a measure of self-efficacy to determine the characteristics that are correlated with each.

Chapter 3

METHODOLOGY

**Overview**

The purpose of this study was to investigate community college engineering

students' conceptual knowledge of electrical circuit analysis, self-efficacy toward circuit

analysis, and how circuit analysis self-efficacy is related to conceptual knowledge.  The

study was performed during the Fall 2013 semester.  Students in three introductory circuit

analysis courses were invited to participate in the study, and a pre-assessment was given

during the second class meeting.  The pre-assessment instrument consisted of two parts:

a three-tiered concept inventory that measured the concepts of voltage, current, and the

physical characteristics of DC electrical circuits, as well as self-efficacy for circuit

analysis, and a demographic survey.  A post-assessment was then administered later in

the semester, approximately one week after each class finished.  Correlation analysis was

performed to answer the following research questions:

- What demographic or academic characteristics are correlated with conceptual
  knowledge of circuit analysis?

- What demographic or academic characteristics are correlated with self-efficacy
  for circuit analysis?

- Does self-efficacy for circuit analysis correlate with conceptual knowledge of
  circuit analysis?

**Participants**

This study was conducted at a large community college in the southwestern United States. Students from three introductory circuit analysis courses in the Electronics program were studied. Participation was voluntary.

**Courses**. Circuit analysis concepts are taught in two sixteen-week courses, ELE 100 and ELE 111. Two sections from ELE 111 and one section from ELE 100 participated in this study. Both courses met twice a week in a lecture-lab environment. ELE 100 met for one hundred-ten minutes, while ELE 111 met for one-hundred seventy minutes.

*ELE 100.* ELE 100 is an introductory course intended to be a broad overview of electricity and electronics for students who may be interested in pursuing a career in electronics. The course also prepares those students for ELE 111 by covering basic circuit analysis. Students in the Electronics program are not required to take ELE 100, however, it is a technical elective for students in other majors. ELE 100 has no pre-requisite courses. In ELE 100, introduction to the concepts of voltage, current and the physical characteristics of DC circuits is completed approximately two-thirds to three-fourths of the way through the course.

*ELE 111*. ELE 111 is an introductory circuit analysis course, primarily covering DC circuit analysis and an introduction to AC circuit components and analysis. ELE 111 is more advanced than ELE 100 because of a co-requisite math requirement and the inclusion of AC circuits. Students must be enrolled in, or have previously passed, ELE 105 - College Algebra and Trigonometry for Technology, or its equivalent, MAT 120 -

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Intermediate College Algebra. ELE 111 is a required course for all students in the Electronics program. In ELE 111, introduction to the concepts of voltage, current and the physical characteristics of DC circuits is completed approximately one-half to two-thirds of the way through the course.

*Pedagogy*. All three classes were taught in a lecture-lab format, i.e., lectures were taught in a laboratory setting and all lab experiments were directly correlated with the lecture material. Homework problems were assigned as units of the text were completed. Students performed lab experiments in the same classroom after key concepts were taught, with experiments requiring one or two class periods to complete. During lab times, the instructors were in the classroom, available to help students who encountered problems with their experiments. Each course was taught by seasoned instructors who have an average teaching time of nineteen years. The least experienced instructor has been teaching in the Electronics program for sixteen years. The first section of ELE 111 was taught in the morning, and ELE 100 was taught in the same classroom during the evening. The second section of ELE 111 was taught in the evening, in a classroom that was physically smaller, however, all of the equipment in both rooms are identical.

**Participants**. The pre-test total enrollment in the three sections was 48. Two groups of students (n = 32) who were enrolled in ELE 111, and a third group (n = 12) that was enrolled in ELE 100 participated in the study. Two students from ELE 111 and two from ELE 100 chose not to participate. The total student sample for the pre-test was 44. Four students (less than 10%), all enrolled in ELE 111, were female. All participants were classified by the institution as freshmen or sophomores with 25% of the subjects self-identified as being first-generation college students.

The enrollment of students decreased from 48 to 41 from pre to post-test. Seven students dropped their courses, leaving 27 from ELE 111 and 14 from ELE 100. Four students, all from ELE 100, did not participate in the post-test, however all students in both ELE 111 sections did participate. This resulted in a post-test sample of 37. All four female students from the pre-test remained in the study. Prior to analyzing the data, the students who did not participate in the post-test were removed from the pre-test data set leaving a pre- and post-test sample of 37 out of a population of 41.

**Measures**

The instrument used for this project had two parts. The first part was a multi-tiered concept inventory. The second part measured key demographics. The instrument is included in Appendix A.

**Concept Inventory.** The concept inventory was a 15 item survey that was created by adapting and combining concept inventory questions from prior work found in the literature. Questions were included by adapting questions related to voltage and the physical characteristics of circuits from the Determining and Interpreting Resistive Electric Circuit Concepts Test 1.0 (DIRECT) (Engelhardt P. V., 1995; Engelhardt & Beichner, 2004), and questions pertaining to current from the Simple Electric Circuits Diagnostic Test (SECDT) (Peşman & Eryilmaz, 2010). Each item consisted of three tiers of questions and response choices. The first tier was a multiple choice question that measured ability to work a problem related to the concept being assessed. The second tier was a multiple choice question that measured the reasoning the subjects used in answering the first tier. The third tier was a newly developed measure of self-efficacy.

***First-Tier Items and Concepts Measured.*** The items used in the concept inventory did not change between pre- and post-tests. An example of a first-tier question is shown in Figure 1. This was used as item number five on the instrument, and was a test of conceptual knowledge of voltage. All of the first tier items, source, correct concept, and misconceptions used as distracters are listed in Table 3.

Figure 1

*First Tier Item Example*
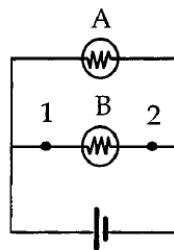


Referring to the figure above, what happens to the potential difference between points 1 and 2 if Bulb A is removed? Circle the letter next to your answer.

a. Increases          b. Decreases          c. Stays the same

***Second-Tier Items***. Continuing with the first-tier example provided previously, the corresponding second-tier item is shown in Figure 2.

The item is a multiple choice question with one response that matches the correct concept, with the remaining responses matching the misconception distractor items from the first tier. The second tier of the concept inventory also included an opportunity for students to explain their reasoning for their response in the first tier. This was done to identify any misconceptions students may have had, which had not previously been identified in the literature. Students were instructed to write their reasoning in the space provided if none of the given response choices matched their reasoning.

Table 3

*Concepts and Misconceptions Measured by Instrument First-Tier Items*

| Item | Source | Concept | Misconceptions |
|------|--------|---------|----------------|
| 1 | DIRECT1.0*(a)* | Voltage | Battery Superposition, Resistive Superposition |
| 2 | SECDT *(b)* | Current | Local Reasoning |
| 3 | SECDT *(b)* | Current | Attenuation Model, Resistive Superposition, Empirical Rule Model |
| 4 | DIRECT1.0*(a)* | Physical Characteristics | Contacts, Sink Model |
| 5 | DIRECT1.0*(a)* | Voltage | Battery as a Constant Current Source, Resistive Superposition |
| 6 | DIRECT1.0*(a)* | Voltage | Term Confusion I/V, Complete Circuit, Rule Application Error, Direct Route, Sequential |
| 7 | DIRECT1.0*(a)* | Physical Characteristics | Term Confusion I/R, Resistance Equals Circuit Equivalent Resistance |
| 8 | SECDT *(b)* | Current | Current Flow as Water Flow |
| 9 | SECDT *(b)* | Current | Current Flow as Water Flow, Empirical Rule Model |
| 10 | DIRECT1.0*(a)* | Voltage | Empirical Rule Model, Local Reasoning, Battery as a Constant Current Source, Local |
| 11 | SECDT *(b)* | Current | Battery as a Constant Current Source, Sequential |
| 12 | DIRECT1.0*(a)* | Physical Characteristics | Short Circuit, Local, Battery as a Constant Current Source |
| 13 | SECDT *(b)* | Current | Current Flow as Water Flow |
| 14 | DIRECT1.0*(a)* | Physical Characteristics | Contacts, Complete Circuit |
| 15 | DIRECT1.0*(a)* | Physical Characteristics | Contacts, Complete Circuit, Short Circuit |

Sources: *(a)* (Engelhardt P. V., 1995). *(b)* (Peşman, 2005)

Figure 2

*Second Tier Item Example*

Which one of the following is the reason for your answer in the first part?  Circle the letter next to your answer.

a.  The battery provides the same amount of current to each circuit, regardless of the circuit arrangement.

b.  Parallel connections have the same voltage.

c.  Since the bulbs are equal, removing bulb A leaves twice as much current for bulb B.

d.  By removing bulb A, there is more current in the circuit, and thus more voltage for bulb B.

e.  _____

**Third-Tier Items**.  The third tier of the concept inventory was a measure of the students' confidence, which was used to gauge self-efficacy for circuit analysis.  The questions were worded as, "How confident are you about your answers given for parts 1 and 2?" This approach was consistent with the literature (Pajares, 2009; Peşman & Eryilmaz, 2010; Carberry, Lee, & Ohland, 2010).  An example of a third-tier item is shown in Figure 3.  Like the previous item examples, it also corresponds with the fifth item on the assessment.

Figure 3

*Third Tier Item Example*

How confident are you about your answers given for parts 1 and 2?  Circle the number that best matches how confident you are.

| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|----|----|----|----|----|----|----|----|----|-----|
| Not at all confident | | | | Maybe/ Not Sure | | | Pretty Confident | | | Completely Confident |

**Demographics**. The second part of the instrument consisted of a demographic survey, to identify key personal and academic characteristics of the participants. These demographics were chosen using theoretical underpinnings, findings in the literature, and how they have been found to uniquely identify the community college population.

The post-test was modified by removing the pre-test demographic items and replacing them with three additional items. The first item asked whether the current semester was the subject's first semester in college. The second new question asked whether the subjects were currently taking a Mathematics course. The third and final question asked which math course the subject was currently taking if the answer to the previous question was "yes". The rest of the assessment was identical to the pre-test.

**Reliability and Validity.** The items adapted from Engelhardt and Beichner (2004) were initially developed for the DIRECT (Engelhardt P. V., 1995). Items were initially tested on over one thousand subjects (Engelhardt & Beichner, 2004). Since its initial publication, it has been used in, or modified for multiple other studies (Peşman & Eryilmaz, 2010; Sangam & Jesick, 2012). The DIRECT has been shown to be reliable, with a Kuder-Richardson formula 20 (KR-20) value of 0.71, which meets the standard of $\geq 0.7$ considered ideal for group measurements (Engelhardt & Beichner, 2004). Face and content validity were established via expert opinion during development. It was also shown to have construct validity via factor analysis (Engelhardt & Beichner, 2004).

The items adapted from Peşman and Eryilmaz (2010) were initially developed for the SECDT (Peşman, 2005). The SECDT was initially tested on over 100 subjects, and since its publication, has been used or modified in other studies (Peşman & Eryilmaz,

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2010; Schaffer, 2013).  The instrument reliability was 0.73 using Cronbach's alpha ($\alpha =$ 0.73) (Peşman, 2005).  An alpha value greater than 0.7 ($\alpha \geq 0.7$) is considered to be acceptable (Gliem & Gliem, 2003).  Face and content validity were established via expert opinion during development of the instrument.  Construct validity was established via factor analysis (Peşman, 2005).

The concept inventory items for the present study were determined to have face and content validity based on the original authors' work (Engelhardt & Beichner, 2004; Peşman, 2005).  Unfortunately, construct validity could not be established for the present study due to the small population and subsequent small sample size.  Common methods of determining construct validity, such as Path Analysis or Structural Equation Modeling (SEM), typically require a bare minimum sample size of 50 subjects, however, 100 is usually considered adequate, with 200 being optimal.  The general rule of thumb regarding sample size for SEM is five subjects for each parameter measured (Hair, Anderson, Tatham, & Black, 1995).  With the number of parameters and the population being studied in the present project, it could very likely take several years to accumulate enough data to establish construct validity.

**Procedure**

The experiment was a One-Group Pretest-Posttest quasi-experimental design without a control group (Shadish, Cook, & Campbell, 2002).  This approach was chosen for four key reasons.  First, the most simple, and least intrusive design is the One-Group Posttest-Only design.  The problem with this approach is that it is unclear if a change has actually occurred due to the intervention.  An improvement to this design is to add a pre-

test (Shadish, Cook, & Campbell, 2002), which provides a comparison to determine if the instruction in circuit analysis resulted in any change in conceptual knowledge.

Second, while a randomized experiment would be ideal, the fact that the subjects were college students, most likely in a technical degree program, meant that assignment to the classes was not truly random. The students chose which class they enrolled in, based on a myriad of factors including schedule, professor, interest, and more. In situations when randomized assignment is not possible, a quasi-experimental design should be used in place of a randomized experiment (Shadish & Luellen, 2006).

The third reason for this approach was for significance. The initial potential subject population was a small group. Any method that required removing more than five subjects for a control group would have resulted in a subject sample that would provide non-statistically significant results.

The final reason for choosing this approach was for practical purposes. Each instructor initially expressed concern regarding the time taken from his lesson plan. Two observations during the semester and a fifteen minute introduction on the first day of class was determined to be the least intrusive approach that would still accomplish the goals of the study.

**Criticism of This Design**. There are criticisms of this design, particularly in regard to their impact on internal and construct validity. Threats to internal validity relate to the conclusions one can make regarding causal relationships, and are primarily dependent on how the treatment is administered (Trochim, 2006). Threats to construct

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validity relate to the inferences one can make from the study results, and are primarily dependent on how the study was designed and carried out (Crocker & Algina, 2008).

Maturation, history, testing and attrition are the criticisms noted in the literature (Shadish, Cook, & Campbell, 2002), however none of these threats to internal validity are applicable to the present study. The purpose of this study is not an attempt to indicate a causal relationship, but instead to establish correlations.

It has been argued in the literature that maturation and history are unavoidable problems for all social science research, regardless of the design, and cannot be overcome (Hake R. , 2007). This is inherent in the fact that all sources of information cannot be controlled. For the present study, this concern is valid, but unavoidable.

As for addressing the testing concern, the time period between pre- and post-assessments was a minimum of six weeks, and subjects were not permitted to keep their completed surveys. As an enticement to get students to participate, the subjects were given their individual results of the concept inventory, but only their overall score, with no specific information on items used to assess each of the three concepts. It is not likely that testing could interfere with the internal validity of the study results with participants receiving neither detailed results nor the questions, along with the long delay between pre- and post-testing.

While attrition was a factor in the present study, the number of subjects was still large enough that the results are statistically significant.

There is one piece of the design that is a threat to construct validity. With this design, there is always the concern that the person administering the treatment may do so

in a manner that would make the results favor the treatment (Shadish, Cook, & Campbell, 2002).  In order to avoid this, the instructions given to the subjects were read from a written script, which was consistent from pre- to post-test.

**Assessment**.  The instrument was created to answer the following research questions:

- What demographic or academic characteristics are correlated with conceptual knowledge of circuit analysis?

- What demographic or academic characteristics are correlated with self-efficacy for circuit analysis?

- Does self-efficacy for circuit analysis correlate with conceptual knowledge of circuit analysis?

*Pre-test*.  The pre-test was administered to all three classes on August 21, 2013, during regular class meeting times.  Students were informed that guessing was permitted if they did not know an answer on the concept inventory. They were instructed to write their reasoning in the second tier of the instrument if they believed an adequate response was not presented as one of the choices.  The identification coding scheme to ensure confidentiality was explained, and students were given one minute to create and write their identifier on their surveys.   The identification coding scheme consisted of a four-digit alpha-numeric code.  The first two digits were the first two letters of the subject's mother's first name.  The last two digits were the last two digits of the subject's

telephone number.  There were no instances of subjects having the same identification

code.

Students were given sixty minutes to complete the survey. Every student

completed it within the allotted time.  For each section, the time required for the first

student to finish the survey, the last student to finish the survey, and the average time to

complete the survey are provided in Table 4.

Table 4

*Pre-Test Completion Times*

| Class | First Completion Time (minutes) | Last Completion Time (minutes) | Average Completion Time (minutes) |
| --- | --- | --- | --- |
| ELE 111 (morning) | 16 | 35 | 23 |
| ELE 100 | 25 | 59 | 38 |
| ELE 111 (evening) | 16 | 35 | 27 |

Finally, when the students submitted their completed surveys, they were invited to

write their names on a separate sheet of paper if they would like their participation to be

personally acknowledged in the acknowledgement section of the dissertation paper.

*Post-test*.  The post-test was administered to each class during regular class time

based on when they completed studying the concepts of voltage, current and the physical

characteristics of circuits, as measured by the assessment.  The evening ELE 111 class

was given the post-test 42 days after the pre-test was administered.  The ELE 100 class

was given the post-test 70 days after the pre-test.  The morning ELE 111 class was given

the post-test 98 days after the pre-test.  The difference in days was due to issues with

instructor approaches to teaching the subject and scheduling the post-test with the instructor.

Prior to beginning the surveys, students were reminded that guessing was okay if they did not know an answer on the concept inventory, and were instructed to write their reasoning in the second tier of the instrument if they believed an adequate response was not presented as one of the choices. The identification coding scheme to ensure confidentiality was explained again, and was consistent with the pre-test. Students were given one minute to create and write their identifier on their surveys. There were no instances of subjects using a different identifier than was used for the pre-test.

Students were given sixty minutes to complete the survey. Every student completed it within the allotted time. For each section, the time required for the first student to finish the survey, the last student to finish the survey, and the average time to complete the survey are shown provided in Table 5.

Table 5

*Post-Test Completion Times*

| Class | First Completion Time (minutes) | Last Completion Time (minutes) | Average Completion Time (minutes) |
|---|---|---|---|
| ELE 111 (morning) | 14 | 34 | 23 |
| ELE 100 | 15 | 47 | 26 |
| ELE 111 (evening) | 10 | 32 | 20 |

**Scoring**. The survey responses for both the pre- and post-test were scored, then recorded using Microsoft Excel 2013. Scoring for the multi-tiered items and for

conceptual knowledge was done according to the results of the literature review (Peşman & Eryilmaz, 2010).

*First- and Second Tier Scoring*.  The first- and second-tier responses were scored as to whether they were correct or incorrect.  A correct response on the first-tier indicates that the subject was able to work the problem correctly or guessed the correct answer.  A correct response on the second-tier indicates that the subject was able to identify the correct concept associated with the correct first-tier answer, or guessed the correct concept.  The correct responses for the first and second tiers are listed in Table 6.  There were no instances of subjects leaving tier-one or tier-two responses blank or providing multiple responses.

Table 6

*First and Second Tier Correct Responses*

| Item | First Tier Correct Response | Second-Tier Correct Response |
|------|------------------------------|-------------------------------|
| 1    | C                            | D                             |
| 2    | B                            | B                             |
| 3    | A                            | B                             |
| 4    | D                            | D                             |
| 5    | C                            | B                             |
| 6    | D                            | A                             |
| 7    | C                            | B                             |
| 8    | B                            | B                             |
| 9    | A                            | C                             |
| 10   | B                            | B                             |
| 11   | B                            | C                             |
| 12   | E                            | C                             |
| 13   | B                            | A                             |
| 14   | B                            | A                             |
| 15   | B                            | B                             |

*Second-Tier Qualitative Response Scoring*.  All of the second-tier items had a

correct response, however, students were given the opportunity to write their own

response, indicating their reasoning for their first-tier answer.  Each qualitative response

was recorded in the Microsoft Excel spreadsheet exactly as they were written by the

subjects.  Before coding the qualitative responses, each was evaluated to determine if the

subject actually wrote the correct concept, instead of circling the choice that matched the

correct concept.  This happened twice on the pre-test, when the subject wrote the exact

same correct response in the qualitative section, instead of circling the letter that

corresponded with the correct response.  In those two instances, the responses were

scored as correct, and the qualitative responses were removed from the set of

misconceptions, since the subject clearly used the correct concepts.  All of the other

qualitative responses represented students using misconceptions, thus the second-tier was

scored as incorrect in these instances.  On the post-test, there were no instances of

qualitative responses that were correct.

Coding for the qualitative responses was done using the a priori attribute approach

(Saldaña, 2013). This allowed for counting the frequency of each misconception, then

comparing them to the known misconceptions identified by the authors of the DIRECT

and SECDT.  This approach indicates if the subjects in the present study had

misconceptions similar to the ones the authors of the DIRECT and SECDT found, or if

other misconceptions are present.  This approach is also consistent with that used by the

authors of the DIRECT with their much larger sample population.

*Conceptual Knowledge Scoring*.  Scoring for conceptual knowledge was based

on combining the scores of the first two tiers.  A correct response on both of the first two

tiers was scored as a correct answer for the entire question because the subject got the right answer using the correct conceptual knowledge.  Any other combination that included a wrong response for either, or both, of the first and second tiers was scored as a wrong answer for the entire question because of incorrect application of the concept, incorrect conceptual knowledge, or both.  This scoring method also has the advantage of reducing the chance of a subject getting a correct response by simply guessing, as the probability of correctly guessing two correct responses is less than the probability of guessing one correctly.  This scoring approach is consistent with the method used by the authors of the SECDT (Peşman, 2005).

***Third Tier Scoring***.  The third-tier responses were scored by simply recording the raw values from the Likert scale directly into the Microsoft Excel spreadsheet, which was used as the source file for the data analysis.  There were no instances of subjects leaving third-tier responses blank or providing multiple responses.

***Demographic Responses***.  The raw demographic responses were recorded directly into the Microsoft Excel spreadsheet, which was used as the source file for the data analysis.

***Data Validation***.  Both the pre- and post-test data sets were validated to ensure they had been correctly recorded.

*Quantitative Data Validation*.  After the data sets were entered into the spreadsheet they were checked twice to ensure they had been entered correctly.  First, each data point was checked to make sure that the recorded value was in fact a valid value.  This was done using the conditional formatting feature of Microsoft Excel, in

which any invalid responses would appear highlighted in red. Items that were invalid responses were investigated and corrected.

Second, the entire data set was reviewed to ensure the accuracy of the entered responses. Each data point was manually examined to ensure it matched the actual responses from the subjects. Items that were valid responses but did not match the actual responses were corrected.

*Qualitative Data Validation*. Each qualitative data response was reviewed to ensure there were no typographical errors made when they were entered into the spreadsheet. All typographical errors were corrected.

**Analysis**

Both pre- and post-test quantitative data sets were analyzed to investigate correlations between demographic data, conceptual knowledge, and self-efficacy for circuit analysis. Both pre- and post-test qualitative data sets were analyzed to identify misconceptions the subjects may have held that were inconsistent with the misconceptions used as distractor responses in the second-tier of the concept inventory.

**Quantitative Analysis**. For both the pre- and post-test, the data from the Excel spreadsheet was imported into SAS software using SAS Enterprise Guide version 5.1.

*Reliability*. Reliability of the entire pre-test instrument was examined using Cronbach's Alpha ($\alpha = 0.935$). The instrument reliability was found to be excellent, as any value greater than 0.9 is considered excellent (Gliem & Gliem, 2003). The reliability of the post-test instrument was tested using Cronbach's Alpha ($\alpha = 0.938$), and was again found to be excellent (Gliem & Gliem, 2003).

*Conceptual Knowledge*.  Next, an Analysis of Variance (ANOVA) was conducted on the three classes' pre- and post-test scores to test for any group effects.  A group effect was found for both the pre- and post-test conceptual knowledge data, indicating that the group effect was related to the instructor.  ANOVA only indicates that there is a group effect present.  It does not specify between which groups the effect exists (Hair, Anderson, Tatham, & Black, 1995).  A post hoc analysis had to be used to determine this specific relationship.

There are several post hoc approaches that were considered for identifying the specific pair-comparison that was the root of the group effect.  The key concern was choosing a method that would ensure the significance would be retained at the desired level ($\alpha = 0.05$) (Hair, Anderson, Tatham, & Black, 1995).  Because of this, the first common method, the Newman-Keuls test was not considered because it does not control the experiment error at the desired alpha level (Hair, Anderson, Tatham, & Black, 1995).  The remaining two most-common approaches, the Tukey Method and Sheffé's Method both control for the desired alpha level.  Scheffé's Method is more popular than the Tukey Method, but it is also very conservative, often resulting in an increased chance of Type II Errors (Hair, Anderson, Tatham, & Black, 1995).  The Tukey Method, on the other hand, is more liberal than Scheffé's Method, but compared to other approaches, it is still rather conservative, yet provides a middle-ground for avoiding Type I and Type II Errors.  In addition to this, it can be modified to analyze subject groups of different sizes, which is crucial for this study, as the two groups were different sizes.  This modified approach is the Tukey-Kramer Method (Neter, Wasserman, & Kutner, 1990).

The Tukey Method provides confidence interval scores that can be used to identify the specific pair comparisons that are statistically significant. Confidence interval scores are used to indicate that when comparing the difference between mean scores, there is a 95% chance that the difference will be between the lower and upper limit of the interval. If that interval includes zero, then there is a chance that the difference in mean scores could be zero, which would indicate that the scores are statistically the same (Hair, Anderson, Tatham, & Black, 1995). In the case of the group effect, the difference between two instructors was found to be significant, indicating that the two classes were different from each other and could not be combined for analysis.

In order to control for the group effect between the instructors, an Analysis of Covariance (ANCOVA) was conducted on the three classes' concept inventory scores. ANCOVA compensated for the differences between the three instructors and introduced the pre-test concept inventory scores as a covariate to reduce the error in the variance. This approach, using the pre-test score as a covariate for the post-test score, is a common method used to assess group effects and control for their effect on dependent variables. It is especially common when working with pre- and post-test data (Neter, Wasserman, & Kutner, 1990; Cohen, Cohen, West, & Aiken, 2003; SAS Institute, Inc., 2013).

While ANCOVA did reduce the error in the variance, the group effect was still present, so an alternate approach to analyzing the data had to be performed. Based on the results of the ANCOVA, the three sections were combined into two groups. The descriptive statistics and qualitative responses for each group were analyzed for anything that might explain the difference between the two groups. A two-sample t-test with

pooled variance (Zar, 1996) was used to compare all of the demographics between the two groups.

Next, the qualitative responses were analyzed to identify any new misconceptions. Using the a priori attribute approach (Saldaña, 2013), the second-tier qualitative responses for the pre- and post-tests were compared to a list of known misconceptions, which had previously been identified by the authors of the DIRECT and SECDT.

Finally, the qualitative responses were analyzed between the two groups to look for common misconceptions that may explain the conceptual knowledge group effect.

*Self-Efficacy*. After establishing the reliability of the instrument, an ANOVA was performed on the pre- and post-test self-efficacy scores. There was no evidence to indicate that the three groups were statistically different from each other, allowing for the entire sample to be treated as one large group. Correlation analysis was performed on the entire data set to examine the correlations between each of the demographic characteristics and self-efficacy for circuit analysis.

*Conceptual Knowledge and Self-Efficacy*. Correlation analysis was performed on the self-efficacy for circuit analysis and conceptual knowledge data to determine if those scores were correlated.

**Summary**

This study was a One-Group, Pre-Posttest quasi-experimental design without a control group. The purpose was to answer the following research questions:

- What demographic or academic characteristics are correlated with conceptual knowledge of circuit analysis?

- What demographic or academic characteristics are correlated with self-efficacy for circuit analysis?

- Does self-efficacy for circuit analysis correlate with conceptual knowledge of circuit analysis?

Participants were students in three introductory circuit analysis classes from the Electronics program at a large community college in the southwestern United States. An instrument consisting of a three-tiered concept inventory that measured conceptual knowledge of circuit analysis, self-efficacy for circuit analysis, and a demographic survey was created.

A group effect was present in the conceptual knowledge results, so the Tukey Method was used as a post-hoc approach to identify the pair comparisons that were statistically significant. Once the significant pair comparison was identified, an ANCOVA was used to compensate for the group effect, but this did not address the problem. In order to investigate this group effect, based on the results of the ANCOVA, two classes were combined into one group, and the third class was a separate group. A two-sample t-test with pooled variance (Zar, 1996) was used to compare all of the demographics between the two groups.

A qualitative component was also included in the second-tier of the concept inventory questions in order to determine if previously identified misconceptions were present in the study's sample. The a priori attribute approach was used to code the qualitative data, which was then compared to known misconceptions previously

identified in the literature. After investigating for new misconceptions, the qualitative data was then analyzed for common misconceptions held by the groups that may explain the group effect that was present.

Correlation analysis was used to investigate the relationships between the demographics and self-efficacy for circuit analysis, and between the conceptual knowledge and self-efficacy for circuit analysis scores.

Finally, the three research questions were answered using the results of these methods.

Chapter 4

DATA ANALYSIS AND RESULTS

**Overview**

Data analysis consisted of three phases. Phase I tested the reliability of the pre-
and post-tests: both were found to be excellent. Phase II addressed the first research
question beginning with an examination of the pre- and post-test concept inventory
scores. The pre- and post-tests were evaluated using Analysis of Variance (ANOVA) to
determine if there were differences among the three classes that participated in the study.
A group effect was discovered for both the pre- and post-tests. A post-hoc analysis using
Tukey's Method was used in order to identify where differences existed for the group
pairs. This approach found that the difference in concept inventory scores between the
morning ELE 111 class and the ELE 100 class was significant. In an effort to account for
that group difference, an Analysis of Covariance (ANCOVA) was performed on the post-
test concept inventory data, controlling for the instructor and introducing the concept
inventory pre-test scores as a covariate to reduce the error in the model. The model with
the variance reduced was significant, indicating that the group effect was still present. In
an effort to explore potential sources of the group effect, the three classes were organized
into two groups, and analysis of the descriptive and qualitative data was performed. The
descriptive data revealed that the only difference between the two groups was the number
of college credit hours each group was taking. The qualitative analysis revealed that
Group B had a large increase in a particular misconception from pre- to post-test. In
addition, it was also revealed that the instructor of Group A used a different approach to
teaching the circuit analysis concepts assessed by the study allowing Group A more time
to practice those concepts than Group B.

Phase III analyzed research questions 2 and 3, beginning by evaluating the pre- and post-test self-efficacy scores using Analysis of Variance (ANOVA) to determine if there were differences among the three classes that participated in the study. The ANOVA was not significant, indicating that there was no difference among the three classes' pre- and post-test self-efficacy scores. The three classes were subsequently combined into one group, and the demographic and academic characteristics were compared with the pre- and post-test self-efficacy scores using correlation analysis. The pre-test analysis did not find any characteristics significantly correlated with the pre-test self-efficacy scores. The post-test analysis identified two categories – Subject's Age and Subject's Father's Education Level – that were significantly correlated with post-test self-efficacy for circuit analysis scores. Neither of these characteristics were previously identified in the literature as correlating with self-efficacy.

Phase III analysis continued by performing a correlation analysis between the pre- and post-test concept inventory and self-efficacy scores. A significant positive correlation between self-efficacy and conceptual knowledge for both the pre- and post-tests was found.

The details for each phase are provided in this chapter, and a summary of the findings for each question is presented at the end of the chapter.

**Analysis**

Prior to beginning the analysis, the data set was modified by removing those subjects from the pre-test data set who did not participate in the post-test. The sample consisted of 37 students out of the total population of 41 students still enrolled in their classes by the post-test.

There were no instances of students who provided multiple responses to the demographic items. Blank responses were recorded as blanks. For the pre-test, there were eight demographic items that had blank responses from at least one subject. For the first two demographic items that were added to the post-test, none had blank responses. The third item added to the post-test did have blank responses, but each one matched the previous item which asked if a student was currently enrolled in a math course. Those who were not currently enrolled in a math course left the third item response blank.

The data for this study was analyzed in three phases. First, the reliability of both the pre- and post-test instruments were calculated. Second, the first research question was investigated using quantitative and qualitative analysis approaches. Finally, the second and third research questions were investigated using correlation analysis and the results from the first research question.

**Phase I Analysis: Reliability**. The internal reliability of the pre-and post-test instruments were calculated using Cronbach's alpha (α). In both cases, reliability was found to be excellent (Gliem & Gliem, 2003), 0.935 and 0.938 respectively.

**Phase II Analysis: Demographics and Conceptual Knowledge**. The pre- and post-test scores were analyzed using ANOVA to determine if there were any group effects present. There was a group effect present for both the pre- and post-tests based on instructor. The Tukey-Kramer Method was used for post hoc analysis to determine the specific pair difference that was the source of the post-test group effect. The results confirmed that there was indeed a group effect between two of the three instructors. An Analysis of Covariance (ANCOVA) was subsequently performed on the post-test concept

inventory scores. This analysis was used to control for the instructor and introduce the pre-test concept inventory scores as the covariate in order to reduce the error in the model. The ANCOVA did not reduce the variation in scores, so descriptive statistics of the two groups and their qualitative responses were analyzed using a priori attribute coding to look for common patterns that may explain the group effect. The details of each of these steps in the analysis are provided in the following sections.

*Examination for Group Effects*. Since the population and subsequent sample was divided into three classes, the concept inventory scores for each class were compared using ANOVA to investigate potential group differences among the classes. The ANOVA for the concept inventory scores was statistically significant for both the pre-test, $F(2,36) = 3.81$, $p = 0.032$, and post-test, $F(2,36) = 7.11$, $p = 0.003$. This indicates that there was a difference among the mean concept inventory scores of the three classes for both the pre- and post-tests. The classes could not be combined and analyzed as a single group for Phase II because doing such would likely provide misleading results. ANOVA only indicates that there is a group effect present. It does not specify between which groups the effect exists (Hair, Anderson, Tatham, & Black, 1995). A post hoc analysis had to be used to determine this specific relationship.

*Identification of Significant Group Pairs*. The Tukey Method was used to identify the instructor pair comparison that was statistically significant for the pre- and post-test scores. The results are shown in Table 7 and Table 8.

Table 7

*Tukey's Studentized Range (HSD) Test Results for Pre-Test Scores*

| Alpha | 0.05 |
|---|---|
| Error Degrees of Freedom | 34 |
| Error Mean Square | 0.03 |
| Critical Value | 3.47 |

| | | 95% CI | |
|---|---|---|---|
| Instructor Comparison | Difference Between Means | LL | UL |
| RM - BN | 0.03 | -0.14 | 0.20 |
| RM – JB | 0.20 | 0.01 | 0.38* |
| BN – RM | -0.03 | -0.20 | 0.14 |
| BN – JB | 0.17 | -0.01 | 0.35 |
| JB – RM | -0.20 | -0.38 | -0.01* |
| JB - BN | -0.17 | -0.35 | 0.01 |

Table 8

*Tukey's Studentized Range (HSD) Test Results for Post-Test Scores*

| Alpha | 0.05 |
|---|---|
| Error Degrees of Freedom | 34 |
| Error Mean Square | 0.03 |
| Critical Value | 3.47 |

| | | 95% CI | |
|---|---|---|---|
| Instructor Comparison | Difference Between Means | LL | UL |
| RM - BN | 0.15 | -0.02 | 0.33 |
| RM – JB | 0.30 | 0.10 | 0.50* |
| BN – RM | -0.15 | -0.33 | 0.02 |
| BN – JB | 0.15 | -0.04 | 0.33 |
| JB – RM | -0.30 | -0.50 | -0.10* |
| JB - BN | -0.15 | -0.33 | 0.04 |

In both cases, the same two instructor pairs were statistically significant. The comparison between RM, the instructor of the morning ELE 111 class, and JB, the instructor of the ELE 100 class, resulted in 95% confidence intervals for the pre-test scores [0.01 – 0.38] and for the post-test scores [0.10 – 0.50]. In the case of instructors

RM and JB, zero is not within either confidence interval range, thus the mean differences between those scores are different from each other.

*Investigating the Group Effect*.  In order to assess the impact of this difference on the concept inventory scores, an Analysis of Covariance (ANCOVA) was performed on the post-test concept inventory scores.  ANCOVA compensates for the difference between the three classes and introduced the pre-test concept inventory scores as a covariate to reduce the error in the model.

The ANCOVA for the post-test concept inventory scores was still significant, $F(2,36) = 4.49$, $p = 0.019$ (See Table 9).  ANCOVA also confirmed that the group effect was related to the two instructors identified by the Tukey analysis, as shown in Figure 4.

Table 9

*ANCOVA Results for Concept Inventory Post-Test Scores*

| Source | DF | SS | Mean Square | F | p |
|---|---|---|---|---|---|
| Model | 3 | 1.12 | 0.37 | 22.58 | <0.0001 |
| Error | 33 | 0.55 | 0.02 | | |
| Corrected Total | 36 | 1.67 | | | |

| Source | DF | Type III SS | Mean Square | F | p |
|---|---|---|---|---|---|
| instructor | 2 | 0.15 | 0.07 | 4.49 | 0.019 |

*Alternative Statistical Analysis Approaches*.  One approach to investigating the two groups is to analyze each class independently.  This approach could be effective if not for the small population of each class (N = 12, N = 14, and N = 15) and subsequent small sample sizes (n = 12, n = 10 and n = 15). The sample is not sufficient to provide statistically significant results for the ELE 100 class due to the number of ELE 100 students who did not participate.  While this approach would provide information about

Figure 4

*ANCOVA Results for Concept Inventory Scores Group Effect*
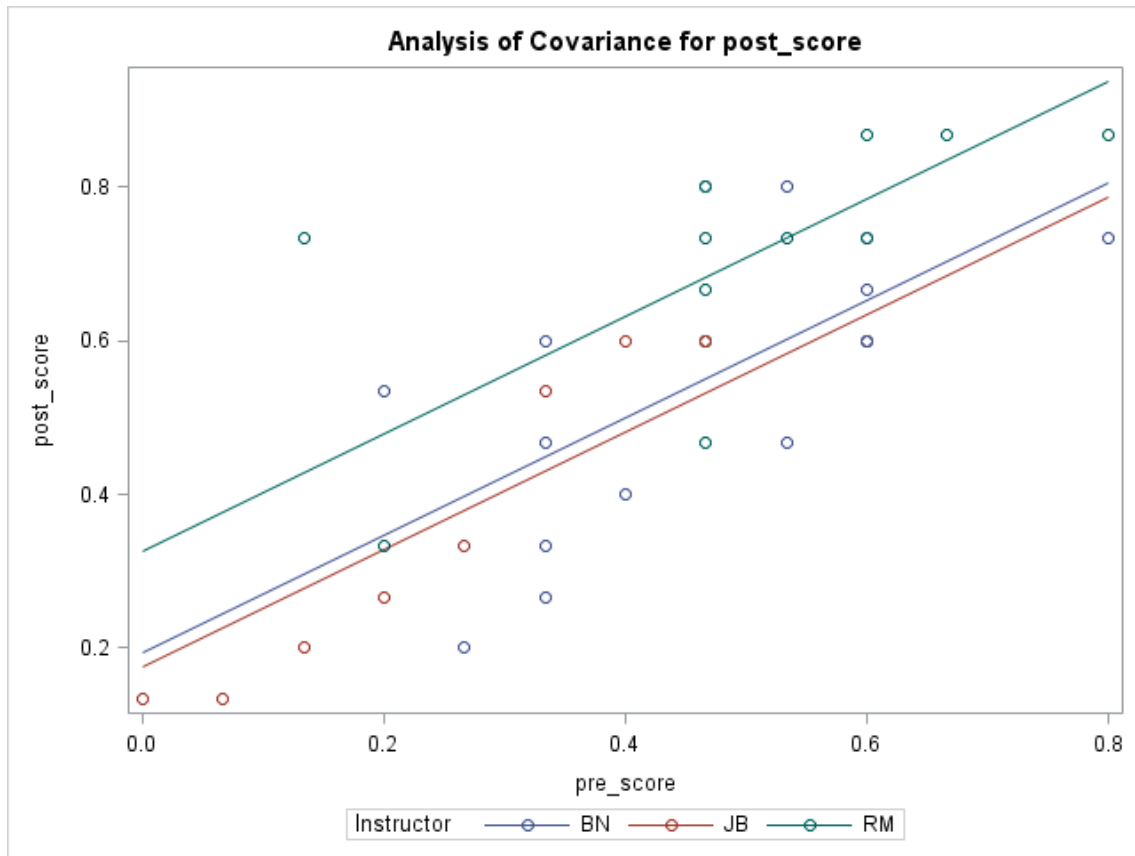


each of the classes, it would only allow statistically significant comparisons between the

two ELE 111 classes.

The concept inventory scores for each class did increase from pre- to post-test.

The evening ELE 111 class average pre-test score was 6.61 (M = 6.61, SD = 2.79) and

the post-test average score was 8.20 (M = 8.20, SD = 2.83). This increase from pre- to

post-test was significant (p = 0.047). The ELE 100 sample average pre-test score was

4.67 (M = 4.67, SD = 2.71) and the post-test average score was 6.00 (M = 6.00, SD =

3.09). This increase from pre- to post-test was significant (p = 0.001). The morning ELE

111 class average was 6.86 (M = 6.86, SD = 2.80), and the post-test average score was

10.5 (M = 10.5, SD = 2.47). This increase from pre- to post-test was also significant (p = 0.001).

The three classes were combined into two groups because the difference between instructor RM (the morning ELE 111 class) and JB (the ELE 100 class) was so distinct in the ANCOVA results in Figure 4. The morning ELE 111 class was called Group A. The ELE 100 and evening ELE 111 classes were combined into Group B for additional analysis of their concept inventory scores. The descriptive statistics and qualitative responses from the pre- and post-test concept inventories were examined for both groups to search for any insight into the source of the difference between them.

*Analysis of Descriptive Statistics*. A comparison of the demographics produced only one characteristic that was significantly different between the two groups. A two-sample t-test with pooled variance (Zar, 1996) revealed that the mean number of college credits Group A was taking (M = 11.17, SD = 3.38) and the mean number of college credits Group B was taking (M = 8.12, SD = 4.06) were different, t(35) = -2.25, p = 0.031, α = 0.05. No other demographic or academic characteristics were significantly different between the two groups (see Table 10).

This difference in the mean number of college credits may help explain the difference in post-test conceptual knowledge between the two groups. It is unclear if it can explain the group difference in the pre-test scores.

Table 10

*Comparison of Descriptive Statistics Between Groups*

| Characteristic | Group A Mean | Group B Mean | p-value |
|---|---|---|---|
| Age | 36.67 | 30.40 | 0.096 |
| Gender | 0.17 | 0.04 | 0.197 |
| Ethnicity | 3.83 | 3.76 | 0.903 |
| Marital Status | 1.08 | 0.97 | 0.750 |
| Have Children | 0.42 | 0.40 | 0.926 |
| # Hours worked | 20.73 | 34.24 | 0.086 |
| % Tuition Paid by Finan. Aid | 56.25 | 30.00 | 0.119 |
| Mother's Education | 2.33 | 2.56 | 0.724 |
| Father's Education | 2.00 | 3.20 | 0.101 |
| Student's Prior Education | 3.00 | 3.24 | 0.573 |
| 1st Generation Student | 0.17 | 0.20 | 0.815 |
| HS GPA | 3.01 | 3.02 | 0.960 |
| HS Chemistry | 1.08 | 1.08 | 0.992 |
| HS Physics | 0.92 | 0.64 | 0.420 |
| HS Math | 3.75 | 3.33 | 0.550 |
| College GPA | 3.10 | 3.31 | 0.473 |
| # Credits this Semester | 11.17 | 8.12 | 0.031* |
| Taken Remedial Math | 0.33 | 0.60 | 0.136 |
| Highest College Math | 5.00 | 4.59 | 0.685 |
| Highest College Math Grade | 3.11 | 2.63 | 0.305 |
| Taken ELE 100 | 0.17 | 0.08 | 0.441 |
| College Chemistry | 0.33 | 0.40 | 0.771 |
| College Physics | 0.08 | 0.28 | 0.381 |
| Taken Remedial English | 0.50 | 0.56 | 0.740 |
| Taken Semester Off | 0.33 | 0.24 | 0.562 |
| # Semesters In Current Prgrm | 1.75 | 1.64 | 0.828 |
| Course Required for Major | 0.83 | 0.80 | 0.815 |
| 1st Semester in School | 0.33 | 0.24 | 0.562 |
| Currently Take Math Class | 0.50 | 0.32 | 0.304 |

*Analysis of Qualitative Data*. The qualitative data from the pre- and post-tests were analyzed using an a priori attribute approach to find any misconceptions that had

not previously been identified in the literature.  There were no new misconceptions identified by the results of either the pre- or the post-test.

The qualitative data from the pre-and post-tests were analyzed by comparing the qualitative responses to the misconceptions that represented the distractor responses and those identified by the authors of the DIRECT and SECDT.  This was to look for common patterns between the two groups that may explain the group effect that was present with the conceptual knowledge scores.  This examination of the pre- and post-test qualitative data identified 13 misconceptions, all of which had previously been identified by the authors of the DIRECT and the SECDT (See Table 11).  The entire list of misconceptions identified by the authors of the DIRECT and SECDT, and the items they apply to in this study, are included in Appendix B.

It should be reiterated that subjects were not required to provide a qualitative response to any of the assessment items.  Subjects were instructed to provide a qualitative response if none of the responses provided in the second tier of the concept inventory matched the subject's reason for giving their response to the first tier.  For every item, there were subjects who gave the correct conceptual response, and there were others who provided an incorrect response.  For twelve items there were subjects who provided qualitative responses.  Only those who did not see a response that matched their reason for answering the first tier gave a qualitative response.

*Pre-Test Qualitative Analysis*.  There were 51 qualitative responses recorded. Twenty of the responses were comments, such as "I guessed", or "No idea", which are not indicative of using misconceptions to solve the problem.  Additionally, there were

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Table 11

*Misconceptions Identified in Present Study*

| Misconception | Description | Source |
|---|---|---|
| Attenuation Model | Current decreases moving through the circuit, until returning to the battery where there is no current left because current has been used up | Peşman & Eryilmaz |
| Battery as a Constant Current Source | Battery supplies same amount of current to each circuit regardless of the circuit's arrangement | Engelhardt & Beichner |
| Battery Superposition | One battery, bulb shines. Two batteries, bulb shines 2X bright | Engelhardt & Beichner |
| Contacts | Unable to identify the contacts on a light bulb | Engelhardt & Beichner |
| Current Consumed | Current decreases as you move through the elements until there is nothing left | Engelhardt & Beichner |
| Empirical Rule | Components that are farther away the voltage source, such as light bulbs, glow dimmer | Peşman & Eryilmaz |
| Local Reasoning | When a change in the circuit occurs, focus is on that change, not the effect on entire circuit | Peşman & Eryilmaz |
| Resistive Superposition | Multiple resistors increase/decrease current by number of resistors in circuit | Engelhardt & Beichner |
| Rule Application Error | Misapplied a rule governing circuits | Engelhardt & Beichner |
| Short Circuit | Unable to identify a short circuit | Peşman & Eryilmaz |
| Sink Model | Only a single wire is necessary to allow current to flow | Peşman & Eryilmaz |
| Term Confusion I/R | Resistance viewed as being caused by the current | Engelhardt & Beichner |
| Term Confusion I/V | Voltage viewed as a property of current. Current is the cause of the voltage. Voltage and current always occur together | Engelhardt & Beichner |

two instances recorded when a subject gave the correct response, but added an additional comment in the space.  In both cases, the subject was the same person, and the added comment expressed the subject's uncertainty with their response.  This left 29 qualitative responses that were included in the pre-test qualitative data set.

All of these pre-test qualitative responses were misconceptions that had been previously identified by the authors of the DIRECT and SECDT.  There were no new misconceptions identified in the pre-test of this study.  The item number, misconception and number of times the misconception was identified for each item are summarized in Table 12.  The full list of item numbers, subject identifiers, actual written comments, and the identified misconceptions are included in Appendix C.

*Pre-Test Misconception Frequency.*  There were 10 distinct misconceptions identified by the qualitative responses.   The misconception identified most frequently was Local Reasoning (eight responses).  The next most frequently identified misconception was Rule Application Error (six responses).  Attenuation Model and Term Confusion I/V were both identified three times.  The misconceptions Current Consumed, Short Circuit and Sink Model were identified twice each.  The remaining three misconceptions, Contacts, Empirical Rule, and Resistive Superposition were identified once each.

*Pre-Test Items and Misconceptions*.  Item 12, which was taken from the DIRECT, tested conceptual knowledge of the physical characteristics of a DC circuit, and had the most qualitative responses.  The six responses corresponded with five unique

Table 12

*Pre-Test Misconceptions, Items and Frequency of Each Misconception*

| Misconception | Item | Frequency |
|---|---|---|
| Local Reasoning | 8.2, 10.2, 13.2 | 8 |
| Rule Application Error | 1.2, 3.2, 7.2, 10.2, 11.2 | 6 |
| Attenuation Model | 3.2, 5.2, 12.2 | 3 |
| Term Confusion I/V | 6.2 | 3 |
| Current Consumed | 3.2, 12.2 | 2 |
| Short Circuit | 12.2 | 2 |
| Sink Model | 3.2, 13.2 | 2 |
| Contacts | 14.2 | 1 |
| Empirical Rule | 12.2 | 1 |
| Resistive Superposition | 12.2 | 1 |

misconceptions. Those misconceptions are Attenuation Model, Current Consumed, Empirical Rule, Resistive Superposition and Short Circuit.

Item 10, which was taken from the DIRECT, tested conceptual knowledge of voltage. This item had five qualitative responses that corresponded with a known misconception. Four of the responses corresponded to the same misconception, Local Reasoning. The fifth response corresponded to the Rule Application Error misconception.

Item 3 was from the SECDT tested conceptual knowledge of current. This item had four unique qualitative responses that corresponded with the known misconceptions Attenuation Model, Current Consumed, Rule Application Error, and Sink Model.

Items 6 and 13 each had three qualitative responses. Item 6 was taken from the DIRECT and tested conceptual knowledge of voltage. All three responses corresponded with the same misconception, Term Confusion I/V. Item 13 was taken from the SECDT and tested conceptual knowledge of current. The three responses corresponded to two unique misconceptions, Local Reasoning and Sink Model.

Items 1 and 8 each had two qualitative responses. Item 1 was taken from the DIRECT and tested conceptual knowledge of voltage. Both responses corresponded with the same misconception, Rule Application Error. Item 8 was taken from the SECDT and tested conceptual knowledge of current. Both of those responses corresponded to Local Reasoning.

The remaining four items, numbers 5, 7, 11 and 14, each had one qualitative response that corresponded with a single misconception. The misconception for Item 5 corresponded with Attenuation Model. The misconception for Item 7 and 11 corresponded with Rule Application Error. The misconception for Item 14 was Contacts.

*Post-Test Qualitative Analysis.* There were 29 qualitative responses recorded, and unlike the pre-test, none were comments such as "I guessed", or "No idea". There were two instances recorded when a subject provided a true statement, but gave no indication as to a concept or misconception that may have guided their answer. For example, Item 2 was a circuit consisting of three resistors connected in parallel, and assessed the concept

of current in a parallel circuit. One subject replied with a qualitative response as follows, "Voltage drop across the circuit to provide power to the loads". There was a voltage supply which provided power to the circuit, making this a correct statement. While this is correct, it gives no indication of the concepts or misconceptions that guided the subject in their response. For this reason, both of these types of responses were not included in the qualitative data.

There was also one instance when a subject provided a qualitative response that was technically correct, but was not applicable because the subject relied on changing the resistance values of components. The concept inventory instructions indicated that values were not to be changed unless explicitly instructed. This instruction was also reiterated to the subjects as part of the introduction at the start of the pre- and post-tests. This response was not included in the qualitative data.

Finally, there was one instance when a subject provided a response with a correct concept referenced, but that concept was not one of those offered as a response choice for that item. Item 1 assessed conceptual knowledge of voltage in relation to the brightness of light bulbs connected in parallel to the voltage source. The correct item response indicated that the bulbs were the same brightness due to the fact that parallel components have the same voltage. The subject responded that the bulbs were the same brightness because they have the same power. This is correct, and would require that the subject understand that parallel components have the same voltage, as voltage is used in the calculation of power, $P = V^2/R$. Using this equation, one would calculate that both bulbs dissipate the same amount of power. Since the resistances of each bulb were given as being equal, one could also calculate that the current through each bulb is the same as

well. Knowing all of this, one could correctly conclude that both bulbs are of equal brightness. This item was scored as correct for this particular subject, and the response was not included in the qualitative data.

Of the 25 remaining qualitative responses, all of the misconceptions identified in the post-test had been previously identified by the authors of the DIRECT and SECDT. There were no new misconceptions identified in the post-test of this study. The item number, misconception and number of times the misconception was identified for each item are summarized in Table 13. The full list of item numbers, subject identifiers, actual written comments, and the identified misconceptions are included in Appendix D.

*Post-Test Misconception Frequency*. There were 10 misconceptions identified by the qualitative responses. The misconception identified most frequently was Short Circuit (seven responses). The next most identified misconception was Local Reasoning (five responses). Rule Application Error and Term Confusion I/V were both identified three times. Term Confusion I/R was identified twice. The remaining misconceptions, Attenuation Model, Battery as a Constant Current Source, Battery Superposition, Contacts, and Sink Model were each identified once.

*Post-Test Items and Misconceptions*. Item 12, which was taken from the DIRECT, tested conceptual knowledge of the physical characteristics of a DC circuit. This item had the most qualitative responses as was the case in the pre-test. Of the eight responses, seven were the same misconception, Short Circuit. The eighth qualitative response corresponded with the Battery as a Constant Current Source misconception.

Table 13

*Post-Test Misconceptions, Items and Frequency of Each Misconception*

| Misconception | Item | Frequency |
|---|---|---|
| Short Circuit | 12.2 | 7 |
| Local Reasoning | 1.2, 5.2, 10.2 | 5 |
| Rule Application Error | 2.2, 11.2 | 3 |
| Term Confusion I/V | 2.2, 6.2 | 3 |
| Term Confusion I/R | 7.2, 10.2 | 2 |
| Attenuation Model | 3.2 | 1 |
| Battery as a Constant Current Source | 12.2 | 1 |
| Battery Superposition | 1.2 | 1 |
| Contacts | 14.2 | 1 |
| Sink Model | 5.2 | 1 |

Item 10, which was taken from the DIRECT, tested conceptual knowledge of voltage. This item had four qualitative responses that corresponded with a known misconception. Three of the responses corresponded to the same misconception, Local Reasoning. The fourth response corresponded with Term Confusion I/R.

Items 6 and 11 both had two misconceptions identified from the qualitative responses. The misconceptions for both items were the same for each; item 6 misconceptions were Term Confusion I/V, and Item 11 misconceptions were Rule Application Error.

Items 1, 2 and 5 also had two misconceptions identified from the qualitative responses, however, the two misconceptions were different for each. Items 1 and 5 were both taken from the DIRECT, and tested conceptual knowledge of voltage. The two misconceptions identified for Item 1 were Local Reasoning and Battery Superposition. The two misconceptions identified for Item 5 were Local Reasoning and Sink Model. Item 2 was taken from the SECDT, and tested conceptual knowledge of current. The two misconceptions identified for this item were Term Confusion I/V and Rule Application Error.

The remaining three items, numbers 3, 7 and 14 each had one misconception identified from the qualitative responses. These misconceptions are Attenuation Model, Term Confusion I/R and Contacts, respectively.

*Comparison of Group Qualitative Data*. A comparison of the qualitative responses of the two groups found one misconception that was commonly held by over 27% of Group B. Examination of this misconception indicates that there may be a common reason to explain why Group B scored significantly lower on the concept inventory than Group A.

Group A consisted of 12 subjects. There were nine qualitative responses from six unique subjects. Four of the misconceptions were related to voltage, and three subjects provided those responses. One of the misconceptions was related to current. The remaining four responses were related to the physical characteristics of a DC circuit, but the underlying misconceptions were different for each. The item numbers,

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misconceptions and frequency of post-test misconceptions for Group A are summarized

in Table 14.

Table 14

*Group A Post-Test Items, Misconceptions and Frequency of Misconceptions*

| Item | Misconception | Frequency |
|------|---------------|-----------|
| 1.2 | Local Reasoning – Current splits evenly | 1 |
| 2.2 | Term Confusion I/V | 1 |
| 5.2 | Local Reasoning – Changes are not global | 1 |
| 7.2 | Term Confusion I/R | 1 |
| 10.2 | Local Reasoning – Changes are not global | 2 |
| 12.2 | Short Circuit | 1 |
| 12.2 | Battery as a Constant Current Source | 1 |
| 14.2 | Contacts | 1 |

Group B provided 16 qualitative responses from 11 unique subjects. There were

six misconceptions related to voltage provided by 5 unique subjects, and two

misconceptions matched those from Group A. There were four misconceptions related to

current, however, three of the misconceptions were identical, and none matched the one

misconception provided by Group A. Finally, there were five misconceptions related to

the physical characteristics of a DC circuit. All five were identical and matched just one

of those provided by Group A. The item numbers, misconceptions, and frequency of

post-test misconceptions for the combined group are summarized in Table 15.

Table 15

*Group B Post-Test Items, Misconceptions and Frequency of Misconceptions*

| Item | Misconception | Frequency |
|------|---------------|-----------|
| 1.2 | Battery Superposition | 1 |
| 2.2 | Rule Application Error | 1 |
| 3.2 | Attenuation Model | 1 |
| 5.2 | Sink Model | 1 |
| 6.2 | Term Confusion I/V | 2 |
| 10.2 | Term Confusion I/R | 1 |
| 10.2 | Local Reasoning – Changes are not global | 1 |
| 11.2 | Rule Application Error | 2 |
| 12.2 | Short Circuit | 6 |

Examination of the group data contained in Table 14 and Table 15 exposes one area where the two groups markedly contrast each other. This difference is related to Item 12, which measured conceptual knowledge of the physical characteristics of a DC circuit. Two subjects in Group A indicated a misconception for this item, and one of the misconceptions was Short Circuit. Six subjects in Group B indicated holding this same misconception. Group B was roughly twice the size of Group A, but there were six times as many respondents who commonly held the same misconception for the same item. For Group B, this represents three times more instances of the same misconception after the group received their circuit analysis instruction. This large concentration – six out of

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7 instances – of the same misconception in a group may be one possible explanation as to the difference in concept inventory scores between the two groups.

*Additional Group Qualitative Information*.  Finally, there is additional qualitative information that may assist in explaining the presence of the post-test group effect.  Upon initial analysis and discovery of the group effect, the instructor of Group A was contacted and told about this difference.  After learning that his class scored significantly higher than the other two, his response was that it may have something to do with his method of teaching introductory circuit analysis.  He indicated that his approach was different from most, in that the order he taught the material allowed his students more time to practice their basic circuit analysis skills.  It took practically the entire 16-week semester to cover the basic material assessed by the concept inventory, whereas Group B covered the same material in seven and ten weeks.

**Phase III Analysis: Demographics and Self-Efficacy**.  The self-efficacy scores were analyzed using ANOVA to determine if there were any group effects present. There were no group effects present in either the pre- or post-tests for self-efficacy, so the demographics and self-efficacy scores were analyzed for the presence of any correlations. The details for each of the steps outlined above are provided in the following sections.

*Examination for Group Effects*.  Since the population and subsequent sample was divided into three classes, the pre- and post-test self-efficacy scores for each class were examined using ANOVA to investigate potential group effects among the classes.

*Self-Efficacy Pre-Test Group Effects*.  The ANOVA for the self-efficacy pre-test scores was not statistically significant, $F(2,36) = 0.50$, $p = 0.612$, indicating that there

was no difference among the self-efficacy scores of each of the classes. Statistically, the classes arrived at the start of the semester with the same level of self-efficacy for circuit analysis.

*Self-Efficacy Post-Test Group Effects*. The ANOVA for the self-efficacy post-test scores was not statistically significant, $F(2,36) = 0.20$, $p = 0.817$, indicating that there was no difference among the self-efficacy post-test scores of the classes. Statistically, the classes took the post-tests with the same level of self-efficacy for circuit analysis.

Since there was no difference among the classes for both the pre- and post-tests, the pre-test data for the three classes were combined into a single group, and the post-test data for the three classes was combined into a single group. Correlation analysis was performed to investigate correlations between the demographic characteristics and the self-efficacy scores.

While the self-efficacy scores for the three classes were statistically the same, it should be noted that the average self-efficacy scores for each class increased from pre- to post-test. The average pre-test self-efficacy score for the evening ELE 111 class was 958.33 ($M = 958.33$, $SD = 387.14$), and the average post-test self-efficacy score was 1161.33 ($M = 1161.33$, $SD = 291.10$). This increase is significant ($p = 0.025$). The average pre-test self-efficacy score for the ELE 100 class was 934.17 ($M = 934.17$, $SD = 198.93$), and the average post-test self-efficacy score was 1163.00 ($M = 1163.00$, $SD = 281.82$). This increase is significant ($p = 0.015$). The average pre-test self-efficacy score for the morning ELE 111 class was 781.43 ($M = 781.43$, $SD = 421.13$), and the average

post-test self-efficacy score was 1220.83 (M = 1220.83, SD = 201.24). This increase is significant (p = 0.003).

*Correlations Among Demographics and Self-Efficacy*. The literature identified eleven characteristics that were found to be correlated with self-efficacy. Those characteristics were previously listed in Table 1. Correlation analysis was performed on the pre-and post-test results. Demographics and characteristics were examined for correlations with the self-efficacy scores from the third-tier of the pre- and post-test concept inventories. The results of the pre- and post-test correlation analyses are shown in Table 16.

Examination of the pre-test correlations revealed that none of the demographics measured were significantly correlated with self-efficacy for circuit analysis. The post-test analysis, on the other hand, revealed that subject's age and subject's father's education level were both significantly correlated with post-test self-efficacy for circuit analysis. Both age and father's education level combined to explain a total of 29.90% of the post-test variance in self-efficacy for circuit analysis. Neither were previously identified in the literature as correlating with self-efficacy.

*Subject's Age*. The age of the subject was significantly correlated with post-test self-efficacy for circuit analysis (R = 0.43, p = 0.008). This represents a moderate correlation (Taylor, 1990), accounting for 18.49% of the post-test variance in self-efficacy for circuit analysis. This positive correlation indicates that the older a student is, the higher their self-efficacy for circuit analysis.

Table 16

*Correlations Among Demographics and Pre- and Post-Test Self-Efficacy Scores*

| Characteristic | Pre-Test | | Post-Test | |
|---|---|---|---|---|
| | R | (p) | R | (p) |
| Self-Efficacy Score | 1 | -- | 1 | -- |
| Age | 0.19 | (0.259) | 0.43* | 0.008 |
| Gender | -0.13 | (0.454) | 0.01 | 0.969 |
| Ethnicity | 0.13 | (0.454) | -0.22 | 0.190 |
| Marital Status | 0.19 | (0.262) | 0.23 | 0.168 |
| Have Children | 0.18 | (0.286) | 0.28 | 0.097 |
| # Hours worked | 0.32 | (0.057) | 0.30 | 0.073 |
| % Tuition Paid by Finan. Aid | 0.12 | (0.478) | 0.28 | 0.104 |
| Mother's Education | 0.08 | (0.634) | -0.11 | 0.519 |
| Father's Education | -0.28 | (0.098) | -0.34* | 0.042 |
| Student's Prior Education | -0.04 | (0.795) | -0.11 | 0.525 |
| 1st Generation Student | -0.18 | (0.300) | -0.12 | 0.462 |
| HS GPA | -0.15 | (0.419) | 0.05 | 0.782 |
| HS Chemistry | 0.15 | (0.365) | 0.02 | 0.917 |
| HS Physics | 0.18 | (0.285) | 0.03 | 0.853 |
| HS Math | -0.16 | (0.354) | -0.07 | 0.705 |
| College GPA | 0.00 | (0.987) | -0.02 | 0.934 |
| # Credits this Semester | -0.25 | (0.140) | -0.09 | 0.577 |
| Taken Remedial Math | 0.11 | (0.532) | 0.08 | 0.634 |
| Highest College Math | 0.02 | (0.894) | 0.27 | 0.135 |
| Highest College Math Grade | -0.05 | (0.802) | 0.08 | 0.701 |
| Taken ELE 100 | 0.25 | (0.137) | -0.04 | 0.818 |
| College Chemistry | -0.14 | (0.423) | 0.14 | 0.416 |
| College Physics | -0.11 | (0.533) | 0.09 | 0.577 |
| Taken Remedial English | -0.11 | (0.530) | -0.27 | 0.106 |
| Taken Semester Off | 0.06 | (0.715) | -0.01 | 0.954 |
| # Semesters In Current Prgrm | 0.13 | (0.452) | -0.05 | 0.758 |
| Course Required for Major | -0.11 | (0.535) | -0.10 | 0.561 |
| 1st Semester in School | -0.21 | (0.219) | -0.08 | 0.650 |
| Currently Take Math Class | -0.06 | (0.720) | 0.09 | 0.591 |

*Father's Education Level.* The education level of the fathers of the study subjects

was negatively correlated with post-test self-efficacy for circuit analysis (R = -0.34, p =

0.042). While this is statistically significant, it is considered a weak correlation (Taylor, 1990), accounting for 11.56% of the post-test variance in self-efficacy for circuit analysis. This negative correlation indicates that the lower the education level of the student's father, the higher the student's self-efficacy for circuit analysis. Likewise, the higher the education level of the student's father, the lower the student's self-efficacy for circuit analysis.

**Phase III Analysis: Self-Efficacy and Conceptual Knowledge**. The literature identified nine characteristics that correlated with conceptual knowledge, as previously shown. This study found that only self-efficacy for circuit analysis was significantly correlated with conceptual knowledge. This was observed on both the pre-test ($R = 0.42$, $p = 0.010$) and post-test ($R = 0.42$, $p = 0.009$), as shown in Table 17.

Table 17

*Pre- and Post-Test Correlations Between Concept Inventory and Self-Efficacy Scores*

| Measure | 1 R (p) | 2 R (p) | Measure | 3 R (p) | 4 R (p) |
|---|---|---|---|---|---|
| 1. pre_score | -- | 0.42 (0.010) | 3. post_score | -- | 0.42 (0.009) |
| 2. pre_selfeff_score | 0.42 (0.010) | -- | 4. post_selfeff_score | 0.42 (0.009) | -- |

In both cases, these positive correlations are considered to be indicative of moderate relationships (Taylor, 1990). These correlations explain 17.64% of the variance in pre-test conceptual knowledge scores, and 17.64% of the variance in post-test conceptual knowledge scores.

**Results: Research Question One**

Research question one asked, "What demographic or academic characteristics are correlated with conceptual knowledge of circuit analysis?" This study finds that the relationship between demographic and academic characteristics, and conceptual knowledge of circuit analysis is inconclusive.

There was a significant group effect present which prevented the ability to conclusively determine the correlations between the characteristics and conceptual knowledge of circuit analysis. ANOVA showed that a group effect was present, $F(2,36) = 7.11$, $p < 0.003$. A post-hoc analysis using the Tukey method identified the two classes that were significantly different. The comparison between the morning ELE 111 class and the ELE 100 class resulted in 95% confidence intervals of $[0.01 - 0.38]$ for the pre-test scores and $[0.10 - 0.50]$ for the post-test scores. ANCOVA accounted for the group and introduced the pre-test score as a covariant, but the model was again significant, $F(2,36) = 4.49$, $p = 0.019$, indicating that there was still a group effect.

Analysis of descriptive statistics and qualitative data provided insight which may explain the relationship between demographics and conceptual knowledge. A two-sample t-test with pooled variance (Zar, 1996) revealed that the difference between the mean number of college credits Group A was taking ($M = 11.17$, $SD = 3.38$) and the mean number of college credits Group B was taking ($M = 8.12$, $SD = 4.06$) was statistically significant, $t(35) = -2.25$, $p = 0.031$, $\alpha = 0.05$. In short, the morning ELE 111 class (Group A) was taking more credit hours than the other two classes (Group B). This may be helpful in explaining the difference in conceptual knowledge between the groups.

The qualitative data also gave insight into two possible sources of the group effect, which may explain the difference in conceptual knowledge between the two groups. The difference is not related to personal or academic characteristics, but instead to the instructors of the courses. Group B was roughly twice the size of Group A, but there were six times as many respondents who commonly held the same misconception, Short Circuit, for the same item. For Group B, this represents three times more instances of the same misconception after the group received circuit analysis instruction.

The second issue related to the qualitative data has to do with the instructor of Group A, the morning ELE 111 class. After the data was initially analyzed, he was approached and told of this difference, at which point he indicated that his approach to teaching the course was different from the others. Ultimately, this different approach resulted in his students having at least six weeks longer than the other two classes to practice the circuit analysis concepts that were assessed by the study.

Finally, there is always the possibility that the group effect was the result of something not measured by this study.

**Results:  Research Question Two**

Research question two asked, "What demographic or academic characteristics are correlated with self-efficacy for circuit analysis?"  This study finds that subject's age and subject's father's education level were both significantly correlated with self-efficacy for circuit analysis.

The pre- and post-test data sets were analyzed using ANOVA, and neither was found to be statistically significant.  The ANOVA results for the pre-test were $F(2,36) =$

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0.50, p = 0.612 and for the post-test was $F(2,36) = 0.20$, p = 0.817. This meant that for both the pre- and post-tests, there was no statistical difference between the mean self-efficacy scores of the three classes, and they could be combined into one single pre-test group and one single post-test group for further analysis.

Correlation analysis was performed on the pre- and post-test data sets to determine what characteristics were correlated with self-efficacy for circuit analysis. The pre-test analysis results found that none of the demographics measured were significantly correlated with self-efficacy for circuit analysis. The post-test analysis results revealed that subject's age and subject's father's education level were both significantly correlated with self-efficacy for circuit analysis. Subject's age was moderately and positively correlated ($R = 0.43$, p = 0.008), while subject's father's education level was weakly and negatively correlated ($R = -0.34$, p = 0.042). Combined, both of these characteristics explain 30.05% of the post-test variance in self-efficacy for circuit analysis.

**Results:  Research Question 3**

Research question three asked, "Does self-efficacy for circuit analysis correlate with conceptual knowledge of circuit analysis?"  This study finds that there is a significant relationship between self-efficacy and conceptual knowledge of circuit analysis.

Correlation analysis revealed that self-efficacy for circuit analysis and conceptual knowledge of circuit analysis appear significantly correlated with each other, and this was true for both the pre-test ($R = 0.42$, p = 0.010), and the post-test ($R = 0.42$, p = 0.009). This finding is consistent with the literature regarding self-efficacy and academic achievement.

Chapter 5


DISCUSSION

This study examined how demographic and academic characteristics were related
to conceptual knowledge and self-efficacy for circuit analysis, as well as how self-
efficacy for circuit analysis was related to conceptual knowledge of circuit analysis.  The
subjects were two groups of students enrolled in three introductory circuit analysis
classes at a large community college.  Group A was enrolled in the morning section of
ELE 111.  Group B was enrolled in the evening sections of ELE 100 and ELE 111.
Three research questions guided this dissertation:

1. What demographic or academic characteristics are correlated with conceptual
   knowledge of circuit analysis?

2. What demographic or academic characteristics are correlated with self-
   efficacy for circuit analysis?

3. Does self-efficacy for circuit analysis correlate with conceptual knowledge of
   circuit analysis?

**RQ 1: Demographics, Academic Characteristics and Conceptual Knowledge**

The results for this research question were deemed inconclusive.  A significant
group effect was present for both the pre- and post-test data.  The specific pair
comparison that was evidence of the group effect was identified and controlled for, but
the group effect remained.  Analysis of the descriptive and qualitative data found that
there were three differences between the two groups of subjects, which may explain why
one group scored higher than the other.  These differences include:

1. Group A took on average just over three credit hours more than Group B during the semester when the study was conducted.

2. Group B had an increase in the Short Circuit misconception between pre- and post-test.

3. Group A instructor taught the material assessed by the study in a different order than the other instructors, which allowed Group A more time to practice using the concepts.

In addition to these three differences, the time of day the subjects took the concept inventory is another potential explanation for the difference in conceptual knowledge between Group A and Group B.

The number of college credits the subjects were taking was the only characteristic measured by the instrument that was significantly different between the groups. The group that scored higher on the concept inventory (Group A) was taking an average of 3.04 more college credits than the group that scored lower (Group B). The relationship between taking more credit hours and scoring higher on an academic test has been documented in the literature. Zajacova, et al. (2005) found that students who take more credit hours tend to have higher levels of academic achievement. Similar results were found by Vasile and his colleagues (Vasile, Marhan, Singer, & Stoicescu, 2010). The sample used by Zajacova consisted of non-traditional, primarily first-year students, with a large portion of minorities, which was similar to the population in the present study. Taking the equivalent of approximately one extra course, while studying circuit analysis, may not entirely explain why Group A scored significantly higher on the concept inventory than Group B, but it certainly may have contributed to the difference. This

may suggest that community college engineering students who take more college credits may also score higher on a DC circuit analysis concept inventory. Unfortunately, the group effect that was present in the data prevents generalization of this finding to all of the students in the study. Additional research is required.

The second difference between the two groups was related to instruction of the concepts assessed by the study. The qualitative responses from the pre- and post-tests revealed a three-fold increase in the number of students in Group B who held the Short Circuit misconception after instruction. This finding may explain why Group B scored significantly lower than Group A. This finding must be considered inconclusive until further data is collected.

The third difference between the two groups involved one instructor's approach used in teaching the concepts assessed by this study. The two Group B instructors taught the material of interest in this study, then allowed the post-test to be given to their students. The Group A instructor taught most of the concepts assessed by this study, but before introducing combined series and parallel analysis, he introduced AC circuit analysis. The AC analysis concepts he introduced are the same as those used for resistors in DC circuits. As his students progressed through this material, he gradually introduced the remaining series/parallel circuit analysis concepts that were of interest to this study. This approach gave his students approximately five to eight more weeks to practice the concepts assessed by this study. This indicates that additional practice may lead to better scores.

A fourth reason that may explain the group difference is the time of day the classes took the concept inventory. Performance can be affected by the time of day a task is undertaken (Smith, et al., 2002; Hartley & Nicholls, 2008). Smith, et al. (2002) also found that people in temperate climates tend to consider themselves "morning-oriented", and perform better on an examination given during morning hours. In the present study, the class that performed best on the concept inventory was the class that met during the morning. This time of day effect could have contributed to Group A scoring higher on the concept inventory than Group B.

**RQ 2: Demographics, Academic Characteristics and Self-Efficacy for Circuit Analysis**

The results of this study indicate that two personal characteristics, subject's father's education level and subject's age, are correlated with self-efficacy for circuit analysis. Self-efficacy is a common theoretical basis for research on engineering education and on community college populations (Schull & Weiner, 2002; Jones, Paretti, Hein, & Knott, 2010). This is rooted in the fact that many of the strategies intended to increase university student achievement and persistence are based on increasing self-efficacy, which is a better predictor of those outcomes than other approaches such as those that are based on values, achievement and desired careers (Jones, Paretti, Hein, & Knott, 2010). As a subset of the general community college population, community college engineering students are different from university engineering students (Tsapogas, 2004). Relationships among personal and academic characteristics and self-efficacy for circuit analysis have not being studied within the community college engineering student population. The present study used correlation analysis to examine these relationships.

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Subject's father's education level was a characteristic correlated with self-efficacy that had not been previously identified in the literature. The correlation was negative, meaning students whose fathers were less educated had higher self-efficacy for circuit analysis. Likewise, the more educated the subject's father was, the lower the student's self-efficacy for circuit analysis. The correlation is considered weak, accounting for only 11.56% of the variance in self-efficacy for circuit analysis, though it was significant. Parental education level is one measure of socioeconomic status (SES) (Bradley & Corwyn, 2002; Wells & Lynch, 2012). Parental education level as a measure of SES has been shown to directly influence children's academic self-efficacy (Inman & Mayes, 1999; Horn & Bobbitt, 2000). One study (Weiser & Riggio, 2010) found that students from low SES families had higher academic self-efficacy than students from high SES families. The authors determined that many of the students in that study were first-generation college students, and simply attending the university was considered an achievement for them. They also determined that many of the students considered lower family SES as motivation for higher achievement. This finding is consistent with the results of a study on Hispanic high school students (Ojeda & Flores, 2008) who viewed their lower-educated parents as "an example of what life would be like if they did not pursue higher education". For the present study, this same inverse relationship between subject's father's education level and self-efficacy was found. Just under 20% of the subjects self-identified as being first-generation students, and the same percentage self-identified as being Hispanic.

Since there is similarity between the subjects used by Weiser and Riggio and those subjects in the present study, Weiser and Riggio's results partially explain the

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relationship between a lower-educated father and a child with high self-efficacy. They do not explain why the child of a higher-educated father would have lower self-efficacy. One explanation may have to do with parental expectations and the stigma associated with attending a community college. Parents who attended prestigious colleges and universities tend to expect the same for their children (Hearn, 1991; Karen, 2002), and will use their influence over their children to guide them toward meeting those expectations (Ma, 2009). This may occur even if the children are unprepared or otherwise not ready to attend college (Wells & Lynch, 2012). Community colleges have a stigma associated with them. Many in the general public do not consider them "college", but instead "high school, Part 2" (Blankenship, 2010; Miranda, 2014). This stigma continues to be perpetuated by low tuition, general lack of knowledge about community colleges, and inaccurate portrayals on popular television shows (Miranda, 2014). In short, community colleges do not have the same level of prestige as most universities. The findings from the present study regarding highly-educated fathers and their children who have low self-efficacy for circuit analysis may possibly be explained as an issue of higher SES students who might feel unprepared to take a difficult course such as circuit analysis, or perhaps feel as though they have disappointed their higher-educated parents for attending a community college.

Subject's age was a factor that was positively correlated with self-efficacy for circuit analysis, accounting for 18.49% of the variance in self-efficacy for circuit analysis. This finding is different from the vast majority of the literature, which tends to indicate no relationship, or even an inverse relationship between age and self-efficacy. One recent study provides support for this finding. Whannell, et al. (2012) studied a

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cohort of students enrolled in a university program intended to prepare those students for university-level studies. Prior to starting the program, age was inversely correlated with self-efficacy. The longer students stayed enrolled in the program, the more their self-efficacy increased. What is unique about this finding is that self-efficacy scores eventually increased so much that the final post-test relationship between age and self-efficacy was no longer inversely correlated. The authors of the study attributed this change in self-efficacy to older students becoming more familiar with professors' expectations and testing procedures. The work of Whannell, et al. may help to explain the findings of the present study because the two populations were of similar age, prior education level, and displayed the same trend. Unfortunately, details of these two similarities cannot be investigated further, as the authors did not provide information regarding the breakdown of age or education level other than ranges and mean values. While this finding is different from much of the literature regarding age and self-efficacy, it is possible that the subjects of the present study saw their self-efficacy increase between the pre- and post-test as they became more familiar with their professors and their circuit analysis course.

Finally, of the eight characteristics that had previously been identified in the literature as being correlated with self-efficacy (gender, race/ethnicity, marital status, dependent children, hours worked each week, percentage of tuition paid by financial aid, total time in program, highest high school math course, taken remedial college math or English courses, and number of college chemistry courses taken), none were significantly correlated with self-efficacy in this study. These characteristics were identified in studies of university students. The result that they are not correlated with self-efficacy in the

present study may further support the assertion that community college students are different from university students.

**RQ 3: Self-Efficacy and Conceptual Knowledge**
The results of this study indicate that conceptual knowledge of circuit analysis and self-efficacy for circuit analysis are directly correlated. The relationship between self-efficacy and academic achievement is well known (Bandura, 1993; Bembenutty, 2009; Pajares, 2009), however, it has not previously been studied in regard to conceptual knowledge and this unique population of community college students.

One explanation for the correlation observed in this study between conceptual knowledge and self-efficacy may be related to feedback the students received from their instructors. Prior to giving the post-test to each of the classes, the instructors of the two Group B classes tested their students on the concepts assessed by the study, but the students had not yet received their exam results. The Group A instructor tested his students on several of the concepts assessed by the study, and the students received those results prior to participating in the post-test. If that feedback was perceived by students as a source of verbal persuasion or evidence of a mastery experience, it may have helped increase self-efficacy (Bandura, 1977; Vogt, Hocevar, & Hagedorn, 2007), which corresponded with increased conceptual knowledge of circuit analysis.

**Prior Research**
There is little research on the community college population, and even less on the community college engineering student population. Prior engineering education research tends to focus on university engineering students, while much of the research on community college students focuses on retention, transfer, or the more broad combination

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of Science, Technology, Engineering and Math (STEM). The present study is unique in that it is an introductory exploration into both engineering education and community college engineering students.

The focus of prior research on conceptual knowledge is highly varied, as many of those studies tended to examine the relationship between single characteristics and conceptual knowledge. The vast majority of studies focus on university students, and this is also the case for studies on engineering students and for conceptual knowledge. There does appear to be general agreement on characteristics that are related to conceptual knowledge, and all of them tend to be related to prior knowledge. The primary sources of prior knowledge are highest math class taken, number of high school chemistry courses, number of high school physics courses (Adleman, 1998; Buchanan, 2006; Tyson, 2011), highest college math course and number of college physics courses (Tyson, 2011). Of the studies on engineering students and conceptual knowledge, only the work of Buchanan (2006) focused on community college engineering students, however, its focus was on the relationships among high school math, science, and conceptual knowledge of engineering students at a Los Angeles community college. It was not as extensive as the present study.

There was one study that examined self-efficacy of university students with findings that are of particular relevance to the present study. Weiser and Riggio (2010) found an unusual inverse relationship between SES and self-efficacy of university students that appeared in this study as well. While this finding is atypical from other results in the literature, the population in the present study is similar to that examined by Weiser and Riggio, which could explain the results of the present study.

There is a plethora of research on the relationships among personal characteristics and self-efficacy of a wide range of populations. Unfortunately, little or none of that research involves engineering students at the community college level. Self-efficacy studies on university engineering students have found correlations among gender (Besterfield-Sacre, Moreno, Shuman, & Atman, 2001), receipt of financial aid (Hayden & Holloway, 1985), and highest high school math class completed (Tyson, 2011). Self-efficacy studies on community college STEM students have identified correlations among hours worked each week (Kane, Beals, Valeau, & Johnson, 2004), race/ethnicity (Kane et al, 2004), time in academic program (Spellman, 2007), gender (Buchanan, 2006), highest high school math class (Buchanan, 2006), number of college chemistry classes taken (Buchanan, 2006), having taken remedial math and English classes (Chatman, 2007), marital status (Chatman, 2007), and having dependent children (Packard, Gagnon, & Senas, 2012). As with conceptual knowledge, many of these studies focused on relationships between single characteristics and self-efficacy. Work conducted by Kane et al., Buchanan, and Chatman were slightly more extensive by examining several characteristics. The present study is more focused than the prior research because it concentrated exclusively on engineering students at the community college and at the same time, is more expansive because it examined the relationships among 30 characteristics and self-efficacy for circuit analysis. This subject is considered to be a difficult topic for engineering students to study. None of these characteristics from the literature were correlated with self-efficacy for circuit analysis in the present study.

Finally, the relationship between self-efficacy and conceptual knowledge is well-established in the literature. Lacking in the literature are studies on self-efficacy and conceptual knowledge of community college engineering students. This is a major gap that has been addressed by the present study. Prior research has found that self-efficacy and academic achievement are related (Bandura, 1977; Brown, Lent, & Larkin, 1989; Bandura, 1993; Peterson & Arnn, 2005; Goldstein & Perin, 2008; Liem, Lau, & Nie, 2008). The present study has found the same relationship in this different population.

**Limitations of the Dissertation Study**

Perhaps the most significant limitation of the study was the inability to accommodate differences in the instructors' teaching methods, which led to the results of the first research question to be inconclusive. The fact that one instructor taught the material in a different order could have been identified much earlier, reducing the amount of practice time provided to the morning ELE 111 class. Having the ability to do this may have changed the conclusion for this research question. Under the given conditions, this limitation probably had the greatest impact on the results of the study.

A second limitation was the small population and subsequent small sample size, particularly for the ELE 100 class. Had there not been a group effect, having only 10 out of 14 subjects participate from that class would not have affected the results. When the group effect was discovered, the population had to be divided into groups to allow further investigation. Unfortunately, such a small sample from the ELE 100 population would not provide a significant comparison among the three classes, so the classes had to be combined into two groups. This provided insight into the group differences, however the

results could not be generalized to all of the students studying circuit analysis in the Electronics program.

A third limitation of the study was the fact that certain characteristics could have been included in the study, but their importance was not realized until after the study had been completed. Knowing more information about family SES and parental expectations may have provided additional insight to the relationship between age and self-efficacy that is contrary to much of the literature.

The final limitation was perhaps the most general one as well. The statistical methods used in this study rely on normal distribution of data. With such a small population, the existing data set cannot definitively be called "normal". Except in instances where generalizations clearly could not be made, the underlying statistical assumptions may not have been met. The only way to correct this is to conduct a longitudinal study that collects more data over a longer time period. Unfortunately that option was not possible for this study.

**Recommendations**

There are several recommendations that should be considered for future studies related to this subject. The biggest limitation of the study stemmed from a lack of communication with the Group A instructor. As previously mentioned, the instructors were asked about the material taught in their classes and the general timeline that material is taught. The instructor of Group A indicated that he taught the same material as the others, within the same time frame. At the minimum, an additional question that should have been asked of the instructors was, "In what order do you teach the course material?" The answer to this question would have immediately indicated that one instructor

approached the course topics in a different order than the others did, and could have led to the post-test being given to Group A earlier than it was.

A stronger recommendation is to have the same instructor teach all three classes, if possible. This would remove variation among instructors, provided the instructor taught the concepts the same way for each of the classes.

The third recommendation is to modify the demographic portion of the survey instrument to include additional questions pertaining to respondent SES. With the scant availability of literature supporting the finding between subject's father's education level and the subject's self-efficacy for circuit analysis, more information will only help to clarify and possibly support this unique finding.

Finally, an intermediate assessment should be considered between the pre- and post-tests. The finding of the relationship between age and self-efficacy is not typical of most studies. The authors of the one study from the literature that had a similar finding noted that the change in self-efficacy was gradual, over the course of the semester. While the present study had a similar end result, there is no indication of when this change in self-efficacy for circuit analysis occurred. This information could have direct applications in the community college engineering classroom. Instructors could identify students with low self-efficacy, then offer additional assistance or scaffolding for a sufficient period of time that would allow those students to build their confidence.

**Future Research**

One avenue for future research includes extending the study into a longitudinal study that would collect more data. This study and Whannell's study had similar

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outcomes with subject samples that had similar characteristics, but there does not appear to have been a follow-up to Whannell's work. Without additional information, the results of both studies may be considered anomalies. If the positive correlation between age and self-efficacy is confirmed, this would not only further support the assertion that community college engineering students are different from university engineering students, but could also identify other characteristics that differentiate community college engineering students from each other in regard to their individual self-efficacy. This could lead to personalized education, which is also one of the 14 Grand Challenges for Engineering proposed by the National Academy of Engineering (National Academy of Engineering, 2008).

A second consideration for future research is to utilize additional qualitative methods, specifically observations, interviews and protocol analysis. Detailed observations would be helpful to also investigate if particular concepts are covered in more or less depth than others. The fact that students in Group B had an increase in a common misconception could indicate those students being taught that misconception or it could also indicate that students struggled with that concept and settled on the Short Circuit misconception as a way of understanding those types of circuits. Observations may be helpful in identifying when difficult topics have not been covered in sufficient detail leaving room for students to struggle and form misconceptions.

Interviewing students would provide a vehicle to identify the existence of new misconceptions. One goal of the present study was to identify if students held any misconceptions that were not identified in the literature. In an effort to discover this, the second tier of the concept inventory provided an opportunity for students to write their

reasons for their responses in the first tier.  No new misconceptions were identified. The second tier also had item responses that included misconceptions, so it is possible students chose a response that appeared similar to the conception or misconception they actually held.  Interviews with students could provide additional in depth information on any misconceptions that may have been held and not revealed using the current study's measures.  The second tier of the concept inventory could also be changed to an entirely qualitative response that requires students to write their reasons for their first tier response, without the option of choosing among a conception and a list of misconceptions.  The biggest potential downfall of doing this is that students may be inclined to leave that response blank because they may not know how to explain their reasoning or simply may not want to put forth the effort to do so.  Interviews should be performed if the second tier responses are changed.

A third consideration for future research would be to perform verbal Protocol or "Think-Aloud" Analysis (Ericsson & Simon, 1993).  This qualitative approach would provide information on the misconceptions students hold, and would also offer insight into the procedural knowledge students have for the concepts assessed by the study.  As the students show how they solved problems in the first tier, they also provide researchers an opportunity to observe the procedure used to get to that answer as well as identify misconceptions and how they may have been used.  This would be interesting because of the relationship between conceptual and procedural knowledge, and could provide insight into whether students memorized a procedure without understanding the underlying concepts.

A final consideration for continuing this research is to expand the study to include other populations. The community college engineering population is different from the university engineering population. Given the role the community college plays in educating a skilled workforce, those differences require educational approaches that match the needs of the population being served. Expanding the scope of this study may help to further identify the characteristics and subsequent needs of a larger population, and possibly help more of those students complete their technical education goals.

**Conclusions**

As the primary source of technical and workplace training, community colleges play an important role in educating a highly skilled engineering and technical workforce. This has not impacted the focus of research in engineering education as most research has focused on university students. There are extremely few studies on the community college engineering population, and most of what does exist tends to focus on retention, transfer, or the larger STEM fields. Like the differences between community college and university students, community college engineering students are also different from university engineering students. The problem is, a different population requires different approaches and solutions to their unique problems.

This study collected the personal and academic characteristics of a group of community college engineering students to see if those characteristics were correlated to conceptual knowledge of circuit analysis and self-efficacy for circuit analysis, as well as examined the relationship between self-efficacy for circuit analysis and conceptual knowledge of circuit analysis. A significant group effect was present in the analysis between personal characteristics and conceptual knowledge which prevented

generalization of the results to the population of students enrolled in the introductory circuit analysis courses that were part of this study. Analysis of descriptive statistics revealed that students in the higher-scoring class were taking just over three credit hours more than the students in the other classes. This suggests that community college engineering students who take more credit hours may score higher on a circuit analysis concept inventory than those students who take less credit hours, however this requires additional investigation before it can be considered conclusive. Finally, qualitative information revealed that students who have more time to practice the concepts assessed by the same concept inventory, may score higher on that assessment. Due to the group effect however, these findings require additional research before they can be considered conclusive.

Regarding the relationships between personal characteristics and self-efficacy for circuit analysis, this study contributes two findings to the body of knowledge on this subject. The age of a community college engineering students is directly correlated with their self-efficacy for circuit analysis, and student's father's education level is inversely correlated with the student's self-efficacy for circuit analysis. Older community college engineering students had higher self-efficacy for circuit analysis than their peers. This finding contradicts much of the literature, however, it has been observed previously in one other study. Although it was a significant finding, given its rarity in the literature, it should be further investigated.

The second finding this study contributes to the body of knowledge is the relationship between student's father's education level and the student's self-efficacy for circuit analysis. Community college engineering students who have lower-educated

fathers were found to have higher self-efficacy for circuit analysis, and those who have

higher-educated fathers had lower self-efficacy for circuit analysis. This finding is new

to the literature, but there are ways of explaining this phenomenon. Due to the novelty of

this finding, additional research should be performed, particularly with regard to the

relationships between SES, first generation students, and self-efficacy.

Finally, the third finding from this study confirms prior knowledge about the

relationship between self-efficacy and academic performance. Self-Efficacy for circuit

analysis and performance on a circuit analysis concept inventory were positively

correlated for this population of community college engineering students. What makes

this finding unique is that this relationship has not been tested on this particular

population. This relationship is well established in the literature for other populations,

and it has now been verified for this population as well.

This dissertation is a first step at shedding light on a population that has not been

the subject of much research, and a topic that has not been applied to this particular group

of students. These findings have potential applications that may be directly imported to

the community college engineering classroom. Age tends to be inversely correlated with

self-efficacy, and if an instructor can identify students with low self-efficacy, then the

instructor may offer additional assistance or scaffolding for a sufficient period of time

that would allow those students to build their confidence. Identification of personal and

academic characteristics may help instructors tailor personalized education plans for their

students, helping more of those students succeed in their engineering studies. More

broadly, these changes may eventually influence higher retention, persistence and

graduation rates from community college engineering programs. Future studies should

be conducted to confirm these findings as well as to identify additional links between personal characteristics, conceptual knowledge, and self-efficacy of community college engineering students.

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APPENDIX A

STUDY INSTRUMENT

## Quantitative Instrument to Measure the Academic and Personal Characteristics of Community College Students that Influence Conceptual Knowledge of, and Self-Efficacy for, DC Circuit Analysis

*Please complete the following survey in its entirety. If you do not know an answer, indicate the answer that you think is most correct. Do not select multiple answers.*

### Directions

You have 60 minutes to complete the following survey. Please wait until you are told to begin, then turn to the next page and begin working.

Feel free to use a calculator and scratch paper if needed. In the first section, each question has three parts (Example: 1.1, 1.2, and 1.3). In the second section, each question only has one part. Please answer each part to all questions in both sections.

Should you complete the assessment early, check your work, then turn in your assessment when you have completed it.

### Additional Comments

- In the first section, the first part of each question has only one correct answer.
- If one of the choices in the second part of each question is not listed, use the blank space to write your answer.
- All light bulbs, resistors and batteries should be considered identical unless you are told otherwise.
- Batteries are assumed to be ideal, and internal resistances are negligible.
- Assume the wires have no resistance.

## Section 1: Concept Inventory and Self-Efficacy

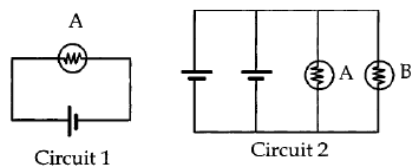Adapted from Engelhardt & Beichner (2004) and Peşman & Eryilmaz (2010)
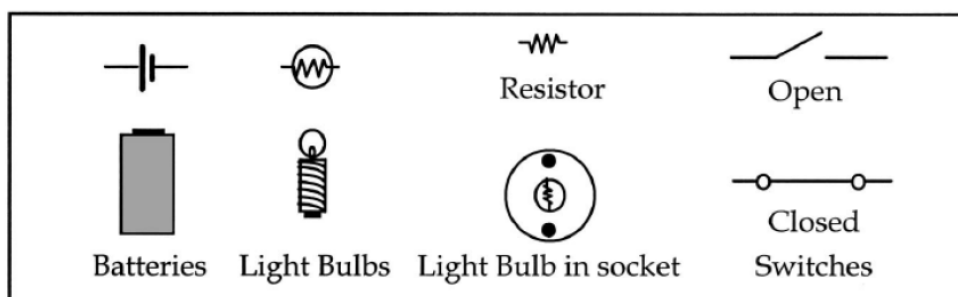
Figure 1

**1.1.** Referring to Figure 1, compare the brightness of bulb A in Circuit 1, with bulb A in Circuit 2. Which bulb is dimmer? Circle the letter next to your answer.

    a.      Bulb A in circuit 1

    b.      Bulb A in circuit 2

    c.      Neither, they are the same

**1.2.** Which one of the following is the reason for your answer in the first part? Circle the letter next to your answer.

    a.   Two batteries shine twice as bright as one battery does.

    b.   Two batteries provide twice the amount of current.

    c.   The bulbs are connected in parallel, so they have less resistance.

    d.   Parallel connections have the same voltage.

    e.   _____

**1.3.** How confident are you about your answers given for parts 1 and 2? Circle the number that best matches how confident you are.

| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|----|----|----|----|----|----|----|----|----|-----|

Not at all                Maybe/              Pretty             Completely
confident                 Not               Confident           Confident
                                Sure


Figure 2

_____

**2.1.** The current at the main branch of Figure 2 is 1.2A. What are the values of currents $i_1$, $i_2$, and $i_3$? Circle the letter next to your answer.

    a.   0.6A/0.3A/0.3A

    b.   0.4A/0.4A/0.4A

    c.   _____

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**2.2.** Which one of the following is the reason for your answer in the first part?  Circle the letter next to your answer.

a.   After the current is divided evenly on the first junction, it is again divided evenly on the second junction.

b.   Because the identical bulbs are in parallel, currents with the same magnitude pass through the bulbs.

c.   _____

**2.3.** How confident are you about your answers given for parts 1 and 2?  Circle the number that best matches how confident you are.

| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|----|----|----|----|----|----|----|----|----|-----|

Not at all confident        Maybe/ Not Sure        Pretty Confident        Completely Confident

_____



**Figure 3**

**3.1.** In Figure 3, compare the magnitudes of the currents at points 1, 2, 3 and 4, as well as the brightness of bulbs A and B.  Circle the letter next to your answer.

| | Current | Brightness |
|---|---|---|
| a. | $i_1 = i_2 = i_3$ | Bulbs A and B are the same brightness |
| b. | $i_3 > i_2 > i_1$ | Bulb B is brighter |
| c. | $i_1 > i_2 > i_3$ | Bulb A is brighter |
| d. | $i_1 > i_2 > i_3$ | Bulbs A and B are the same brightness |

**3.2.** Which one of the following is the reason for your answer in the first part?  Circle the letter next to your answer.

a.   The closer the bulb is to the battery, the brighter it is.

b.   In circuits in series, magnitude of the current is the same at any point.

c.   Because the electric current is consumed by the bulbs, it diminishes.

d.   _____

**3.3.** How confident are you about your answers given for parts 1 and 2?  Circle the number that best matches how confident you are.

| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|----|----|----|----|----|----|----|----|----|-----|

Not at all confident        Maybe/ Not Sure        Pretty Confident        Completely Confident

_____

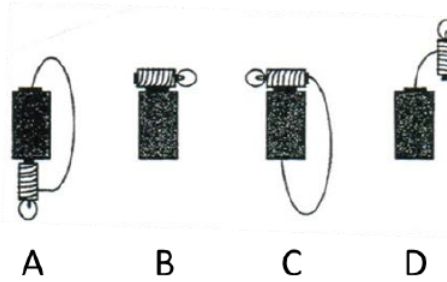130

*Figure 4*

**4.1.**  Referring to Figure 4, which circuit(s) will light the bulb?  Circle the letter next to your answer.

a.  A            b.  C            c.  D            d.  A and C            e.  B and D

**4.2.**  Which one of the following is the reason for your answer in the first part?  Circle the letter next to your answer.

a.   A is a complete circuit

b.   C is a complete circuit

c.   Current is flowing through D

d.   Both A and C are complete circuits

e.   Both B and D are complete circuits

f.   _____

**4.3.**  How confident are you about your answers given for parts 1 and 2?  Circle the number that best matches how confident you are.

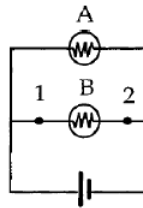| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|----|----|----|----|----|----|----|----|----|-----|
| Not at all confident | | | | Maybe/ Not Sure | | | Pretty Confident | | | Completely Confident |

_____



**Figure 5**

**5.1.**  Referring to Figure 5, what happens to the potential difference between points 1 and 2 if Bulb A is removed?  Circle the letter next to your answer.

a.  Increases            b.  Decreases            c.  Stays the same

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**5.2.** Which one of the following is the reason for your answer in the first part? Circle the letter next to your answer.

    a. The battery provides the same amount of current to each circuit, regardless of the circuit arrangement.

    b. Parallel connections have the same voltage.

    c. Since the bulbs are equal, removing bulb A leaves twice as much current for bulb B.

    d. By removing bulb A, there is more current in the circuit, and thus more voltage for bulb B.

    e. _____

**5.3.** How confident are you about your answers given for parts 1 and 2? Circle the number that best matches how confident you are.

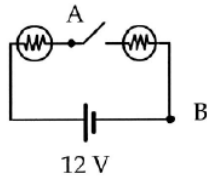| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|----|----|----|----|----|----|----|----|----|-----|
| Not at all confident | | | | Maybe/ Not Sure | | | Pretty Confident | | | Completely Confident |

---



12 V

**Figure 6**

**6.1.** Referring to Figure 6, what is the potential difference between points A and B? Circle the letter next to your answer.

    a. 0V          b. 3V          c. 6V          d. 12V

**6.2.** Which one of the following is the reason for your answer in the first part? Circle the letter next to your answer.

    a. The voltage across an open component equals the voltage provided by the battery.

    b. No current means there is no voltage.

    c. The resistors are equal, so the voltage splits evenly.

    d. Because of the open circuit, only the first resistor has voltage.

    e. _____

**6.3.** How confident are you about your answers given for parts 1 and 2? Circle the number that best matches how confident you are.

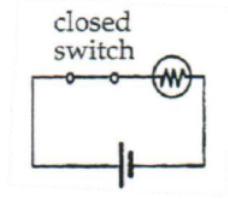| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|----|----|----|----|----|----|----|----|----|-----|
| Not at all confident | | | | Maybe/ Not Sure | | | Pretty Confident | | | Completely Confident |

---

**Figure 7**

**7.1.**   Referring to Figure 7, immediately after the switch is opened, what happens to the resistance of the bulb?  Circle the letter next to your answer.

a.   The resistance increases

b.   The resistance decreases

c.   The resistance stays the same

d.   The resistance goes to zero

**7.2.**   Which one of the following is the reason for your answer in the first part?  Circle the letter next to your answer.

a.   There is no current, so there is no resistance

b.   Resistance is based on the resistor

c.   In an open circuit, the resistance is infinite

d.   _____

**7.3.**   How confident are you about your answers given for parts 1 and 2?  Circle the number that best matches how confident you are.

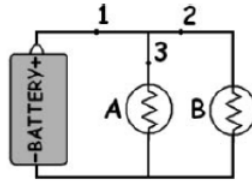|  0  |  10  |  20  |  30  |  40  |  50  |  60  |  70  |  80  |  90  |  100  |
|-----|------|------|------|------|------|------|------|------|------|-------|
| Not at all confident | | | | Maybe/ Not Sure | | | Pretty Confident | | | Completely Confident |

_____

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**Figure 8**

**8.1.** Referring to Figure 8, compare the amount of current at Points 1, 2 and 3. Circle the letter next to your answer.

    a.      $i_1 > i_2 > i_3$

    b.      $i_1 > i_2 = i_3$

**8.2.** Which one of the following is the reason for your answer in the first part? Circle the letter next to your answer.

    a.  As the split occurs, more current passes through the branch in the same direction with the main branch and less current passes through the bent branch.

    b.  The current is divided evenly because the bulbs are identical

    c.  _____

**8.3.** How confident are you about your answers given for parts 1 and 2? Circle the number that best matches how confident you are.

| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|----|----|----|----|----|----|----|----|----|-----|

Not at all             Maybe/           Pretty           Completely
confident             Not            Confident        Confident
                        Sure

**9.1.** Referring to Figure 8, compare the brightness of bulb A with bulb B. Circle the letter next to your answer.

    a.      Bulbs A and B are equal brightness

    b.      Bulb A is brighter

    c.      Bulb B is brighter

**9.2.** Which one of the following is the reason for your answer in the first part? Circle the letter next to your answer.

    a.  Most of the current passes through bulb B.

    b.  Bulb A is closer to the battery

    c.  Currents with the same magnitude pass through bulbs A and B

    d.  _____

**9.3.** How confident are you about your answers given for parts 1 and 2? Circle the number that best matches how confident you are.

| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|----|----|----|----|----|----|----|----|----|-----|

Not at all             Maybe/           Pretty           Completely
confident             Not            Confident        Confident
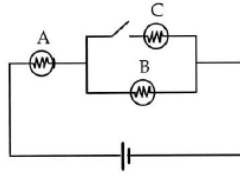                        Sure

_____

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**Figure 9**

**10.1.** Referring to Figure 9, what happens to the brightness of bulbs A and B when the switch is closed?  Circle the letter next to your answer.

    a.      A stays the same, B dims

    b.      A gets brighter, B dims

    c.      A and B increase

    d.      A and B decrease

    e.      A and B remain the same

**10.2.** Which one of the following is the reason for your answer in the first part?  Circle the letter next to your answer.

    a.    The closer the bulb is to the battery, the brighter it is.

    b.    Closing the switch changes the current for the entire circuit.

    c.    The battery provides the same amount of current to each resistor.

    d.    Current splits evenly at each junction, regardless of resistance.

    e.    _____

**10.3.** How confident are you about your answers given for parts 1 and 2?  Circle the number that best matches how confident you are.

| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|
| Not at all confident | | | | Maybe/ Not Sure | | | Pretty Confident | | | Completely Confident |

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**Figure 10**

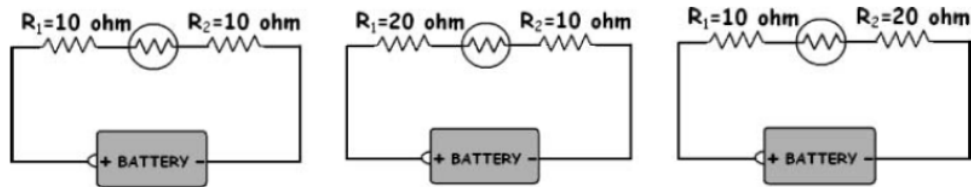| R$_1$=10 ohm  R$_2$=10 ohm | R$_1$=20 ohm  R$_2$=10 ohm | R$_1$=10 ohm  R$_2$=20 ohm |

**Figure 11**  **Figure 12**

**11.1.** Referring to Figure 10, a battery, a bulb, and two resistors are shown. By exchanging *only R₁* for a 20 ohm resistor, the circuit shown in Figure 11 is created. By exchanging *only R₂ in Figure 10* for a 20 ohm resistor, the circuit shown in Figure 12 is created. Does the brightness of the bulb in Figure 11 and Figure 12 change with respect to the bulb in Figure 10? Circle the letter next to your answer.

| | Figure 11 | Figure 12 |
|---|---|---|
| a. | Yes | No |
| b. | Yes | Yes |
| c. | No | Yes |
| d. | No | No |

**11.2.** Which one of the following is the reason for your answer in the first part? Circle the letter next to your answer.

a. Before the current reaches the bulb, it is influenced by Resistor R$_1$.

b. Before the current reaches the bulb, it is influenced by Resistor R$_2$.

c. In both figures, the current changes because total resistance in Figures 11 and 12 changes with respect to Figure 10.

d. The current is the same, due to the same batteries

e. _____

**11.3.** How confident are you about your answers given for parts 1 and 2? Circle the number that best matches how confident you are.

| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|

Not at all
confident

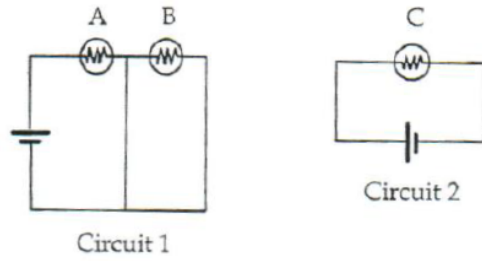Maybe/
Not
Sure

Pretty
Confident

Completely
Confident

**Figure 13**

**12.1.** Referring to Figure 13, compare the brightness of bulbs A and B in Circuit 1 with the brightness of bulb C in Circuit 2. Which bulb or bulbs are the brightest? Circle the letter next to your answer.

a.     A

b.     B

c.     C

d.     A = B

e.     A = C

**12.2.** Which one of the following is the reason for your answer in the first part? Circle the letter next to your answer.

a.    Current splits evenly through each branch

b.    The battery supplies the same current to each bulb

c.    No current flows through bulb B

d.    Bulbs A and C are connected in parallel

e.    _____

**12.3.** How confident are you about your answers given for parts 1 and 2? Circle the number that best matches how confident you are.

| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|----|----|----|----|----|----|----|----|----|-----|

Not at all confident        Maybe/ Not Sure        Pretty Confident        Completely Confident

_____

137
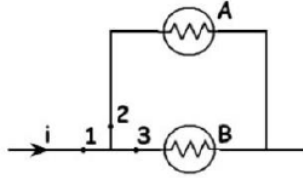
**Figure 14**

**13.1.** Referring to Figure 14, the direction of current is shown. Rank the currents at Points 1, 2, and 3. Circle the letter next to your answer.

    a.       $i_1 > i_3 > i_2$

    b.       $i_1 > i_2 = i_3$

**13.2.** Which one of the following is the reason for your answer in the first part? Circle the letter next to your answer.

    a.   The current is divided evenly into the branches at the junction because the resistances of the bulbs are equal.

    b.   When the split occurs, more current passes through the branch in the same direction with the main branch, and less current passes through the bent branch.

    c.   _____

**13.3.** How confident are you about your answers given for parts 1 and 2? Circle the number that best matches how confident you are.

| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|----|----|----|----|----|----|----|----|----|-----|

Not at all
confident

Maybe/
Not
Sure

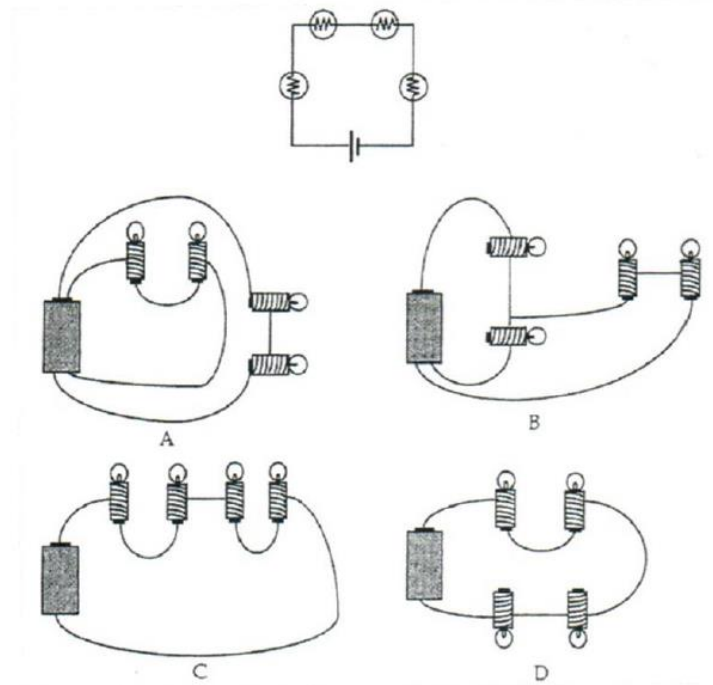Pretty
Confident

Completely
Confident

_____

**Figure 15**

**14.1.** Referring to Figure 15, which realistic circuit(s) represent(s) the schematic diagram shown? Circle the letter next to your answer.

a. B

b. C

c. D

d. A and B

e. C and D

**14.2.** Which one of the following is the reason for your answer in the first part? Circle the letter next to your answer.

a. All bulbs are connected in series

b. All bulbs are connected in parallel.

c. Half of the bulbs are connected in series, half are connected in parallel

d. _____

**14.3.** How confident are you about your answers given for parts 1 and 2? Circle the number that best matches how confident you are.

| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|----|----|----|----|----|----|----|----|----|-----|

Not at all
confident

Maybe/
Not
Sure

Pretty
Confident

Completely
Confident

139
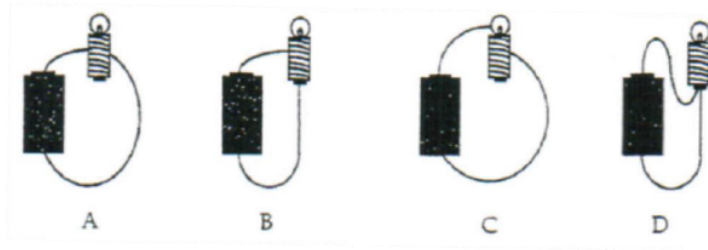
**Figure 16**

**15.1.** Referring to Figure 16, Will all bulbs be the same brightness? Circle the letter next to your answer.

    a.      Yes

    b.      No

**15.2.** Which one of the following is the reason for your answer in the first part? Circle the letter next to your answer.

    a.    Yes, because they all have the same type of circuit wiring

    b.    No, because only B will light. The connections to A, C and D are not correct

    c.    No, because only D will light. D is the only complete circuit

    d.    No, C will not light, but A, B and D will

    e.    _____

**15.3.** How confident are you about your answers given for parts 1 and 2? Circle the number that best matches how confident you are.

| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|----|----|----|----|----|----|----|----|----|-----|
| Not at all confident | | | | Maybe/ Not Sure | | | Pretty Confident | | | Completely Confident |

_____

# Section 2:  Demographics and Academic Characteristics

16.  Age: _____

17.  Gender:          Male          Female

18.  Please circle the best description of your race or ethnicity

American Indian      Asian      Black or African      Hispanic or      Native Hawaiian or      White      Other
or Alaska Native                 American              Latino           Other Pacific Islander

19.  Marital status
     Single      Not Married, but      Married      Separated      Divorced      Widow /
                 in a relationship                                              Widower

20.  I am a parent of (a) dependent child(ren):     Yes          No

21.  Number of hours **you** work at a job each week: _____

22.  Approximate percentage of your tuition and school fees that are **paid from financial aid**: _____%

23.  **Mother's** education

Some high      Received      High school      Some      Associate's      Bachelor's      Master's      Ph.D
school         GED           graduate         college   degree           degree          degree

24.  **Father's** education

Some high      Received      High school      Some      Associate's      Bachelor's      Master's      Ph.D
school         GED           graduate         college   degree           degree          degree

25.  **Student's** education **prior to this semester**

Some high      Received      High school      Some      Associate's      Bachelor's      Master's      Ph.D
school         GED           graduate         college   degree           degree          degree

26.  I am the first in my family to attend college:          Yes          No

27.  **High school** grade point average (GPA): _____

28.  Indicate the number of chemistry courses you completed in **high school**: _____

29.  Indicate the number of physics courses you completed in **high school**: _____

30.  Highest math course you completed in **high school**

Pre-Algebra      Algebra I      Algebra II      Geometry      Trigonometry      Pre-Calculus      Calculus

31.    **Current** college grade point average (GPA): _____

32.    This semester, I am taking a total of _____ credit hours in all of my college courses.

33.    **Prior to this semester**, I have taken at least one of the following college Math courses:  MAT 082, MAT 090, MAT

       091 or MAT 092:          Yes                No

34.    Circle the **highest** math course you completed **in college**

Arithmetic        Introductory        Intermediate        College Algebra        Trigonometry        Pre-Calculus
                  Algebra             Algebra

Calculus I        Calculus II         Linear Algebra          Discrete              Calculus III        Differential
                                                             Mathematics                                Equations

35.    Grade earned in highest **college** math course:      A        B        C        D        F

36.    **Prior to this semester**, I completed ELE 100

                   Yes              No

37.    Grade earned in ELE 100:        A        B        C        D        F

38.    Indicate the number of chemistry courses you completed in college: _____

39.    Indicate the number of **physics** courses you completed in college: _____

40.    **Prior to this semester**, I have taken any one of the following **English** courses:  ENG 081, ENG 091, ENG 100:

                   Yes              No

41.    While enrolled in my current program, I have had to take at least one semester off from school:

                   Yes              No

42.    I have been working on my current degree for _____ semesters

43.    **This course** is required for my major:

                   Yes              No

APPENDIX B

MAP OF STUDY ITEM CONCEPTS AND OTHER MISCONCEPTIONS TO

REFERENCES

| Study Item # | Source | General Concepts | Misconceptions Used as Distractors |
|---|---|---|---|
| 1 | Engelhardt & Beichner # 16 | **Voltage** – Current is influenced by the voltage maintained by the battery and resistance in the circuit | **Battery Superposition** – 1 battery, bulb shines. 2 batteries, bulb shines 2X bright.<br><br>**Resistive Superposition** – Multiple resistors increase/decrease current by number of resistors in circuit. |
| 2 | Peşman & Eryilmaz # 2 | **Current** – Current in a parallel circuit splits based on the resistance in the parallel branches | **Local Reasoning** – When a change in the circuit occurs, focus is on that change, not the effect on the entire circuit |
| 3 | Peşman & Eryilmaz # 4 | **Current** – In a series circuit, the magnitude of the current is the same at any point | **Attenuation Model** – Current decreases as you move through the circuit, until you return to the battery where there is no current left because current has been used up<br><br>**Resistive Superposition** – Multiple resistors increase/decrease current by number of resistors in circuit.<br><br>**Empirical Rule Model** – Components that are farther away from the voltage source, such as light bulbs, glow dimmer |
| 4 | Engelhardt & Beichner # 9 | **Physical Characteristics** – Functional two-endedness: Elements have two possible points with which to make a connection | **Contacts** – Unable to identify the two contacts on a light bulb.<br><br>**Sink Model** – Only a single wire is necessary to allow current to flow. |

| 5 | Engelhardt & Beichner # 15 | **Voltage** – Potential difference in a series circuit sums, while in a parallel circuit, it remains the same | **Battery as a Constant Current Source** – Battery supplies same amount of current to each circuit regardless of the circuit's arrangement |
| | | | **Resistive Superposition** – Multiple resistors increase/decrease current by number of resistors in circuit. |
| 6 | Engelhardt & Beichner # 28 | **Voltage** – Potential difference in a series circuit sums, while in a parallel circuit, it remains the same | **Term Confusion I/V** – Voltage viewed as a property of current. Current is the cause of the voltage. Voltage and current always occur together |
| | | | **Complete Circuit** – Unable to identify a complete, closed circuit |
| | | | **Rule Application Error** – Misapplied a rule governing circuits. |
| | | | **Direct Route** – The battery is the only source of charge, so only those elements with a direct contact to the battery will light |
| | | | **Sequential** – Only changes before an element will affect that element |
| 7 | Engelhardt & Beichner # 23 | **Physical Characteristics** – Concepts of resistance, including that resistance is a property of the resistor, and that in series, resistance increases as more resistors are added to | **Term Confusion I/R** – Resistance viewed as being caused by the current |
| | | | **Resistance Equals Circuit Equivalent Resistance** – Equating the equivalent |

| | | | |
|---|---|---|---|
| | | the circuit, and decreases when more resistors are added to a parallel circuit | resistance of a circuit with an individual resistance value |
| 8 | Peşman & Eryilmaz # 6 | **Current** – In a parallel circuit, when the resistors have equal value, the current through each will be the same | **Current Flow as Water Flow** – Current flows like water does, such as, when a circuit splits, more current will continue flowing in the same direction as the original flow |
| 9 | Peşman & Eryilmaz # 7 | **Current** - In a parallel circuit, when the resistors have equal value, the current through each will be the same | **Current Flow as Water Flow** – Current flows like water does, such as, when a circuit splits, more current will continue flowing in the same direction as the original flow<br><br>**Empirical Rule Model** – Components that are farther away from the voltage source, such as light bulbs, glow dimmer |
| 10 | Engelhardt & Beichner #29 | **Voltage** – Potential difference in a series circuit sums, while in a parallel circuit, it remains the same | **Empirical Rule Model** – Components that are farther away from the voltage source, such as light bulbs, glow dimmer<br><br>**Local Reasoning** – When a change in the circuit occurs, focus is on that change, not the effect on the entire circuit<br><br>**Battery as a Constant Current Source** – Battery supplies same amount of current to each circuit |

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| | | | regardless of the circuit's arrangement |
|---|---|---|---|
| | | | **Local** – Current splits evenly at every junction, regardless of the resistance of each branch |
| 11 | Peşman & Eryilmaz # 9 | **Current** – Changing the resistance of a series circuit changes the current in that series circuit | **Battery as a Constant Current Source** – Battery supplies same amount of current to each circuit regardless of the circuit's arrangement |
| | | | **Sequential** – Only changes before an element will affect that element |
| 12 | Engelhardt & Beichner #10 | **Physical Characteristics** – Identify and explain a short circuit (more current follows the path of lesser resistance) | **Short Circuit** – Unable to identify a short circuit |
| | | | **Local** – Current splits evenly at every junction, regardless of the resistance of each branch |
| | | | **Battery as a Constant Current Source** – Battery supplies same amount of current to each circuit regardless of the circuit's arrangement |
| 13 | Peşman & Eryilmaz # 11 | **Current** - In a parallel circuit, when the resistors have equal value, the current through each will be the same | **Current Flow as Water Flow** – Current flows like water does, such as, when a circuit splits, more current will continue flowing in the |

| | | | same direction as the original flow |
|---|---|---|---|
| 14 | Engelhardt & Beichner #22 | **Physical Characteristics** – Interpret pictures and diagrams of series, parallel and combination circuits | **Contacts** – Unable to identify the two contacts on a light bulb.<br><br>**Complete Circuit** – Unable to identify a complete, closed circuit |
| 15 | Engelhardt & Beichner #27 | **Physical Characteristics** – Identify and explain a short circuit (more current follows the path of lesser resistance) | **Contacts** – Unable to identify the two contacts on a light bulb.<br><br>**Complete Circuit** – Unable to identify a complete, closed circuit<br><br>**Short Circuit** – Unable to identify a short circuit |
| Not Used | Engelhardt & Beichner | | **I Causes E** – Current is the cause for the electric field inside the wires of a circuit |
| Not Used | Engelhardt & Beichner | | **Topology** – All resistors lined up in series are in series whether there is a junction or not. |
| Not Used | Engelhardt & Beichner | | $V = R_{eq}$ – Voltage calculated using equations for equivalent resistance |
| Not Used | Peşman & Eryilmaz | | **Shared Current Model** – Current is shared equally by electrical devices |
| Not Used | Peşman & Eryilmaz | | **Clashing Current Model** – Positive and negative electricity meet at a device, and clash there, thus running the device |

| | | |
|---|---|---|
| Not Used | Peşman & Eryilmaz | **Parallel Circuit Model –** Resistors are obstacles to current flow, and total resistance increases as the number of parallel resistors increases |

APPENDIX C

PRE-TEST ITEMS, SUBJECT IDENTIFIERS, QUALITATIVE COMMENTS AND

FREQUENCY OF IDENTIFIED MISCONCEPTIONS

| Question | ID | Comment | Misconception |
|----------|-----|---------|---------------|
| 1.2 | CA92 | Bulb A (circuit 1) receives the entire current while bulb A in circuit 2 has divided current | Rule Application Error – Components connected in parallel have same voltage, which does not affect current |
| 1.2 | WE45 | 2 Batteries in parallel combine for total | Rule Application Error – Components connected in parallel have same voltage, which does not affect current |
| 3.2 | CA92 | Current diminishes across a resistor | Current Consumed – Current decreases as you move through the circuit components until you return to the battery with no more current left |
| 3.2 | CR01 | Voltage drop across resistor makes B not as bright | Attenuation Model – As current flows through the first component, it is "used up", leaving less for the next. This results in lower voltages for the next as well. |
| 3.2 | RO39 | The resistors slow down the current after each point | Sink Model – Equating current flow with water flow. Resistors slow flow of current |
| 3.2 | TE60 | In circuits in series with equal resistance, magnitude of the current is the same at any point | Rule Application Error – This is true for any series circuit. It has nothing to do with resistance values. |
| 5.2 | WE45 | its in series so potential decreases | Attenuation Model – As current flows through the first component, it is "used up", leaving less for the next. This results in lower voltages for the next as well. |
| 6.2 | EL17 | Not a complete circuit for either | Term Confusion I/V – Voltage and current always occur together |

| | | | |
|---|---|---|---|
| 6.2 | HA94 | Incomplete circuit, no voltage | Term Confusion I/V – Voltage and current always occur together |
| 6.2 | TO56 | No voltage because open circuit | Term Confusion I/V – Voltage and current always occur together |
| 7.2 | TE60 | The bulb never loses its resistance value unless it becomes infinit | Rule Application Error – This is true, but the subject indicates that an open circuit is the only way the resistor's value can change.  This ignores the fact that a short circuit can also cause the resistors value to change as well. |
| 8.2 | CI70 | Current is divided by 2 since there are 2 branches | Local Reasoning – Current splits evenly at every junction regardless of resistance of each branch |
| 8.2 | FR73 | The current is divided evenly in parallel circuit | Local Reasoning – Current splits evenly at every junction regardless of resistance of each branch |
| 10.2 | CA92 | Closing the switch cuts B's current in half | Local Reasoning – Changes to a circuit only affect where the change was made, not on the global circuit |
| 10.2 | CI70 | More circuit resistance = less voltage per bulb | Rule Application Error – Miscalculated total resistance |
| 10.2 | CR01 | B & C legs will now share the voltage, dimming | Local Reasoning – Changes to a circuit only affect where the change was made, not on the global circuit |
| 10.2 | TA10 | I don't know if it effects this as a whole or if it's past it where it is effected.  Im just going to go For it and say it is the whole thing insted of being isolated | Local Reasoning – Changes to a circuit only affect where the change was made, not on the global circuit (Note:  answer chosen for first tier showed |

| | | | |
|---|---|---|---|
| 10.2 | TH76 | Circuit changes from Series to now include a parallel branch | Local Reasoning – Changes to a circuit only affect where the change was made, not on the global circuit |
| 11.2 | WE45 | Current is Equal b/c in series | Rule Application Error – This is only true if the changed resistors had the same values as previously |
| 12.2 | DA19 | The closer the bulb is to powr the brighter is is. | Empirical Rule Model – The further away the bulb is from the battery, the dimmer the bulb. |
| 12.2 | DE88 | A and B will be dimer cause the share the battery | Attenuation Model – As current flows through the first component, it is "used up", leaving less for the next.  This results in lower voltages for the next as well. |
| 12.2 | EL17 | A & B are series, A resists flow to B | Short Circuit – Unable to identify a short circuit, or ignoring a short circuit |
| 12.2 | RO39 | Bulb C is on it's own branch recieving more current | Current Consumed – Current decreases as you move through the circuit components until you return to the battery with no more current left |
| 12.2 | SH78 | Circuit 1 has more resistance | Resistive Superposition – Current is reduced based on number of resistors, regardless of configuration |
| 12.2 | TO56 | Current hits A in Circuit 1 at the same value of C in Circuit 2 | Short Circuit – Unable to identify a short circuit, or ignoring a short circuit |

| 13.2 | CA92 | Less current goes through A because of path of least resistance | Sink Model – Equating current flow with water flow. Water will flow straight through a pipe easier than into and through a side pipe |
|------|------|---|---|
| 13.2 | CI70 | After a split, the current is divided per how many splits | Local Reasoning – Current splits evenly at every junction regardless of the resistance of each branch |
| 13.2 | LA11 | Current is split evenly due to being a parallel circuit | Local Reasoning – Current splits evenly at every junction regardless of the resistance of each branch |
| 14.2 | PA59 | For some reason, it just looks correct | Contacts – Unable to identify contacts on a light bulb |

APPENDIX D

POST-TEST ITEMS, SUBJECT IDENTIFIERS, QUALITATIVE COMMENTS AND

FREQUENCY OF IDENTIFIED MISCONCEPTIONS

| Question | ID | Comment | Misconception |
|---|---|---|---|
| 1.2 | CA86 | Two batteries in parallel provide the same voltage as one battery, and a parallel circuit is a current divider (less current to bulb) | Local Reasoning – Current splits evenly at every junction regardless of the resistance of each branch |
| 1.2 | CI70 | Double voltage and double load equals same brightness | Battery Superposition – Brightness determined by number of batteries, regardless of configuration |
| 2.2 | LA11 | The only value given is current | Term Confusion I/V – Voltage and current always occur together |
| 2.2 | PA37 | The Bulbs are parallel and have different currents | Rule Application Error – This only applies if resistances are different |
| 3.2 | CR01 | Voltage drop across the resistor (bulb) would make "B" not as bright | Attenuation Model – As current flows through the first component, it is "used up", leaving less for the next. This results in lower voltages for the next as well. |
| 5.2 | SH78 | Opening a branch in a parallel circuit won't affect the other branches | Local Reasoning – Changes to a circuit only affect where the change was made, not on the global circuit |
| 5.2 | TH76 | Removing bulb A causes current to more readily flow thru that loop | Sink Model – Equating current flow with water flow. Removing one branch allows more current to flow through another |
| 6.2 | AN78 | It is not a complete circuit | Term Confusion I/V – Voltage and current always occur together |
| 6.2 | XO91 | Open circuit = No voltage | Term Confusion I/V – Voltage and current always occur together |
| 7.2 | LA11 | If switch is opened, there is nothing to resist after the switch | Term Confusion I/R – A resistor resists the current, so a current |

| | | | must flow for there to be any resistance |
|---|---|---|---|
| 10.2 | CA92 | Closing switch means a lower resistance for B and C than just B, which means A picks up the slack | Term Confusion I/R – Resistance is caused by current |
| 10.2 | EL17 | Closing the switch splits current for bulbs C & B | Local Reasoning – Changes to a circuit only affect where the change was made, not on the global circuit |
| 10.2 | SH78 | Closing the switch puts B parallel with C, splitting the current | Local Reasoning – Changes to a circuit only affect where the change was made, not on the global circuit |
| 10.2 | TH76 | Closing the circuit changes the current for B&C | Local Reasoning – Changes to a circuit only affect where the change was made, not on the global circuit |
| 11.2 | AN78 | Current is equal in series circuit | Rule Application Error – This is only true if the changed resistors had the same values as previously |
| 11.2 | MA13 | Is a series circuit so current is always the same | Rule Application Error – This is only true if the changed resistors had the same values as previously |
| 12.2 | CA92 | Less resistance in circuit 2, so more current | Short Circuit – Unable to identify a short circuit, or ignoring a short circuit |
| 12.2 | DA19 | A,B are in series, C is a single circuit | Short Circuit – Unable to identify a short circuit, or ignoring a short circuit |
| 12.2 | DE88 | Current splits in parallel there for there more current going through Bulb C | Short Circuit – Unable to identify a short circuit, or ignoring a short circuit |
| 12.2 | AN78 | The total resistance in circuit one will be less than circuit 2 thus the total current is higher | Short Circuit – Unable to identify a short circuit, or ignoring a short circuit |

| 12.2 | PA37 | A and B are in parallel. C is series | Short Circuit – Unable to identify a short circuit, or ignoring a short circuit |
|---|---|---|---|
| 12.2 | RO39 | Bulbs A and B are on the same battery giving them less current | Short Circuit – Unable to identify a short circuit, or ignoring a short circuit |
| 12.2 | EL17 | C sees full current, A sees full current before the split | Short Circuit – Unable to identify a short circuit, or ignoring a short circuit |
| 12.2 | TR23 | All get same current | Battery as a Constant Current Source – Battery supplies same amount of current to each circuit, regardless of configuration |
| 14.2 | TR23 | None have all in series | Contacts – Unable to identify contacts on a light bulb |

APPENDIX E

INSTITUTIONAL REVIEW BOARD (IRB) DOCUMENTATION

On Fri, Apr 19, 2013 at 11:51 AM, Tiffany Dunning <Tiffany.Dunning@asu.edu> wrote:
Dear Dr. Baker and Carl Whitesel,
1304009056 **Study Title:** Value, Academic, and Personal Characteristics that Explain Self-Efficacy and Conceptual Knowledge of DC Circuit Analysis

The above-referenced protocol is considered exempt after review by the Institutional Review Board pursuant to Federal regulations, 45 CFR Part 46.101(b)(1) (2). Attached to this email is a copy of your approval letter. Research may begin.

Sincerely,
Tiffany

Tiffany Dunning | IRB Coordinator, Office of Research Integrity & Assurance
Arizona State University | Office of Knowledge Enterprise Development | Operations
t 480-639-7396 | f 480-965-7772

tiffany.dunning@asu.edu |                    http://researchintegrity.asu.edu

How am I doing?  Email my supervisor

**ASU** Knowledge Enterprise
Development

Office of Research Integrity and Assurance

| | |
|---|---|
| **To:** | Dale Baker<br>EDB |
| **From:** | Mark Roosa, Chair<br>Soc Beh IRB |
| **Date:** | 04/19/2013 |
| **Committee Action:** | **Exemption Granted** |
| **IRB Action Date:** | 04/19/2013 |
| **IRB Protocol #:** | 1304009056 |
| **Study Title:** | Value, Academic, and Personal Characteristics that Explain Self-Efficacy and Conceptual Knowledge of DC Circuit Analysis |

The above-referenced protocol is considered exempt after review by the Institutional Review Board pursuant to Federal regulations, 45 CFR Part 46.101(b)(1) (2) .

This part of the federal regulations requires that the information be recorded by investigators in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.  It is necessary that the information obtained not be such that if disclosed outside the research, it could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

You should retain a copy of this letter for your records.

**Maricopa County Community College District**
**2411 West 14th Street**
**Tempe AZ, 85281**
**TEL: (480) 731-8701**
**FAX: (480) 731 8282**

| | |
|---|---|
| **DATE:** | April 28, 2013 |
| **TO:** | Baker, Dale, Other |
| | Whitesel, Carl, Other |
| **FROM:** | MCCCD Institutional Review Board |
| **PROTOCOL TITLE:** | Value, Academic, and Personal Characteristics that Explain Self-Efficacy and Conceptual Knowledge of DC Circuit Analysis |
| **FUNDING SOURCE:** | NONE |
| **PROTOCOL NUMBER:** | 2013-03-266 |
| **FORM TYPE:** | NEW |
| **REVIEW TYPE:** | EXEMPT |

Dear Principal Investigator,

The MCCCD IRB reviewed your protocol and determined the activities outlined do constitute human subjects research according to the Code of Federal Regulations, Title 45, Part 46.

The determination given to your protocol is shown above under Review Type.

You may initiate your project.

If your protocol has been ruled as *exempt,* it is not necessary to return for an annual review. If you decide to make any changes to your project design which might result in the loss of your exempt status, you must seek IRB approval prior to continuing by submitting a modification form.

If your protocol has been determined to be *expedited or full board review,* you must submit a continuing review form prior to the expiration date shown above. If you make any changes to your project design, please submit a modification form prior to continuing.

Weappreciateyourcooperationincomplyingwiththefederalguidelinesthatprotecthumanresearchsubjects.Wewishyousuccessinyourproject.

Cordially,
MCCCD IRB