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Undergraduate engineering students' understanding of complex circuit concepts: An investigation of the intersection of students' prior knowledge, design of learning environments and the nature of the content

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UNDERGRADUATE ENGINEERING STUDENTS' UNDERSTANDING OF COMPLEX CIRCUITS: AN INVESTIGATION OF THE INTERSECTION OF STUDENTS' PRIOR KNOWLEDGE, DESIGN OF LEARNING ENVIRONMENTS AND THE NATURE OF THE CONTENT

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Nicole P Pitterson

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This dissertation is dedicated to my mother, Valrie Pitterson,

and the memory of my father

Charles Pitterson (1943-2006)

I would not be who I am today if not for your love and support.

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ABSTRACT

Pitterson, Nicole P. Ph.D., Purdue University, December 2015. Undergraduate Engineering Students' Understanding of Complex Circuit Concepts: An Investigation of the Intersection of Students' Prior Knowledge, Design of Learning Environments and the Nature of the Content. Major Professor: Ruth Streveler.

Research focused on increasing students' conceptual understanding of electric circuits discuss this concept as difficult to not only teach but for students to grasp. This difficulty has been attributed to the fact that students tend to hold inaccurate pre-conceptions of electricity which becomes problematic as the level of complexity increases from the most basic to more advanced circuit concepts. The combination of inaccurate and inadequate prior knowledge has the potential to prevent students from being able to assimilate new material they come in contact with when instructed about electric circuit concepts in formal settings. Often times, students' inability to associate this new concept with correct pre-existing conception or prior knowledge leads to the development of misconceptions about the nature of electricity. With these issues in mind, this study focused on exploring undergraduate engineering students' conceptual understanding of electric circuits through an investigation of three interconnected areas. The overall purpose of this study was to give a descriptive account of learning complex circuits.

This dissertation took the form of three stand-alone in-depth studies aimed at answering the broad overarching question of: what are the underlying reasons for students' perceived difficulty in learning complex circuit concepts? Using three distinct methods of inquiry such as an inductive/deductive thematic analysis of historical data, a systematic literature review of published work and a single descriptive case study with multiple embedded units, the central theme of this study was the alignment of prior knowledge, design of learning environments and how concepts are taught. The common finding of this work highlighted the lack of alignment between content, assessment and pedagogy. It was also found that in introductory courses students are exposed to concepts mostly in a mathematical way without much emphasis on the use of qualitative discussions. These results have significant implications for the teaching and practice of engineering. In addition, this work contributes to the body of literature on complex circuits such as alternating current (AC) circuits and students' conceptual understanding. The model used to guide the study in terms of how the three individual studies support each other and align with the overarching research question provide useful information that can significantly improve the methods used to teach students complex concepts in introductory courses.

CHAPTER 1. INTRODUCTION

1.1 Background

Research focused on increasing students' conceptual understanding of electric circuits have discussed this concept as difficult to not only teach but for students to grasp (Duit & von Rhöneck, 1998; Johnstone, 1991). In introductory circuit courses students are exposed to the concept of basic circuit concepts such as direct current (DC) circuits and the more complex circuit concepts such as alternating current (AC) circuits. However for each type of circuit the requirement for identifying circuit operating conditions, the interaction of voltage, current and resistance among circuit components and the type of circuit design whether series, parallel or series-parallel remains the same. Yet alternating current (AC) circuits specifically have been described as more difficult than general direct current (DC) circuits (Licht, 1991). This difficulty has been attributed to the fact that students tend to hold very little formal prior conceptions of electricity with which to assimilate the new material they are being taught when they experience instruction on electricity in a formal setting (Biswas et al., 1998, 2001; Holton, Verma, & Biswas, 2008).

Additionally, as the level of complexity increases from simple to complex, students seem to lack the necessary conceptual frames of reference such as what is happening in the circuit at a given time, relationships between variables and how components operate individually and holistically just to name a few, with which to associate the new material. Often times, students' inability to associate this new concept with some pre-existing conception or prior knowledge leads to the development of misconceptions about the nature of electricity (Carstensen & Bernhard, 2009; Shipstone, 1988). These misconceptions are further compounded by the level of difficulty associated with the dynamic and time-varying nature of alternating current (AC) sources when compared to its static and steady direct current (DC) alternative. This adds another level of complexity especially since students are usually taught DC and AC circuits combined without there being any direct dissociation made between the two in terms of how fundamentally different they are (Bernhard & Carstensen, 2002; Biswas et al., 1997). Despite previous dissertations on the nature of electric circuits and students' understanding in introductory circuit courses (Engelhardt, 1997; Sangam, 2012) there is the need for studies intent on taking a deeper look at the interaction students' prior knowledge, design of learning environment and the strategies used to convey information about complex circuits.

In the study by Engelhardt (1997), the primary focus was students' understanding of electrical circuit concepts using two methods of testing: multiple choice items and follow up interviews. Engelhardt (1997) found that while students were able to correctly translate between realistic representation and schematic diagrams, they lack an understanding of the underlying mechanisms governing the circuit. On the other hand, the work of Sangam (2012) focused on how the nature of students' conceptual development is fostered by the efficacy of textbooks as well as students' social and affective perspective of the material and instructional practices. The very important gap of exploring the intersection of prior knowledge/experiences, design of learning environment and how the content is taught to mitigate the level of difficulty theorized to be associated with electricity needs to be studied. The intent of this study is to investigate the reasons for the perceived underlying difficulties related to learning and understanding complex circuit concepts associated with alternating current (AC). In this dissertation complex circuit concepts are denoted by topics in a circuit course where the input source of the circuits has AC properties such as phasors, advanced Kirchhoff voltage and current law application, sinusoidal steady state analysis, frequency response and power transfer.

1.2 Problem Identification

In previous studies (Biswas et al., 2001; Carstensen & Bernhard, 2009; Grotzer, 2000; McDermott & Shaffer, 1992b), recommendations have been made for the inclusion of innovative teaching strategies aimed at engaging students actively in the process of learning about AC circuits. Similarly, calls for the use of more engaging learning strategies in engineering learning environments suggest that when students are actively involved in the process of learning they are better able to retain and learn the new material (K. A. Smith, Sheppard, Johnson, & Johnson, 2005). While some studies (Dykstra, Boyle, & Monarch, 1992; Roth & Roychoudhury, 1994) have been aimed at exploring how innovative teaching strategies are beneficial in increasing students' understanding and learning of complex scientific concepts, the lack of literature in engineering that speaks specifically to complex concepts such as circuits having AC sources makes this study a fruitful venture in engineering (Bernhard & Carstensen, 2002; Schwartz et al., 2000).

In addition, the complex and abstract concepts associated with AC circuits has been a limiting factor to the number of studies conducted on issues associated with this area of study (Grotzer & Sudbury, 2000). According to Cartensen and Bernhard (2009), the topic of AC circuits has not been studied in depth mainly due to the fact that the concept of AC circuits is one that is quite difficult to understand hence very few researchers have attempted to look more deeply into this issue. It has also been discussed that studies that do focus on AC circuits lean towards studying introductory physics classes at the college or high school level. The simple nature in which AC circuits are discussed at these levels barely address the more high-order classroom material that undergraduate students are usually taught (Duit & von Rhöneck, 1998; Licht, 1991).

1.3 Research Questions

This dissertation took the form of three stand-alone in-depth studies aimed at answering the overarching question of: What are the underlying reasons for students' perceived difficulty in learning complex circuit concepts? The central theme of this study was the alignment of prior knowledge, design of learning environments and how concepts are taught. The purpose of this study was to give a descriptive illustration about difficulties associated with learning complex circuits in general. The rationale for choosing these three specific studies and method of conducting them stemmed from recommendations made by various researchers for an approach to teaching and learning complex scientific concepts that explores the relationship between the role of learning environments, student' experiences, prior knowledge and how difficult concepts are taught in a classroom (Carstensen & Bernhard, 2009; Holton et al., 2008; Johnstone, 1991; Licht, 1991; McDermott & Shaffer, 1992b; McDermott, 1993; Schwartz et al., 2000). This approach was also fueled by the curiosity of the researcher to investigate the relationship professed to exist between these three factors in learning. The findings suggest these studies highlight the cyclical relationship that exists between the knowledge and experiences students bring to the learning environment and how this knowledge in turn influences what concepts are emphasized as important. The figure below shows the connection between the three studies.

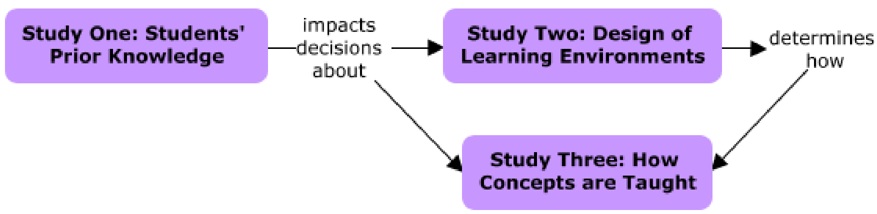

Figure 1- Relationship among studies

1.3.1 Study One: Engineering students' use of analogies and metaphors when discussing circuit concepts.

This study was guided by the following research questions:

a. How does students' prior knowledge hinder/enhance learning about complex circuit concepts?

b. How do students use analogies and metaphors to explain circuit concepts?

To answer the above research questions an integration of inductive and deductive analysis of data collected from electrical engineering majors at a Western US college conducted using a think aloud protocol was done. This approach to qualitative analysis allowed the researcher to evaluate the data from which specific themes, important patterns and interrelationships could be explored and further confirmed using guiding analytic principles derived from existing literature. Using this iterative process, the researcher had the ability to be objective while still allowing the data to speak for itself. The use of this integrated approach offered benefits such as allowing themes to emerge, before a rigid analytic approach was used, which would have otherwise gone unnoticed.

This data was a part of a larger project aimed at uncovering engineering students' misconceptions about common scientific concepts using a Delphi study with expert faculty (Streveler et al., 2011). The interview data used in this study were conducted with nine (9) electrical engineering majors. The think aloud protocol was developed by researchers in collaboration with the course instructors from which the information for this study was drawn. The students who participated in the study were classified as juniors and seniors (Nelson et al., 2005). Students' classification as juniors and seniors indicate they would have taken at least two circuit courses, mandatory introductory physics and calculus courses as well. The questions students were interviewed with were primarily open ended conceptual questions aimed at getting students to explain the how and why about certain circuit phenomena. Consequently, the questions were structured to identify misconceptions by having students discuss what was happening in the circuit at a given time, a justification of their thought process on the given concept and why this was the case.

Significance of study

The primary goal of introductory courses is to ensure that students have developed foundational knowledge that can be transferred to more complex courses as they make progress to their degrees and beyond. An investigation of students' ability to reflect on their prior knowledge and how it impacts their explanation of concepts long after they exited the learning environment highlights decisions made by instructors about which concepts to reinforce as significant. The findings of this study formed the basis for the other two studies conducted in this dissertation. The nature of the students' prior knowledge gave the researcher the starting point to frame the criteria for inclusion in the second study and the data to collect in the third study.

Limitations

The data analyzed were historical and as such the ability to follow up with the students was not possible. In addition the students did not attend the same institution in which study three was conducted therefore there is a possibility of classroom design and climate being different. However while these limitations are merited, the concepts discussed as problematic and the influence of prior knowledge by previous research are substantiated in the findings of this study. A study that could be used to overcome this limitation would be to use the same or a modification of the think aloud protocol used with students who have been previously enrolled in the introductory circuit course at the university study three was conducted.

1.3.2 Study Two: A systematic review of undergraduate engineering students' perception of the types of activities used to teach electric circuits.

The need to include more engaging activities in large lecture classes saw the increase in active learning approaches, however the dearth of studies focused on how these activities were received by students speaks volumes. The research questions developed for this study were motivated by the need to investigate students' perception on the types of activities used to convey knowledge about circuit concepts in introductory courses. The guiding questions were:

a. How are engineering learning environments designed to promote students' understanding of electric circuits?
b. What are students' perceptions of the types of activities used in enhancing their understanding of circuit concepts?

The method used to conduct this study and to answer the research questions was a systematic literature review. This approach helped the researcher to create for readers a general overview of previous work done on a topic under study (Mosteller & Colditz, 1996). The three main benefits of a systematic literature review are the opportunity to explore and combine areas among previous studies to answer to new research questions, the ability to summarize many issues of research described by previous studies and the prospect of demonstrating gaps in previous work so as to highlight areas of minute evidence that can support a particular concept (Borrego, Foster, & Froyd, 2014). The study was conducted using a combination of Cooper's (2010) and Borrego, Foster and Froyd's (2014) method of systematic literature review. The interactive-constructive-active-passive (ICAP) framework (Chi, 2009) was used as an organizing principle for the data extracted from the studies while the data were analyzed using a thematic approach.

Significance of study

Recommendations for the use of active learning strategies in the engineering classrooms led to the increase of learning activities aimed at engaging students. However, this need to actively include students in the process of learning can sometimes come at the expense of decreasing student interest in the material and engagement in the activity being used. A study that investigates students' perception of the types of learning activities being used provides instructors with information about how these activities are received. The work of Sangam (2012) explores how the combination of epistemological, ontological and affective beliefs influence conceptual change of electric circuits. However there have been no studies dedicated to describing the classification of the types of learning activities and how students perceive the activity's ability to increase their learning of the content.

Limitations

The studies selected for inclusion in this study were evaluated using a specific criteria list. This led to the use of only 10 studies for this study. The small number of studies can be considered a limitation of this work. In addition only two databases were searched for literature pertaining to this study. This therefore means there could be other studies that were not part of the selection process. Additionally, this work was limited to published studies due to the researcher's inability to access "gray" matter such as white papers or other unpublished reports. A suggestion for future work is to expand the databases and search criteria by using more refined key words.

1.3.3 Study Three: Complex circuit concepts in an introductory electrical engineering course: A descriptive case study

A single descriptive case study with embedded units was the method used to conduct this study. Three sections of an introductory circuit course were used as units for this study. The case study protocol used was based on the propositions from the literature and findings from studies one and two which were also used to determine the data gathered. The research questions that were investigated are:

a. How are complex circuit concepts taught to students enrolled in a compulsory introductory circuit course?
b. What decisions are made by professors about how to communicate knowledge about complex circuit concepts to students?

The theoretical framework used to guide data collection and analysis within and across units was the pedagogical content knowledge (PCK) framework. The components in this framework are centered on decisions instructors make about how to help students understand a particular subject matter or set of concepts (Magnusson, Krajcik, & Borko, 1999). Data collection methods were direct classroom observations, professor interviews and course document analysis. Findings were presented specific to each unit and in terms of the overall case. The results indicate the influence of prior knowledge and learning environments on how concepts are taught.

Significance of study

A study that describes the decision making process that goes into the dissemination of information and design of learning environments has significant benefits to the field of engineering. The most ideal learning environment consists of a combination of the four perspectives which has the capability to increase student learning (National Research Council, 2000). In addition to the design of learning environments, the alignment of what and how concepts are taught and subsequently assessed is necessary for deep conceptual learning (Streveler et al., 2011; Streveler, Litzinger, Miller, & Steif, 2008). This study aims to explore this alignment in order to provide insights about the interaction of learning environment, prior knowledge and student learning. This is an important area to be researched as it helps to uncover the relationships that exist between the way in which information about these circuit concepts are conveyed and possible barriers to students' understanding.

Limitations

The time frame in which this study was conducted was the off semester for electrical engineering majors meaning a majority of the students in the course at the time of data collection were other engineering majors. While the focus of this study is on engineering students in general further study can be conducted in the semester when the majority of the students enrolled in the course are electrical engineering majors. In addition, students could be interviewed so as to ascertain their opinions on the nature of their learning environments and decisions made about teaching of circuit concepts.

1.4 Broader impact

The results of this study have theoretical and practical significance to the field of engineering as well as contribute to the body of literature on complex circuits such as alternating current (AC) circuits and students' conceptual understanding. Furthermore the results of this study are an important addition to engineering literature since the electric circuits studied by physics education researchers is at the introductory level (Carstensen & Bernhard, 2009) and more in depth study of circuits at a higher level is important in order to understand students' understanding at varying levels of circuit difficulty (Holton et al., 2008). Unlike the work conducted by Sangam (2012) that focused on the social and affective interaction of students' perception and motivation for learning introductory and advanced circuit concepts, this study explored the alignment of three very important and influential factors that can be applied to any discipline. Similarly, whereas the work of Engelhardt (1997) investigated students' understanding of direct current circuits and the nature of testing this study's primary focus is on the teaching of more complex concepts that are understudied. Consequently, this work is a start in filling an obvious gap in engineering research both in practical and theoretical aspects.

In the area of practicality, engineering faculty who are desirous of increasing student participation in their classes can apply the learning environment designs discussed as having significant benefits on deep conceptual learning in this study to do so. In addition, engineering courses mode of delivery can be transformed to help students better understand and learn these concepts. For future study, this work can be extended by looking at the learning environments of other disciplines and how complex concepts within these areas are taught. This would not only create a scholarship of integration but would provide educators with a broad view of how learning can be improved where necessary to increase or elicit conceptual understanding gains.

1.5 Dissertation Roadmap

This study consists of three distinct studies aimed at answering a broad research question. The line of coherence is maintained throughout the study based on the recommendations of previous research. The study concludes with a discussion of the propositions from the literature and how the combined findings of the three studies validate or dispel these propositions.

Chapter two: a broad overview of the literature is presented. This chapter starts with an overview of the topic understudy and the major components related to each study synthesized. These major components are: conceptual change and learning scientific concepts, conceptual change and the importance of student engagement, nature of electric circuits, difficulties associated with teaching and learning complex circuit concepts, the importance of mathematical knowledge and educational implications. The chapter concludes with a summary that identifies the gap in previous work.

Chapter three: presents the first study which is an inductive/deductive analysis of electrical engineering majors think aloud interviews. The focus of this study is the manner in which students use their prior knowledge to discuss circuit operations and conditions.

Chapter four: using a systematic review of literature approach, this study is aimed at exploring students perception of the types of learning activities used to increase their conceptual learning of concepts in introductory circuit courses.

Chapter five: a single descriptive case study with multiple embedded units is conducted focused on how complex circuit concepts are taught to students. The context of this study is a compulsory introductory course for all engineering majors in which three sections are used as units of analysis. Data was collected through direct classroom observations, professor interviews and course documents such as course outline and lecture notes. Findings are presented specific to units and collectively across all units.

Chapter six: compiled findings from all three studies are presented based on how the findings align with proposition from the literature as well as instances of emerging information discussed. The chapter concludes with a theory of difficulty about learning complex circuit concepts, implications and recommendations for future study..

CHAPTER 2. LITERATURE REVIEW

2.1 Overview

In chapter one, the topic of the study “Exploring undergraduate engineering students’ conceptual understanding of complex circuit concepts” was introduced and the methods of inquiry summarized. The three study approach to this dissertation work is intent at investigating the topic from three conceptual lenses. In this chapter the supporting literature for each lens will be presented. This chapter begins with a synthesis of the work on eliciting conceptual change and learning scientific concepts and the importance of student engagement. This section is meant to provide readers with a broad overview of conceptual change. The second section goes more in-depth with a synthesis of literature on the nature of electric circuits and the reported difficulty associated with teaching and learning complex concepts. The third section highlights the discussion of the educational implications specifically focused on teaching and the learning environment. The chapter concludes with a summary of what was previously discussed and the identified gap the following chapters will seek to fill. The idea behind this chapter is to use previous work to show how the three areas to be studied in depth relate to each other as well as support the overall focus of this study. Since each individual study consists of its own literature review directly related to that specific study this review will be done as an overview of the broad topic of this dissertation and therefore without much specificity.

2.2 Conceptual change and learning scientific concepts

The issue of conceptual change has been one of importance to educational researchers for a number of years. Posner et al. (1982), Hewson and Hewson (1984) and Chi (2009) among others have postulated that the child does not enter the classroom as an empty vessel awaiting the inpouring of information of the teacher but that they in fact have conceptions that are sometimes rigorous and deeply rooted in their mental framework. Children grow and develop these concepts because it is through these concepts that they are able to “make sense” of the world around them (Vosniadou et al., 2001). Similarly studies by Zirbel (2006) have shown that because students are not “blank slates”, they enter the classroom with formulated theories on how the world is connected and these conceptions sometimes are “robust” (Slotta & Chi, 2006) and well defined. Therefore there is a tendency to make associations so that they can better be able to relate to the experience they interact with in the learning environment.

Consequently, conceptual change in science learning is defined as the process whereby pre-conceptions about a specific concept is modified or completely changed through the introduction of new material (Carey, 2000; Duit, Treagust, & Widodo, 2008; Reiner, Slotta, Chi, & Resnick, 2000; Vosniadou, 2007a, 2008). The previous definition however, does not capture the complexity associated with conceptual change or the conditions necessary for conceptual change. Research has suggested problems associated with conceptual change can be attributed to the inability of schools to structure effective means of reforming the instructional process through which students can directly engage in the teaching and learning process so as to overcome this difficulty (Gorodestksy & Keiny, 2002; Sinatra, 2002; Streveler, Brown, Herman, & Montfort, 2014). The call for reformation of the instructional process challenges the idea of simple memorization of facts and rote learning. These approaches have been discussed as inadequate in equipping students with the ability to restructure their naïve theories (Slotta & Chi, 2006; Vosniadou et al., 2001). Furthermore Vosniadou (2007) argues that conceptual change is domain-specific meaning students hold distinctive thoughts about concepts in a particular domain which provides strong constraints on how the process of learning and understanding is approached. In order to make sense of new knowledge or unfamiliar information, children tend to form theories labeled as naïve theories which are domain-specific. Consequently, when they are exposed to new knowledge these naïve theories are both reinforced and built upon or they experience a change in belief referred to as a conceptual change. Zirbel (2006) also believes that conceptual change is difficult because our brains are created to build upon prior ideas given that learning is a process that evolves from birth to death. The pattern of association that develops over time is dependent on each new experience as our brain goes through the process of linking new experience or knowledge with an existing framework.

Another group of researchers argue learning as a rational activity in which the student engages in a kind of inquiry with the objective of structuring ideas from the evidence that supports them (Posner et al., 1982; Vosniadou, 2007a). It is therefore reasoned that learning is in itself conceptual change. This school of thought is influenced by the work of Thomas Kuhn and his belief that learning causes a paradigm shift. Other researchers have characterize this shift as evidence of conceptual change (Elen, Clarebout, Léonard, & Lowyck, 2007; Von Secker & Lissitz, 1999). However, this paradigm shift is easier said than achieved. Chi, cited in Slotta, Chi and Joram (1995, p. 374) discusses "some misconceptions are easily removed in the course of instruction whereas others are characteristically robust". Salient questions raised by Chi (2008) in relation to interacting factors surrounding conceptual change are "in what ways is knowledge misconceived? Why is such misconceived knowledge resistant to change? What constitutes a change in prior knowledge? And how should instruction be designed to promote conceptual change?" (p. 61). In support of the issues raised by these questions, Holton, Verma and Biswas (2008) discuss where misconceptions in scientifically complex concepts exist there is a requirement of a more targeted and intense approach since it is argued misconceptions can be attributed to the level of abstraction. Reiner, Slotta, Chi and Resnick (2000) designates this possibility as a tendency of "novices to adopt substance-based conceptions when reasoning about abstract concepts such as light, heat and electricity" (p. 8). One of the main choices to dealing with abstract concepts is the use of instructional analogies to elicit conceptual change. This is usually because through the use of analogies students are able to relate a known concept to an unknown. Posner et al. (1982) based on the work of Piaget attribute this change in belief through two types of modification processes: assimilation where students rely on the existing concepts to understand new phenomena or accommodation where the central concept is replaced or re-organized based on the new information or new experience.

However diSessa (1998) refers to conceptual change as the addition and deletion of consulting elements that forms the big picture. A concept, as a part of the whole, allows the individual to develop an understanding of how a system or process works. With exposure to new knowledge, whether through instruction or experience, the student has to re-think their previous beliefs and then make a decision to either reject this new information, add it to their preconceived belief or put away the belief all together. Conceptual change, he argues, should draw the line between memorization and gradual changes in belief. If concepts are at the core of our knowledge and form the basis for what we believe then conceptual change is more than just the application of new knowledge. Conceptual change has to be seen as a process that starts at the foundation of our knowledge and experience and involves the shifting and restructuring of the current concepts.

A more historical approach to the discussion of students' conceptions and conceptual is offered by Duit and Treagust (2003). They explain early research started with Piaget, constructivists' ideas followed shortly after in conjunction with the Piagetian conditions of assimilation and accommodation. These researchers propose, along with Yan Yip (2001), Limon (2001) and Gorodestksy and Keiny (2002), that conceptual change is more than conceptual but has more emphasis on the change that the learner must undergo themselves. Conceptual change is therefore claimed to take place at various levels through different situations. In the world of science and scientific concepts, conceptual change is denoted as the pathways of learning from students' preconceptions to the actual science concepts to be learned through effective instructions (Limon, 2001). The typical mode of conceptual change involves the teacher encouraging students to use alternative frameworks that challenges their prior knowledge and cause dissatisfaction through the use of various instructional strategies.

The National Research Council (2012) reports that undergraduate education is marked by moving students along a continuous path between novice and expert understanding. Recommendations in order to achieve this goal include being able to identify what students know and how these ideas align themselves with the scientific knowledge that instruction will stimulate and how to restructure those ideas that are not in alignment. The report calls for conceptual change based on the idea that students have incorrect knowledge likely to be in conflict with the new material to be learned. Nevertheless, Slotta and Chi (2006), Vosniadou (2007) and Smith et al. (1993) discuss that it is usually challenging and difficult to promote conceptual change solely through the use of instruction because conceptual change is a slow and tedious process and some concepts are more deep rooted than others. For conceptual change to be effective, immense emphasis needs to be placed on students pre-existing understanding and beliefs that they use to form hypotheses or models about how the world works. In order to change these beliefs, students must come in contact with empirical evidence that dispels their previous understanding (Chan, 2001). Even though classroom instructions might cause conceptual change, these instructional strategies, on their own, it is not guaranteed to ensure that this new belief is retained throughout the course of study, or even the lifetime of the student. It is on this foundation that cognitivists have purported that students will continue to change their conceptions as they relate with more content and learning processes.

2.3 Conceptual change and the importance of student engagement

Concepts are defined as the "building blocks of more complex and even abstract representations" (Zirbel, 2006, p. 3). Contingent upon this definition is the manner in which instruction is designed to constructively teach concepts while avoiding the development of misconceptions. Discussions have been centered around the premise that when students have formed conceptions with which they enter new learning processes as the tendency is to connect their pre-existing conceptions with the new information based on their perceived similarities (Limon, 2001; Vosniadou, 2007a; Zirbel, 2006). It has also been theorized that "students at all levels, from preschool through college, enter instruction with various commonsense but incorrect interpretations of scientific and engineering concepts and skills" (National Research Council, 2012, p. 58). While it has been discussed that conceptual change can be elicited through instruction some researchers have made the claim that instructions by themselves not sufficient enough to achieve this feat (Picciarelli, Di Gennaro, Stella, & Conte, 1991b). For example, in a study conducted by Bilgin and Geban (2006), it was found that students who were taught scientific concepts through the traditional instructional methods such as lectures intent on memorization and rote learning showed very little achievement when given a test and that they had incorrect understanding of the content. Given that concepts are well connected and represented through their thought processes, it is utmost important that instructions allow for the construction of concepts on a particular topic that connects without creating misconceptions.

Vosniadou (2007) argues instruction on scientific concepts, if not effectively executed, can lead to misconceptions due to the mismatch that can develop between what naïve theories originally existed and what new information is being imparted. Consequently, the implication for instruction is that students are made aware of inconsistencies that may exist between their naïve theories and the scientific concepts being taught. Zirbel (2006) supports this point by suggesting that in dealing with misconceptions, teachers have to create a learning environment in which students are encouraged to construct meaning for themselves and in so doing they learn to accept the dissatisfaction they feel with what they previously knew or understood as scientific facts. "When a learner makes sense of new material, he/she is able to make the connections between different concepts" (Zirbel, 2006, p. 3). This is based on the premise that deep understanding is usually the end result of students being challenged by new information that promotes critical thinking. This deep understanding stems from "student engagement in approaches to learning which leads to greater academic gain, better grades and understanding of concepts" (Laird, Shoup, Kuh, & Schwarz, 2008, p. 469).

Researchers have argued the traditional method of teaching science does not always work especially when the concepts seem to counter that which the student already believes. Constructivist theorists have suggested that the learning process should be so structured that students are encouraged to employ deep thinking and by extension engage themselves actively in the learning process. The implication for instruction based on their view is that the learning environment should be more learner-centered than teacher-centered. The type of instruction being implied is active learning, which is generally defined as the instructional setting where students are actively involved in their own learning. "In short, active learning requires students to do meaningful learning activities and think about what they are doing" (Prince, 2004, p. 1). Chi (2009) in discussing “being active” (p.76), emphasizes that active learning indicate something is being done and through the process of doing, or completing a task, or becoming engaged with the learning material, through direct interaction, learning occurs.

In support of this interaction between students and learning environment, Hewson and Hewson (1984) infer that since concepts are formed based on our intellectual environments then the same intellectual environment, if structured properly, can cause these concepts to be changed as well. They believe that if a child has a misconception that remains unchanged by new knowledge, there is a conceptual conflict that will continue to impede further learning. “Learning involves an interaction between new and existing conceptions with the outcome being dependent on the nature of the interaction. If these conceptions can be reconciled, learning proceeds without difficulty. If, however, they cannot be reconciled, then learning requires that existing conceptions be restructured or even exchanged for the new. The recognition that change of this nature may have to occur forms the basis of conceptual change model of learning” (P. W. Hewson & Hewson, 1984, p. 6). This posit is reinforced by Sinatra (2002) in that she discusses “the conditions required for conceptual change necessitate a classroom climate that promotes reflection, values questioning and helps student knowledge become explicit and open to evaluation” (p. 195). The general idea is the learning context within which conceptual change is being fostered should be so designed whereby students have the opportunity to interact with the material whether through instructional strategies or learning activities. This type of affordance, Slavin (1996) recommends, may be quite effective in promoting conceptual change.

2.4 Nature of the electric circuits

A simple electric circuit consists of four main parts: a source, control device, load and conductors. While circuit diagrams can range from very simple to complex, the components and related sections of the circuit are derived from these four basic parts. In addition electric circuits tend to take one of three forms: series, parallel or series-parallel. In any of the three configurations there are three important variables voltage, current and resistance upon which the operation of the circuit and its components are highly dependent. Though each variable serves a very distinct and definite purpose in the circuit their interaction through the circuit components have significant implications for how the circuit operates and the function it is meant to serve. It is the interaction of these variables that prove most difficult for students to understand (Cohen, Elyon, & Ganiel, 1983). Students' inability to distinguish the three variables independently and collectively as well as their respective function in a circuit has been of significant interest to researchers for a number of years (Cohen et al., 1983; Engelhardt & Beichner, 2004; Lee & Law, 2001; Shipstone, 1988; Shipstone et al., 1988; Streveler et al., 2006). Most common is the interchangeable use of voltage and current and their respective attributes that have been reported to be problematic (Carlton, 1999; J. P. Smith et al., 1993; Streveler et al., 2008). One reason for this difficulty has been attributed to students' inclination to sequential reasoning (Dupin & Joshua, 1989; Grotzer, 2000; Stocklmayer & Treagust, 1994). Other researchers have theorized that the manner in which circuits are taught lean towards suggesting each variable operates independently of each other and specific to a particular component (Liegeois & Mullet, 2002; McDermott & Shaffer, 1992a).

Consequently Métioui, Brassard, Levasseur and Lavoie (1996) suggest that since students are inclined to think these concepts are the same it is necessary that efforts be made by instruction to explain current and voltage as different variables. However this would require serious effort. According to these authors instruction fails when mathematical relationships, such as ohm’s law, are not introduced at early stages. While Ohm's law does not speaks to switches, lamps or types of circuits, the concept of ohm's law aids the understanding of the duality between current and voltage while explaining how fundamentally different they are. It is this researcher’s belief that though this approach might have benefits, the authors fail to discuss how instructors would incorporate the use of a complex and demanding representation, such as ohm's law, to facilitate complete understanding without having significant impact on the learning process. Introducing students to the equations involved would not be of much benefit if they are not made to understand why such equations are important or the principles on which they have been formulated. In subsequent sections the importance and reliance on equation and mathematical approaches to the teaching and understanding of simple and complex circuit concepts is discussed.

2.4.1 Difficulty associated with learning complex concepts

When learners are exposed to new concepts in instructional settings, it is common for them to attempt to assimilate the new information with some existing conception that they hold about the topic being taught (Duit & von Rhöneck, 1998; McDermott & Shaffer, 1992b). However, unlike other scientific concepts, it has been previously discussed that the concept of electricity is one in which students tend to hold very little formal concrete prior conceptions (Biswas et al., 1997; Shipstone, 1988). Therefore it is fair to conclude that in electricity, most conceptions and misconceptions come through formal instruction (Biswas et al., 1998; Holton et al., 2008; McDermott, 1993). The limited pre-conceptions about electricity lead to students' inability to even begin to create mental models of what electricity is. This inability is further compounded by the level of difficulty associated with the teaching and learning of complex scientific concepts such as AC circuits. Concepts associated with electricity in general are very abstract in nature, hence the repeated theory of difficulty when the concept is being taught (Johnstone, 1991; McDermott, 1993). Students' initial conceptual models for understanding new information tend to lead them to think of a direct relation between the nature of knowledge and abstract concepts (Grotzer & Sudbury, 2000). Consequently misconceptions are formed or developed when formal instruction present materials that conflict with their initial belief. The difficulty understanding these concepts is fueled by students lack of exposure to the real life occurrence electrical concepts with which to make conceptual connections (Liegeois & Mullet, 2002; Marks, 2012). In most cases, the teacher will attempt to use analogies such as the water flow model to help students to create a visual representation of electricity. However, researchers have found that the use of the water flow model leads to even more complex misconceptions that are harder to repair (Clement, 2000; Gentner & Gentner, 1983; Grotzer, 2000). While it might be obvious how the difference in current values manifests itself when connected to lamps of varying wattage ratings, learners have no framework for the changing values of current and resistance that render this feat possible (Dupin & Joshua, 1989). Consequently, mathematical reasoning and the ability to think in terms of proportions and relationships plays an integral role in learning electricity (Biswas et al., 1997; Schwartz & Moore, 1998).

Researchers hypothesize one of the main reasons the learning of AC circuits is so difficult is the fact that unlike DC circuits, AC cannot be easily linked to everyday phenomena (Biswas et al., 1998; Carstensen & Bernhard, 2009; Johnstone, 1991; Shipstone, 1988). The relationship among variable is not easily explained due to the dynamic nature of the AC waveform. Consequently, students do not have an existing frame of reference when attempting to relate AC circuits to their previous scientific knowledge. Most researchers have also reported students are unable to correctly distinguishing between voltage and current in DC circuits (Bernhard & Carstensen, 2002; Biswas et al., 1998; Carlton, 1999; Duit & von Rhöneck, 1998; Lee & Law, 2001). This inability, they discuss, is made even more difficult when transferred to AC circuits where the time-varying natures of both quantities are to be included in the understanding of the concept. Ultimately students tend to disregard the fact that there is a positive and negative attribute to these quantities. For example, because the nature of DC circuits does not lend itself to an instantaneous change in polarity, calculation of problems associated with these types of circuits need not account for a change in sign notation beyond what is introduced at the beginning of the problem. Reasoning about AC circuits however, requires this acknowledgement of the continuous shift in sign notation due to the changing nature of the waveform. In some cases the student is able to produce the visual representation of the characteristics of AC by the use of waveforms and vectors, as well as to prove mathematical principles through the use of equations. However it has been reported that despite this knowledge of mathematical principles students still experience difficulties when attempting to conceptually express the connection of these concepts and how they come together to effect the understanding of these type of circuits (Holton et al., 2008; Sangam & Jesiek, 2012).

McDermott and Shaffer (1992) on the other hand, highlight three main areas of difficulty that tends to arise when students learn about electricity. These reasons are described as students' inability to apply formal concepts to electricity, improper use and interpretation of formal representation of circuits and the lack of qualitative reasoning skills about the behaviour of circuits. These researchers suggest the misconceptions students develop about electricity occur in formal instruction they engage with when they are first learning about the topic. Based on their recommendations, a complex concept such as electricity cannot be isolated from qualitative reasoning or formal representation. Consequently, an approach to instruction that does not include all three aspects lacks the ability to elicit deep conceptual understanding. When students are exposed to formal discussions about complex circuit concepts, they tend to associate technical operational definitions to more relatable terms hence concepts are shown to be related to each other by the use of formulas and mathematical terminologies. The heavy reliance on quantitative reasoning of concepts sometimes permits students from being able to develop absolute understanding of circuits (Carlton, 1999).

2.4.2 Difficulty teaching complex concepts

The teaching of AC circuitry has focused mostly on the use of quantitative measures in order to express circuit phenomenon, however more qualitative and verbal reasoning need to be employed to uncover the "gray" areas. These “gray” areas are characterized as students' ability to completely understand not only how the mathematical equations and circuit concepts interact with each other, but knowing the how and why of this interaction (Bernhard & Carstensen, 2002). Students should be afforded the opportunity to explore these complex concepts through the development of scientific reasoning skills so as to overcome conceptual difficulties which are not easily overcome by traditional instructional methods (Shipstone et al., 1988). When the study of AC circuits was compared to previous knowledge of DC circuits, it was found that students had difficulties trying to switch between the mathematical aspects of circuits based on the fact that rote learning and application of formula is common in electric circuits (Bernhard & Carstensen, 2002). These authors also conjectured that the use of mathematical principles to express circuit phenomenon differs from the actual physical representation of the concept. Subsequently, students do not seem to easily recognize the changes in symbols, polarity and equations which are important concepts that make AC circuits significantly different from DC circuits.

Holton et al. (2008) argue students' conceptual difficulties with regard to electricity tend to fall into two broad categories. These categories are difficulties with tying mathematical equation to the physical nature of circuits and understanding how the function of various components differ when connected in AC or DC circuits. While electrical circuits are usually introduced in physics classes, as students become more advanced in electrical engineering courses, the level of complexity increases and therefore requires a more in-depth approach to instruction. When teaching AC concepts, measures should be taken to ensure that students understand the importance of all the intervening factors without being led to believe that any one aspect is more important than the other. Use of symbols, equation and concept theory should be discussed as having equal roles as opposed to more focus being placed on manipulating formulas during problem solving as a way of accounting for the underlying unchanging principles associated with the circuit (Ainsworth, 2008). With this being the case, students should be instructed in such a manner that they are encouraged to think about current as not only the emergence of an action from the source of the circuit but as a cycle of electrons that are always present within the wires used in a circuit (Cohen et al., 1983). According to Schwartz et al. (2000) the use of iterative models of scientific concept teaching is an acceptable approach to help students develop the ability to consider cyclically simultaneous causation where a circuit is considered as a whole system instead of focusing on its parts. It can therefore be argued that the conditions for conceptual learning of complex scientific concepts occur when there is an equal distribution on the importance of highly mathematical, qualitative and graphical components specific to the concept being taught.

Johnstone (1991) also recommends students must be brought to appreciate each facet of a complex concept as an integral part of the concept before they are expected to make conceptual links between them. The use of language is a detrimental factor in this case since science learning is further compounded by the use of unfamiliar technical words and students tend to assume they understand without seeking clarification (Carstensen & Bernhard, 2009). The nature of science learning as discussed by the author (Johnstone, 1991) is such that the learner has to possess the ability to visualize the same concept on all three levels, macro (tangible), micro (invisible) and visual representation, while appreciating and understanding each level on its own merit. For example, when learning about electric current the student has to know the electrons separate from electricity and even more separated from the lines of a waveform. This requires a certain detachment of concept and representation which is superficial because in learning science they can never be truly separated (Licht, 1991).

In teaching complex scientific concepts, much emphasis is normally placed on the ability to employ deductive reasoning and less inductive reasoning. Licht (1991) and McDermott (1993) discuss that students should be aided in developing both quantitative and qualitative models for approaching problem solving which will help them to understand the relationship among concepts. Their lack of ability to properly link new complex concepts to their own mental models causes them to revert to intuition or formulas. Consequently, students will tend to disregard underlying relationships between concepts when an equation is introduced as their quantitative reasoning ability overtakes the concept. One recommendation made for the teaching of scientific concepts, that are heavily influenced by mathematical representation, is to delay the introduction of equations and mathematical models until after students have developed a grounded framework for the concept (Driver, Asoko, Leach, Scott, & Mortimer, 1994).

2.5 Importance of mathematical knowledge

In the book *Where Mathematics Comes From: How the Embodied Mind Brings Mathematics into Being* (Lakoff & Nunez, 2000), the authors discuss abstract human ideas that make use of precisely formulatable cognitive mechanisms such as conceptual metaphors to import models of reasoning from our sensory-motor experience. The human tendency, therefore, is to apply mathematical reasoning to abstract conceptual tasks hence the use of human cognitive mechanism is at the heart of our conceptual understanding. Our tendency is to think all complex concepts can be reduced, if the appropriate formula or approach is applied to the "problem" sometimes even at the expense of understanding the basic underlying structure (Kuo, Hull, Gupta, & Elby, 2013). This dependence on mathematical thought tends to foster conceptual metaphors. These metaphors then become the neural mechanism that create inferential structures such that one conceptual domain can be used to explain or understand another (Lakoff & Nunez, 2000).

Based on their argument, in the case of scientific concepts one can infer we are inclined to attempt to employ a cross-domain mapping process in order to made sense of this new material (Gentner, 1983). Mathematical thought normally dictates the use of symbolic representation to construct an understanding of abstract concepts hence our brains always try to align an abstract concept with symbolization in order to make them more concrete. This is how we not only make sense of complex concepts but of mathematical symbols in general. According to Lesh and Harel (2003) when learning complex material or solving mathematical problems “problem solvers produce conceptual tools that include explicit mathematical models for constructing, describing or explaining mathematically significant systems” (p. 159). The philosophical approach proposed by Lakoff and Nunez (2000) and validated by the previous quote from Lesh and Harel (2003) demonstrate how the mind weaves mathematical thought throughout one's learning of complex concepts. These theories speak less about the focus of instruction but more on what is happening the mind of the students. Application of this perspective suggests alternative instructional strategies instructors can incorporate when teaching complex scientific concepts (Lakoff & Nunez, 2000).

In previous work, the power of mathematical knowledge and thinking populates research on engineering students' learning and more specifically on the incorporation of mathematics in the design of engineering curriculum (Cardella, 2008; Gupta & Elby, 2011). Similarly research done by Schwartz and Moore (1998) and Biswas et al. (1997) suggest that the development of quantitative reasoning skills is highly dependent on the social, symbolic and physical interactions of the student and the concept. Consequently, mathematics knowledge maps on the world based on the pre-existing structure of understanding fostered by the construction of one's own mathematical environment. In addition, our nature of problem solving dictates the use of mathematical manipulation of intervening factors and the decision making aspect of our individualized thinking by which we include or exclude certain factors (Schoenfeld, 1992). This kind of acceptance and rejection of which factors to include is the process by which we arrive at "correct" conceptions. The absolute truth, as stipulated by mathematics, is that the learning and solution of everyday problems can be resolved using one's experience and the introduction of proportional relationships based in a mathematical nature. One suggestion, as it relates to the learning of scientific concepts, usually requires the application of the EQM framework. This is defined as the interpretation of an Empirical situation using a Qualitative schema to which a Mathematical procedure is mapped to arrive at solutions (Schwartz & Moore, 1998). Additionally Cardella (2008) summarizes features of mathematical thinking that could be incorporated in the learning environments aimed at teaching problem solving to engineers shown in Table 1 below.

Table 1- Aspects of mathematical thinking (Cardella 2008, p. 27)

Aspect	Definition/description	Main theoretical source
Knowledge base	Cognitive resources: Mathematical content knowledge	Schoenfeld (1)
Problem solving strategies	Global or local strategies learned from mathematics courses	Pólya (8), Schoenfeld (7)
Use of resources	Social resource: Peers, experts Material resources: textbooks, time, computers	McGinn and Boote (9)
	Use of resources: metacognitive processes such as planning and monitoring	Schoenfeld (7)
Beliefs and affects	Beliefs about mathematics and one's mathematical ability, feelings towards mathematics, Emotions or feelings experienced	Schoenfeld (7)
Mathematical practices	Activities or actions that engineers or mathematicians engage in, or activities that involve mathematics.	Schoenfeld (7); Cardella (10)

According to Dreyfus (2002) there lies difficulty in defining what understanding of mathematical concepts truly constitutes as mental processes needed to be present for learning to be effective. However, reflection on one's mathematical experience is important in arriving at solution to problems of a complex nature. This is one of the outstanding characteristics of mathematical thinking in that the more abstract the concept; the more advance the mathematical thinking that has to be employed. In relation to the understanding of a complex concept, the use of mental models and creation of visual representation stems from our mathematical and psychological aspects that can rarely be separated (English, Lesh, & Fennewald, 2008). However, one must be cautioned against the dependence on the representation of concepts where difficulties might arise. While symbols are important in helping to make the abstract concrete, the use of symbols should be made relatable to similar concepts such that they are of significance to the students.

Not only is mathematical knowledge useful in explaining or relating the material world to the abstract, research suggest mathematical knowledge is best suited for learning complex scientific concepts (Biswas et al., 1997, 1998; Booth, 2008; Schwartz & Moore, 1998). Most introductory engineering courses are designed dependent on students' possession of required mathematical knowledge acquired in pre-requisite courses (Willcox & Bounova, 2004). However on a deeper level students are not only required to have the "particular mathematical knowledge, they have to learn to use it appropriately and effectively in a scientific context. This is an essential component of developing adaptive expertise in engineering" (Redish & Smith, 2008, p. 301). This assumption is built on the idea that our minds are "wired" to think mathematically where complex scientific concepts are concerned. This being the case, the two can never be separated as one will always rely on the other (Lakoff & Nunez, 2000). Since students' mathematical knowledge is considered a scaffold for learning more complex concepts, problems in learning arise when students lack this pre-requisite knowledge or the ability to apply it effectively (Adamczyk, Reffeor, & Jack, 2002; Willcox & Bounova, 2004). In addition the application of mathematical thinking for problem solving should be considered a core principle in learning complex concepts in any discipline (Schoenfeld, 1992). According to Schoenfeld (1992, p. 3) "learning to think mathematically means developing a mathematical point of view, developing competence with the tools of the trade and using those tools in the service of the goal of understanding structure" otherwise termed mathematical sense-making. This sense-making can be credited to the nature of our logical thought that naturally assumes the ability to create, test and prove abstract concepts using mathematical notation. This is a conceptual model professors tend to foster when the focus is primarily on mathematical reasoning which leads to the students developing and applying structure to any concept they cannot immediately conceptualize (Lesh & Harel, 2003). However a degree of difficulty is introduced since not all concepts have a linear model or can be discussed as sequential. This attribute of complex circuit concepts has significant implications for teaching and instruction.

2.6 Educational implications

Complex scientific concepts such as AC circuits, having quantitative and qualitative components that are of equal significance, warrant the use of teaching approaches that provide identical focus on their individual and combined importance (Ainsworth, 2008; Johnstone, 1991; Licht, 1991; Schoenfeld, 1992). The previous discussion on the difficulty in teaching and learning AC circuits speaks to the interaction between qualitative reasoning about concepts, mathematical representation of variable relationships and multiple forms of concept representation through the use of conceptual models (Lesh & Harel, 2003). The conceptual change theoretical framework suggests that in learning environments where new concepts are introduced, there should be multiple approaches through which the student has the ability to actively engage with the material (Dede, Salzman, Loftin, & Sprague, 1999). This school of thought is based on the premise that the teaching of difficult concepts should be approached from an active learning framework as students will more likely recall information with which they had extensive engagement.

Vosniadou, Ioannides, Dimitrakopoulou and Papademetriou (2001) recommend “learning environments should support active learning and guide the students towards the acquisition of self-regulated processes” (p. 382). In such a setting, students would therefore be encouraged to construct their own knowledge and skills in learning these concepts through actively navigating their role in learning about these concepts.

Consequently, various studies have been conducted into methods of teaching and assessment that can be implemented in engineering learning environments aimed at increasing students' conceptual understanding (Chi, 2009; National Research Council, 2000, 2014). The accepted approach to the teaching of any scientific concept is that students should have more responsibility in the process in order for learning gains to be optimized (K. A. Smith et al., 2005).

The most general approach to learning complex scientific concepts utilizes the constructivist view of learning in designing environments. Researchers (Chin, 2007; Dede et al., 1999; Driver et al., 1994; E. L. Smith, Blakeslee, & Anderson, 1993; Vosniadou et al., 2001) are of the belief that complex scientific concept learning is best achieved in environments that support the use of engaging learning activities, authentic tasks and give students some level of autonomy over their own learning. These researchers commonly discuss the benefits of having students take ownership of their own learning and constructing meaning for themselves as they tend to be more motivated to learn the concept regardless of the perceived difficulty. However, the discussion is now more focused on whether students learn better together or alone or a mixture of both (Alfonseca, Carro, Martín, Ortigosa, & Paredes, 2006). Along the continuum of active learning activities aimed at increasing students' conceptual learning gains, Chi (2009) hypothesized that the most fruitful learning experiences and activities are those in which students interact with the material, each other and/or instructor. According to Pea (1993) meaning of concepts is negotiated when members within a community of learners collaboratively "construct common ground beliefs and understandings they share in activity as well as to specify their differences" (p. 268).

2.6.1 Models for curriculum design to foster translation of complex circuit concepts

Coupled with the use of engaging learning activities, learning environments should also incorporate the use of models of representation for abstract concepts. Carey (2000) describes this as studying the mechanisms that trigger conceptual change. The standard logical model of moving from one concept to another with the hope that students, by themselves, are capable of detecting the inter-connectedness of these concepts might not always be successful. Instead, learning environments and curricula should be designed with the opportunity to not only teach these concepts but also the ability to build representational models (Carey, 2000). In the following sections two representational models that can be used to design curriculum or instruction will be discussed.

2.6.1.1 The Lesh Translation Model

The Lesh Translation Model (LTM) is aimed at helping educators and students develop an understanding of the deep underlying concepts within mathematical learning (Lesh & Doerr, 2003). The LTM consists of five major types of representation which should not be considered as existing in silo or directly mapped to any one concept. Instead these five areas, as represented by the proceeding figure, are shown to be individually and collectively related to each other with equal emphasis. The LTM was developed based on the following observations:

1. Meanings associated with a given conceptual system tend to be distributed across a variety of representational media.
2. Representational fluency underlies some of the most important abilities associated with what it means to understand a given conceptual system.

3. Solution processes for model-development activities (or other types of problem solving experiences) often involve shifting back and forth among a variety of relevant representations (Lesh & Doerr, 2003, p. 12).

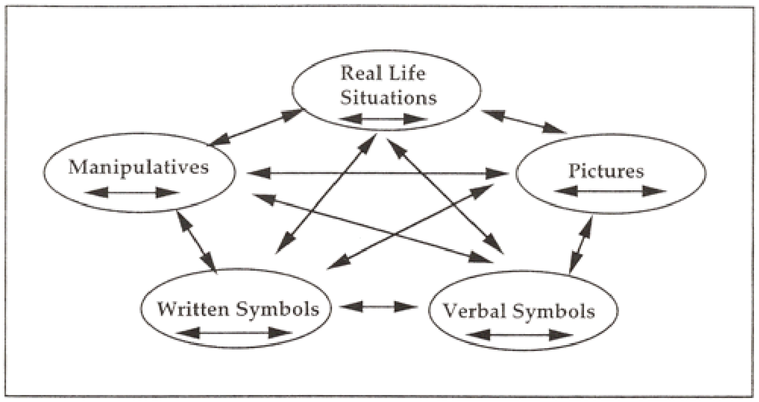

Figure 2 – The Lesh Translation Model (Lesh and Doerr, 2003, p. 449)

Use of this model can influence the development of curriculum and other learning materials such as lesson plans, classroom activities, group projects all intent on helping students develop critical thinking and fluency in concept representation. However while this model is grounded in the mathematics discipline it can be applied to other disciplines such as engineering or science where there is a heavy emphasis on mathematical knowledge and skills.

2.6.1.2 Licht's model

A five step model of practical applicability is proposed by Licht (1991) aimed at helping students learn and understand circuit concepts. This model introduces an approach that is the opposite of what is typically done in engineering classes. Instead of introducing concepts and then using mathematical equations and formulas to prove relationships Licht's model recommends "introduction to the topic with qualitative reasoning about changes in electric circuits and with a dynamic model to represent current, voltage and electric energy" (Licht, 1991, p. 273). This model incorporates the use of qualitative discussions, mathematical representations and real-life explanations of electricity and circuit behaviour. The five steps are summarized below:

1. A phenomenological overview: opportunities for general overview of concepts are provided such that students are able to identify irregularities that exist in circuit phenomena. Information about circuits are introduced using purely qualitative reasoning as well as instructional strategies to gauge students pre-existing conceptions (p. 274).
2. A qualitative macroscopic approach: achievement of students understanding at the overview level can be built on through the use of language and terminologies about operational variables such as voltage and current. While the development of conceptual difficulties may be impossible to avoid such as the substance type reasoning, qualitative discussions are "powerful in predicting the behaviour of circuits" (p. 274).
3. A qualitative microscopic approach: "once pupils have achieved some understanding of the electric circuit behaviour at the qualitative macroscopic level, it should be seen as an important skill in electricity education that they are able to think back and forth between two conceptual domains" (p. 275). It is necessary for students to be able to move between the macro (voltage and current) and micro (electrons and charge) domains as well as being able to

conceptualize the circuits as a complete system while appreciating the fundamental relationship between the components and operational variables.

4. A quantitative macroscopic approach: the mastery of qualitative understanding of circuits leads to the introduction of quantitative reasoning about the relationship that exists between concepts. At this level mathematical formulas and equations are introduced and the rules of their use are emphasized (p. 276)
5. A quantitative microscopic approach: similar to the previous discussion on the importance of being able to move between the macro and micro domains of qualitative discussions, this ability is also necessary at the quantitative level. In addition to being able to use formulas and understand how they are derived, the natural phenomena of electrical storms and the everyday context of electricity is explored (p. 276).

Decisions about the manner in which concepts are taught and the prerequisite knowledge students are expected to have in order to learn science concepts is guided by a theory known as pedagogical content knowledge (PCK). Pedagogical content knowledge can be assessed as a category of knowledge or a theoretical framework (J. A. Baxter & Lederman, 1999; Miller, 2007). As a category of knowledge, PCK is defined as the link between teachers' cognitive understanding of course content and how teachers use their knowledge when designing and executing instructions (Miller, 2007). In general "pedagogical content knowledge is the knowledge of experienced teachers such as knowledge of how to organize a classroom and manage students during instruction" (J. A.

Baxter & Lederman, 1999, p. 148). As a framework, PCK "assumes that as teachers become experts in a specific subject area through the construction of specific knowledge that informs them of superior teaching methods for that subject" (Miller, 2007, p. 86). As instructors develop this expertise they are also able to create meaningful experiences for their students through the decision of daily learning activities and the relevant instructional strategies. The work of Magnusson, Krajcik and Borko (1999), though focused on science education, can be applied to other disciplines such as engineering education. As a framework these authors describe PCK as having five components discussed below:

1. Orientations toward science learning: this involves daily instructional decisions regarding class objectives and content, student engagement and use of curricular materials (p. 97).
2. Knowledge and beliefs about science curriculum: this involves how information about the goals of the class is communicated to the students over the duration of the course as well as the activities and materials used in achieving these goals (p. 104).
3. Knowledge and beliefs about students' understanding of specific science topics: this involves prerequisite knowledge and skills students are required to have, how teachers incorporate individual student ability in the dissemination of class activities and what concepts students find difficult to understand (p. 105).

4. Knowledge and beliefs about assessment in science: this involves decisions made about appropriate means of assessing student learning such as approaches, activities or specific procedures (p.109).
5. Knowledge and beliefs about instructional strategies for teaching science: this involves various approaches used to represent scientific concepts and principles in a manner that best facilitates student learning.

2.7 Chapter Summary and Gap Identification

This chapter demonstrates that most of the work done on circuit concepts, whether in electrical engineering or physics education, is at the introductory level and as such there is a significant lack in work on more advance and complex concepts associated with circuits. Recommendations made about the teaching and learning of circuits suggest students develop and use qualitative reasoning skills about circuits before the introduction of circuit diagrams and equations. At the very least it is suggested instructional strategies should make use of the intersection of all three factors. Since simple DC circuits are taught before complex AC circuits it is theorized students will tend to "cluster" their understanding of DC circuits and then attempt to map this understanding to AC circuits. This is due mainly to their conceptual beliefs as well as the fallacy of instructional strategies that portray these two circuit domains as fundamentally similar. As with science learning, circuits are commonly misunderstood due to the tendency of students to think about actions and operations within a circuit as local and sequential. This sequential reasoning does not incorporate the idea that the operation of a circuit is the end result of the holistic function of all components present within the circuit. The identification of this tendency relates to the need for conceptual change focused instruction. Instead of teaching AC circuits as an extension of DC circuits students should be made to understand that while there are some similarities between these two concepts they have significant differences in their operation. In addition, instruction focused on AC circuits and other complex circuit concepts should make use of tangible and real life application where possible. Providing students with the ability to engage with the concept in a concrete manner is reported to have lasting impact on their ability to recall and transfer their knowledge from one domain to another (Jacobson & Wilensky, 2006; National Research Council, 2014; Pitterson & Streveler, 2015).

The previous sections have also demonstrated there is a lack of proper instruction on the application of mathematical principles to the actual physical representation of an abstract concept. Propositions made for the use of multiple representational models are proposed to help students have better frames of reference when learning about the one concept. In addition, students' mental models to problem solving lead them to assume the knowledge of equation is by itself sufficient to explain and understand circuit phenomena, thus the emphasis is more on the use of formula than the actual underlying structure of the concept. Another drawback of this idea is the complexity of AC circuit equations, hence students tend to lack the ability to correctly select the appropriate equation. The tendency to think in linear causal models due to prior and existing conceptual beliefs and mental framework is transferred to the learning of complex scientific concepts that most times require a cyclical simultaneous model in order to understand how complex systems work as is similar to the operation of AC circuits. Since learning of circuit concepts is theorized to depend heavily on the use of mathematical modeling it is important that students are not only exposed to mathematical formulas but have the ability to engage in critical thinking about these principles. Students' ability to answer questions such as why is one formula more appropriate than the other? What conditions are necessary for a formula to be applicable to a particular problem? What assumptions are being made when translating from one domain to the other? This critical thinking skill can be developed through the derivation and use of formulas as well as having a deep conceptual understanding of how the formula relates to the concept being modeled.

Based on these discussions this study is designed to explore the intersection of students' prior knowledge, design of learning environments specifically learning activities aimed at engaging students and how knowledge about concepts are conveyed to the students in introductory circuit courses. The overarching question that guided the study was "what are the underlying reasons for students' perceived difficulty in understanding complex circuit concepts?" To answer this question three individual studies were conducted each having their own research questions. These questions were:

a. How does students' prior knowledge hinder/enhance learning about complex circuit concepts? How do students use analogies and metaphors to explain circuit concepts?
b. How are engineering learning environments designed to promote students' understanding of electric circuits? What are students' perceptions of the types of activities used in enhancing their understanding of circuit concepts?
c. How are complex circuit concepts taught to students enrolled in a compulsory introductory circuit course? What decisions are made by professors about how to communicate knowledge about complex circuit concepts to students?

CHAPTER 3. ENGINEERING STUDENTS' USE OF ANALOGIES AND METAPHORS WHEN DISCUSSING ELECTRIC CIRCUIT CONCEPTS[1]

3.1 Abstract

Electric circuit concepts are abstract in nature and have proven difficult for students to understand. Instructors most times rely on the use of analogies and metaphors to help students make connections between what is being taught and their prior knowledge or experiences. In this study we seek to answer the following research questions: 1) What types of analogies and metaphors do students use to explain basic circuit concepts? and 2) How does the use of constructive analogies enhance/hinder students' conceptual understanding of circuit concepts? A think aloud protocol consisting of theoretical and real-life examples of circuits was completed by the participants. Transcripts were analyzed in two phases using an inductive/deductive approach. Results indicate participants used some variation of constructive analogies and metaphors in their discussion of the circuit. We also found evidence of students' meta-cognitive thinking about their prior learning. Our findings can inform instructional strategies used in circuit courses where students are exposed to the concept for the first time.

Index Terms – Analogies and metaphors in instruction, conceptual understanding of electric circuits,

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[1] Concise version of this paper in review for IEEE Transactions on Education

3.2 Introduction

Engineering students' inability to verbalize knowledge about key circuit concepts they are capable of proving mathematically is a significant area of research interest (Carstensen & Bernhard, 2009; Duit & von Rhöneck, 1998; Holton et al., 2008; Johnstone, 1991). This perceived difficulty experienced by students can be attributed to the fact that when these concepts are being taught the abstract nature of the concept dictates emphasis on the use of mathematical approaches to make them relatable. In order to help students develop a level of qualitative understanding of circuits and the interaction of circuit parameters, research has suggested the use of analogies and metaphors when discussing these concepts (Bishop, 2006). The argument for the implementation of analogies and metaphors in scientific instruction is made based on the premise that students' formal prior knowledge of the electricity is minimal.

Researchers have posited that the teaching of scientifically complex concepts requires the use of other related concepts to help students make sense of the new information (Bernhard & Carstensen, 2002; Brown & Clement, 1989) In scientific instruction, an analogy is the use of a comparative argument whereby a known concept (also referred to as the base concept) is used to explain an unknown concept (also referred to as the target concept) having similar attributes (Glynn, 2008). A common analogy used when describing the movement of electric current within a circuit is the comparison to how water/fluid flows through a pipe. The similarities how current behaves in a circuit since it is assumed that students already have some practical knowledge of how water moves through a pipe. Metaphors on the other hand are a “the main mechanism through which we comprehend abstract concepts and perform abstract reasoning” (Ortony, 1993, p. 244). In this case an example of a scientific metaphor is asking students to picture or to visualize a situation when introducing a new concept. Students are therefore expected to engage their imagination as well as prior knowledge and experience to prepare them for the new material they are about to be presented with. The application analogies and metaphors in discussing abstract concepts such as electricity helps the student to conceptualize the new information by cognitively mapping what they are already familiar with to the unknown and abstract concept being taught. Additionally, the use of analogies and metaphors when teaching abstract circuit concepts is described as valuable teaching tools (Treagust, Duit, Joslin, & Lindauer, 1992). This claim is made on the benefits analogies and metaphors provide instructors and students by allowing them the ability to create relationships between the concrete and abstract. While analogies help learners categorize and better understand abstract and non-observable concepts such as electricity (Duit et al., 2008; Dupin & Joshua, 1989) metaphors are described as the mechanisms whereby learners are able to reconcile the differences between their intuition and formal conceptions (Sfard, 1998).

This study is aimed at exploring electrical engineering undergraduates’ perception of current, voltage and resistance in electric circuits. This study was conducted with specific focus on how students use analogies and metaphors in their discussion of circuit operation and how their understanding of circuits is enhanced or hindered by the use of such. In order to achieve its goals the research was guided by two questions. These are:

a. What types of analogies and metaphors do students use to explain basic circuit concepts?

b. How does the use of constructive analogies enhance/hinder students' conceptual understanding of circuit concepts?

In this work, students were presented with a think aloud document consisting of theoretical and real-life circuit examples and instructed to verbalize their thoughts as they solved the problems. This approach was aimed at eliciting their conceptual understanding of the nature of electric current in each case. Findings from this study can inform instructional strategies especially in introductory engineering circuit courses where students are most times exposed to basic circuit concepts which then forms the basis for their core understanding.

3.3 Perspectives from literature

3.3.1 Analogies and metaphors in instruction

In scientific learning, analogies speak to explicit measures whereby the learner is encouraged to make connections between or across two specific domains. A metaphor, on the other hand, is an implicit comparison where the basis of this comparison must be created by the concept to which it is applied (Clement, 1993; Duit, 1991). In other words, analogies afford us the opportunity in the teaching of abstract concepts to use what frames of reference or prior knowledge we already have to directly map onto new information through the process of comparison. Metaphors, on the other hand, foster the ability to compare the known and the unknown but employing a more hidden approach. It is on this basis that Sfard (1998) makes that claim that metaphors are inherently our intuitive knowledge developed through experiences or prior conceptions about how the world works that in turn shapes our learning or understanding of formal scientific conceptions. Though analogies and metaphors are two different constructs, their effect on the learning of scientific concepts should not be considered as mutually exclusive. This means metaphors in most cases utilize a comparative approach between two concepts in a manner similar to analogies. It is through this comparative approach that “the generative characteristics of metaphors can stimulate the construction of analogical relationships and facilitate conceptual change” (K. Tobin & Tippins, 1996, p. 716).

One important caution on the use of analogies and metaphors is the role of language and the manner in which comparisons are made. According to Heywood (2002) it is through language, that is the words used to describe scientific phenomena such as electricity, an abstract concept derived from a concrete entity takes on meaning to become an entity as real as the concrete concept. Similarly, language used to discuss specific concepts can lead the learner down a path where the understanding of one concept systematically leads to the understanding of another which exists in a seemingly unrelated conceptual domain (Sfard, 1998). This being the case, there is the possibility of the analogy and metaphor being used leading students down the path of developing misconceptions about the targeted concept. Conceptual change researchers (Forišek & Steinová, 2012; Limon, 2001; Zirbel, 2006) discuss at length the potential for the development of misconceptions when analogies and metaphors are used to describe abstract concepts as they claim that in the process of making a concept relatable the main idea behind the concept tends to be overshadowed by the analogy or metaphor. However, other empirical studies have reported students' learning showed significant increase in cases where analogical thinking and metaphor use was encouraged when thinking about the material. This, they discussed, was mainly due to the fact that learners were able to think of these concepts within contexts with which they could relate (Duit, 1991), (Coll, France, & Taylor, 2005).

Researchers have theorized that the use of analogical thinking activities have significant influence on conceptual growth because it not only helps students to understand concepts but students can also form associations between various concepts using the same system of analogies and metaphors (Duit, 1991; Treagust, Chittleborough, & Mamiala, 2002; Treagust et al., 1992). In addition, the constructivist approach to learning warrants the use of analogical thinking and metaphor as this perspective is more meaningful when learners can construct similarities between the known and unknown (Bishop, 2006; Clement, 2000, 2013; Sfard, 1998). Analogies and metaphors are also beneficial to learning in the sense that abstract ideas can be presented in an imaginative manner that require the learner to engage in thought provoking activities that appeals to not only their cognitive but affective knowledge as well (Dagher, 1995). The general assumptions usually made about learning when analogies and metaphors are used to explain a concept are explained in seven steps (Brown & Clement, 1989, p. 238):

1. The student has little knowledge or understanding of the target situation and would find a comparison to a more familiar situation helpful.
2. The base concept is understood by the student.
3. The student accepts the analogy as sound which could be due to acceptance of the analogy as appropriate or the level of authority ascribed to the teacher.
4. The student makes the correct comparison between the elements of the base concept and the target concept.

5. An expert would view the analogy as sound, meaning the elements of both concepts are similar enough that use of an analogy would benefit students' understanding.
6. The student is motivated to accept the comparison.
7. The outcome of the use of the analogy is aimed at conceptual growth.

The application of analogies and metaphors under these assumptions is then directly aimed at knowledge acquisition where the intent is to use students' prior knowledge and experience to make sense of new incoming information (Brown & Clement, 1989). A more fruitful approach to the use of analogies and metaphors would seek to elicit conceptual change. This approach would not only use analogies and metaphors to leverage students' understanding of the analogy or metaphor when mapped to the target concept but would highlight cases when students supposed understanding of target concepts fosters the development of misconceptions.

3.3.2 Constructive analogies

The recommendation for the application of analogical reasoning in scientific learning also comes with the caution of using analogies that are considered "good" (Glynn, Yeany, & Britton, 1991). As mentioned earlier, the nature of making comparisons between two similar yet different concepts can come at the expense of reinforcing misconceptions. Consequently, instructors are encouraged to ensure that the analogy used is appropriate for the concept being explained. A good analogy is measured by the following three characteristics:

1. The number of features being compared – the power of the analogy to explain the target concept increases significantly when there are numerous features of the analogy in alignment with the concept being explained.

2. The similarities of the features being compared – an analogy must possess the ability to map important features that are similar in the base and target concept.
3. The conceptual significance of the features being compared – an analogy is beneficial to enhancing students understanding only when the analogies are able to explain the concept in terms that the students already understand (Glynn et al., 1991, p. 226).

3.4 Methodology

3.4.1 Study Design and Data Collection

The data, collected from nine (9) undergraduate electrical engineering students at a school in the Western US, was done using the think aloud method. This data was a part of a larger project aimed at uncovering engineering students' misconceptions about common scientific concepts using a Delphi study with expert faculty (Nelson et al., 2005; Streveler et al., 2006). The students who participated in the study were undergraduate engineering juniors and seniors who had taken at least two circuit courses. The think aloud protocol was developed by researchers in collaboration with the course instructors from which the information for this study was drawn.

In the protocol, students were presented with simple electric circuits and tasked with explaining the operation of the circuit based on the voltage applied and the current through the various components. Students were instructed to talk aloud as they solved the examples in order to gauge their understanding of the concepts presented in the document. Interviewers asked students probing or clarifying questions where necessary. The protocol also consisted of real-life examples of electric circuits and students were instructed to explain how the results observed could be explained by circuit parameters such as current, voltage and resistance. For example students were presented by with a picture of a line operator that was electrocuted and asked to explain how current, voltage and resistance played a role in that event.

The appropriate IRB paper work was filed and the data collected after permission was granted and students had signed the required consent and release forms. After the interviews were transcribed, all audio recordings were destroyed. Pseudonyms were assigned to the participants and the data was cleaned to remove any personal identifiers so as to protect the identity of the participants.

3.4.2 Data Analysis

The analysis was done in two phases to address the two research questions respectively. For phase one, the data were analyzed using an inductive/deductive approach. The inductive aspect of the analysis consisted of first reading the data for a sense of the whole allowing patterns to emerge across the nine transcripts. For the deductive aspect a literature search for evidence of the emerging patterns was conducted. Codes were created and then used to code the data under these broad headings. The findings are reported further in the paper under these derived themes.

For phase two of data analysis, a deductive analysis was conducted using the three characteristics of constructive analogies (Glynn et al., 1991). In this phase the transcripts were analyzed using the three characteristics as a guide. Instances of each characteristic was recorded and the findings discussed in terms of the significance of the characteristics.

3.4.2.1 Phase One – Types of analogies and metaphors

Initially two researchers read through the think aloud transcripts repeatedly to get a sense of the whole. At the second reading of the interviews, notes were made and comments to each other in a Google document about initial impression of the students' responses. Broad themes that emerged from transcripts were highlighted. To refine the themes into smaller categories, a search and synthesis of literature was done from which a coding framework was developed.

Development of Coding Framework

Using literature (Clement, 1993; Duit, 1991; Sfard, 1998), an integration of the theory of analogies and metaphors was conducted. One model (Duit, 1991) described analogies as having two levels. The direct mapping of two concrete structures, level one, and the comparison of identities or parts of structures, level two. In this framework (Duit, 1991) the comparison speaks directly to the analogy and the target concept. Another study (Clement, 1993) introduced the idea of an intermediary concept that links the abstract and the target, this the author describes as a "bridge". The use of analogies in both cases follow some logical progression from one point (abstraction) to another (concrete knowledge). This supported the notion that analogies are indicators for explicit learning (Duit, 1991). However, even with the introduction of the intermediate concept (Clement, 1993) there is still the assumption that students' understanding of the target concept will be logically sequenced.

This is a limitation on the previous work done on the use of analogies. This limitation however, can be accounted for by not only looking at students' use of analogies but also examining their use of metaphors. Investigating of the use of metaphors strengthens claims made about the benefits of analogies. Analogies are characterized by the mapping of structural similarities between the base and target concept. Metaphors, however, support a deeper explanation of the target concept as they provide evidence of specific attributes of the base that can be mapped on to the target concept (Gentner, 1983). The two types of metaphors for which there exist previous work speak to the visualization of abstract concepts and the association of thinking and feeling. Metaphors in science teaching are usually of two distinct types: the link between new and existing knowledge that in most cases takes the form of an image associated with the concept and the influence of one's intuition on their cognition (Ortony, 1993; K. Tobin & Tippins, 1996). Revisions to the coding framework were included based on the work of Gentner and Gentner (1983) and Brown and Clement (1989) that resulted in the modification of the metaphor section to be subtitled "representative models". Table 2 shows the types of analogies and metaphors that emerged from the literature. This framework was used for phase one of data analysis in order to answer the first research question. Table 3.2 in the results section provide specific examples of the types of analogies and metaphors/representational models based on the coding framework.

Table 2 – Coding framework used in phase one

Types of analogy	**Definition**
Level One (A1)	The relation between two domains of reality (use of a tangible domain to describe an abstract domain e.g. water in a circuit).
Level Two (A2)	The relation between identities or parts of a structure (no logical hierarchy between analogy and target, the target being the concept that the analogy is being used to describe).
Level Three (A3)	The use of an intermediate concept (bridge) that links initial analogy and target e.g. A is analogous to B and B is analogous to C, hence A is analogous to C, which is the breaking down of one large concept into two smaller ones that make it easier to understand.
Types of metaphor (representational models)	**Definition**
Imaginative (M1)	Introduces a degree of imagination, helps with visualizing abstract ideas e.g. associating the understanding of a concept to the selection of an appropriate formula.
Level of comfort (M2)	Links thinking with feeling (bridges the gap between cognitive and affective domains) e.g. how the level of comfort experienced when learning a concept made it easier to understand.

3.4.2.2 Phase two – Constructive analogies and students' understanding of concepts

To answer the second research question the characteristics of constructive analogies (Glynn et al., 1991) were used to conduct phase two of data analysis. These were:

- *Characteristic 1*: The number of features of the target concepts to which base concept is compared.
- *Characteristic 2*: The similarity of the features being compared.
- *Characteristic 3*: The conceptual significance of the features compared.

The findings are discussed based on how many examples of analogies had only one characteristic, a combination of two characteristics as well all three characteristics evident.

3.5 Results

3.5.1 What types of analogies and metaphors do students use to explain basic circuit concepts?

In the transcripts we found eight of nine participants used some combination of analogies and metaphors spontaneously in their discussion of the circuit or individual component operation due to the presence of an electric current. Of the eight participants, all used level one (A1) analogies; three participants used level two (A2) analogies while none used level three (A3) analogies. For the metaphors/representative models, all eight participants used imaginative models (M1) and five participants used imaginative models (M2). Our findings are summarized in Figure 3.

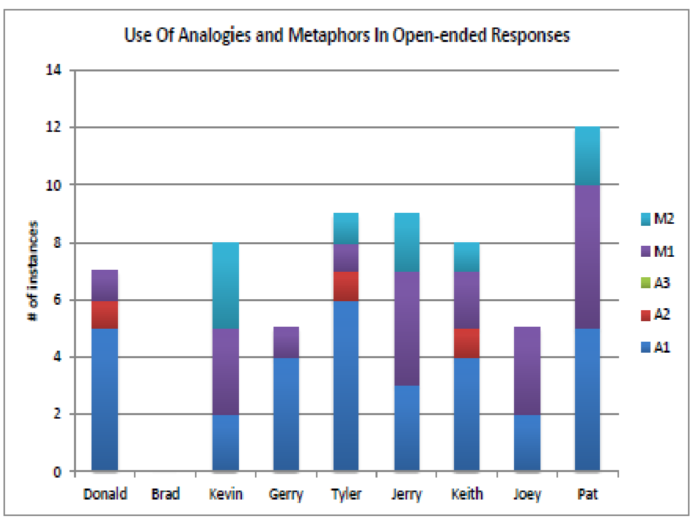

Figure 3 – Use of Analogies and Metaphors/Representative Models by Participants

Across the data set the use of analogies and metaphors associated with representative models were quite evident. Eight of the nine participants used level one (A1) analogies which is the use of a tangible domain to describe an abstract concept, for example, use of water flow to describe current in a circuit. Within the transcripts we found several instances of students using comparative analogies to justify their thought processes on a question for the interview or when probed by the interviewers to clarify something they had previously said. Some students commented on how their previous instructors or professors used these analogies to convey meaning of the abstract concept. We also found examples of level two (A2) analogies being used to show the relationship between parts of a concept. For example, one of the students compared resistors to shrinking the pipe and another participant compared water pressure to voltage.

Participants relied on the use of metaphors/representative models to help them explain difficult concepts often times with the help of formulas and graphical representations. For example, when asked about a three-phase power source one of the participants discussed repeatedly trying to "visualize the concept" and having a related image coming to mind. By definition, this is an instance of imaginative (M1) model. We also found several instances of (M2) model usage where participants attempted to link their thinking with their emotions. For example, one of the participants in talking about his experience learning about circuits described it as being hard because he had no interest in the concept being taught and as a result he did not put much effort into it. In other examples, several participants discussed how an external influence, such as having a good teacher, had a positive impact on their learning. Examples of the coded analogies and metaphors/representative models are shown in Table 3.

Table 3 – Examples of analogies and metaphors

Level one (A1) Analogy: So, I see some analogies where you'll consider each one of these elements to be, to behave like a mechanical element. Something familiar like a spring – or a damper, or something like that. And, yeah, in some of the course work that's just how they explain it. And I think it makes a lot more sense after you think of it like that. Well resistance is easy. That other ones just like, you know kind of putting, like putting the scarf over your mouth to breathe. So basically with, with DC power, or direct current, it's kind of like a fire hose, so as you're pushing a fire hose through, let's say a small tube, or even a larger tube, it doesn't really matter, you're going to have the water that kind of clings to the walls essentially. That's kind of the general idea of resistance.
Level two (A2) Analogy: Like you could think of potential as like if you have a – a battery is basically like a reservoir in that high altitude. And you get like so much pressure or whatever at the bottom of the dam. So, that's your potential. The water's going to run down from that wherever you need it – the city. So, you can –you can think of it like that And like resistors are like shrinking the pipe, and inductors are, let's see – like fluid flow, probably like a storage, no that would be a capacitor would be a storage tank, and I don't remember what the inductor was. But they did have any analogy that like, 'cause most people take just fluids, they take fluids beforehand.
Imaginative (M1) Representative Model: I'm trying to visualize what the three-phase power is. And I keep getting this, I keep getting either a star or Y-system in my head. I can't really visualize what a one-phase system is. I guess it would probably just be a single sinusoid with the, with the wires coming off of it. I'm not positive on that. Yeah, I'm visualizing it basically. I know that a voltage through a wire creates a current basically. I'm always looking for ways to, to visualize something a little bit better. I think being able to visualize what the different components were intending to do, rather than just hoping your equations works out right—
Level of comfort (M2) Representative Model: And I could see it at the beginning. It was the, you know, 12 divided by 2 is 6. And, just kind of real easy equations. And you know, and then, and then it got real complex, and it got a little bit harder. And I don't know, I was just able to pick up on it relatively quickly, and felt that would be my best fit. So, that was I think more or less why I chose my major If you can't have any tangible grasp in your head on it, then I think it definitely can help in that sense. So I guess for me the, I, I, I always try and understand it first, 'cause I, I always want to understand things— Just because I relate really well to the algebra side of it where, okay here's the formula, manipulate it this way and this is what my outcomes going to be.

These findings give evidence to that fact the students were using the analogies and metaphors/representational models the literature discussed as supportive in understanding abstract concepts without being prompted by the interviewers. Interestingly, the type of analogy that was most prevalent in the transcripts was level one analogy. By its definition this type of analogy is the most basic comparison students can make between two constructs and is usually the most common type of analogy used. The use of this level analogy by all but one of the participants indicate students had, whether through their own personal experiences or in instruction, developed a tendency to liken an unknown to a known concept. For example, students' discussion of how the use of analogies was a skill they learned from their instructors support this idea.

The absence of supporting examples of level three analogies may be attributed to the two specific reasons. The first is the fact that this type of analogy assumes students have a logical and sequenced understanding of the target concept based on their ability to make direct associations between two smaller concepts. The second reason deals with the idea that this type of analogy was developed through the use of intended instructional strategies that the students who participated in this study might not have been exposed to (West & Pines, 1985). This explanation supports our purpose in that we were hoping to find that students would naturally use analogies and metaphors when talking about circuit concepts without having to be asked for examples.

Similar to the use of analogies, all but one participant used imaginative metaphors/representational model. This finding can be attributed to the fact that in circuit courses the introduction of a concept is usually followed by the use of a graphical illustration or a mathematical equation. Research suggests multiple ways of representing a concept as necessary since it is impossible for students to see the movement of current or the operation of a capacitor (Ainsworth, 2008; Johnstone, 1991).

3.5.2 How does the use of constructive analogies enhance/hinder students' conceptual understanding of circuit concepts?

In phase two of the analysis, we found 29 examples of analogies that had the three characteristics. We found cases where there were only one of the three characteristics evident, combinations of two of the three characteristics evident as well as cases where all three characteristics were present. There were three examples in which only characteristic 1 was evident and two that were only characteristic 2. There were no examples where only characteristic 3 was present. In terms of the combination of more than one characteristic, there were eight examples of characteristic 1 and 2, one example of characteristic 1 and 3, one example of characteristic 2 and 3. There were 15 examples that had characteristic 1, 2 and 3. These findings are illustrated in Figure 4.

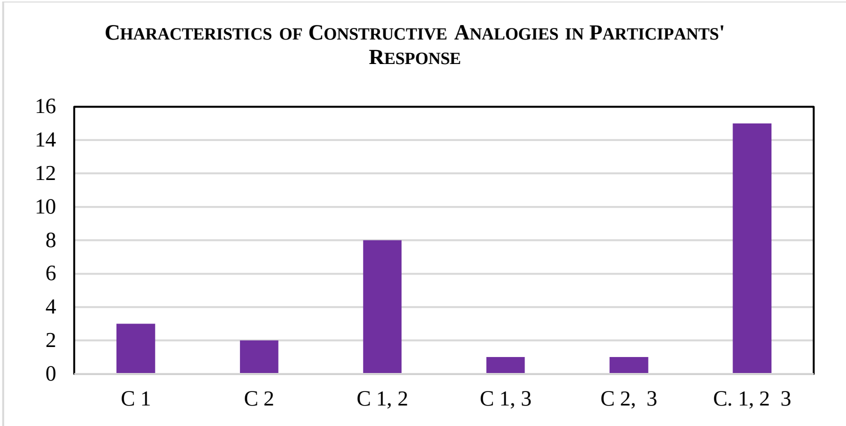

Figure 4 – Number of constructive analogy characteristics used by participants

Researchers have suggested that the use of analogies or terms associated with analogies such as “it is just like this” or “if you think about it like that” are so ingrained in human conversations it is easy to develop the ability to compare two similar concepts. Being able to go beyond the comparison of similar concepts gives evidence to higher order conceptual understanding of the target concept (Glynn et al., 1991). This therefore makes the three characteristics discussed as indications of constructive analogies important to be included in analogies used when teaching scientific concepts. Consequently, since more than half of the analogical examples found had all three characteristics the conclusion can be made that there are constructive analogies in the students’ knowledge base. These examples also demonstrate that while analogical thinking or reasoning can be considered commonplace in scientific contexts, the point at which these participants learned these analogies all three characteristics were included. In addition, the second highest combination of characteristics was the eight examples of characteristics one and two. This finding shows students possess the ability to not only identify similar features in the two concepts being compared but to also discuss how these features map unto each other. In Table 4 below we show examples of three cases of analogy use that had all three characteristics and helped the student's understanding, had all three characteristics and was reinforcing a misconception and one analogy that was incomplete.

Table 4 – Examples of analogies having constructive characteristics

Analogy had all three characteristics and supported understanding: So basically with, with DC power, or direct current, it's kind of like a fire hose, so as you're pushing a fire hose through, let's say a small tube, or even a larger tube, it doesn't really matter, you're going to have the water that kind of clings to the walls essentially. That's kind of the general idea of resistance. *(1- comparison of power as pressure in a fire hose, 2 – size of tube compared to resistance, 3 – explains the concept of resistance well)*
Analogy had all three characteristics that reinforced a misconception: So initially if the switch is closed, we're going to have a voltage flowing through our circuit. You'll have a current flowing around here. It's going and, it's just flowing, flowing, flowing actually–and then when the switch opens, it's still wanting to flow through it. And so that's what causes that initial arc. So it's, it wants to keep going. Like how the switch gets far enough away–that it doesn't flow anymore. And so the arc is actually just the flow of electrons continuing. So suppose that you have your pipe and you broke the pipe, the water's still going to flow through it that's it really. *(A – implied water analogy, B – current movement compared to fluid flow, C – misconception is reinforced by the analogy)*
Incomplete analogies: There's a pipe flow analogy that the teacher use in the beginning. And like resistors are like shrinking the pipe, and inductors are, let's see – like fluid flow, probably like a storage, no that would be a capacitor would be a storage tank, and I don't remember what the inductor was. But they did have any analogy that like, 'cause most people take just fluids, they take fluids beforehand. *(A – explicit discussion of water analogy, B – resistor compared to the shrinking of a pipe, capacitor as storage, C – not evident)*

While the presence of all three characteristics in an example indicates the use of constructive analogies, these characteristics on their own do not prevent against students ability to develop or reinforce existing misconceptions. Analogies used in instruction that are not explicitly discussed and explained can lead students to develop misconceptions about the nature of the concept being taught.

> *I guess I never really used fluid flow analogy, but it helped in describing it to other people. So I guess I kind of already had the idea in my mind before I heard the analogy that went with it, it kind of helps to identify some; might indirectly*

> *help. But, yeah, there are definitely some things, some circuit components that you can't describe with a fluid flow; like a transistor, I mean, it just doesn't have any correlations, so in that sense it could definitely bog you down, but by the same token it can also help you visualize something. And in, when describing to some of my friends as much it, it's been very beneficial to help them to see it.*

Here this student exhibits evidence of meta-cognitive thinking about their understanding of the concepts and their use of analogies. This emerging finding suggests that while it is natural for humans to use comparative language as theorized by Glynn et al. (1991) in some instances students are able to understand on their own that analogies and metaphors do not always completely describe the concept being studied. In the preceding quote it can be seen that this particular student use analogies as a tool to communicate knowledge to others and not necessarily as a method to understand the material. The ability to visualize the concept and to acknowledge this visualization that happened even before the analogy was introduced speaks to this particular participant's aptitude to reflect on how s/he came to understand.

These findings support the claim that analogies are "double-edged swords" (Glynn et al., 1991, p. 224) in that analogies can be both beneficial and detrimental to the learning of scientifically complex concepts. Overall these findings have significant implications for how analogies are used in instruction.

3.6 Conclusion

The results of this study provide evidence for the spontaneous use of analogies and metaphors by students when discussing electric circuit concepts. These results show that even after students have progressed in their courses of study when asked to describe their knowledge of these concepts they default to the use of analogies and metaphors they were exposed to in their introductory courses. We also demonstrated that while analogies are effective teaching tools for abstract concepts their use can have significant impact on students' learning.

The implication for instructors is that whenever an analogy is used to discuss a concept direct measures should be taken to ensure that students understand the purpose of the analogy and why it is being used. Discussion of the base and target concept should be done in a way that communicates to students their similarities while explicitly identifying where the analogy is no longer applicable to the concept being taught. Instructors should also design classroom discussions or assignments to gauge students understanding or thought processes of concepts taught where necessary.

For future work, our emerging finding of the students' use of meta-cognitive thinking can be further investigated in terms of how their thinking about the applicability of analogies helps their own understanding of the circuit concepts. In addition, other studies can be focused on alternative analogies generated by students and how effective these are to students' understanding. A limitation of this study was that there were only nine think aloud interviews used as the data. This study could be conducted using a larger sample size so as to determine if students at another institution use the same or different types of analogies and metaphors. It is believed that a larger sample size would also provide the opportunity to validate the findings of this study on a wider scale.

3.7 Addendum to study not included in paper submitted for review

3.7.1 Additional findings about context

In this study it was found that students struggled in their explanations when the context of the questions were based on real life concepts as opposed to their discussions of clinical textbook problems. For example in one section of the protocol students were instructed to explain natural occurrences of electricity in real life contexts such as why a herd of cattle in a field were killed after a thunderstorm. In response to this question one student explained that the cattle was frightened by the storm and died. Other irrational responses such as had to do with electricity passed through the heart of the cattle and caused defibrillations. This indicated students either were unexposed to or had no proper understanding of the natural phenomena of electricity. This finding demonstrates the need for real life application of concepts that goes beyond mathematical proofs and circuit diagrams. The fifth step in Licht’s (1991) model noted as a quantitative microscopic approach students would be exposed to concepts related to electricity in an everyday setting. Implementing this model would provide students with the ability to understand the underlying principles between circuit variables, components and how the operation of each individually component and variable contributes to the overall purpose of the circuit. In addition, students would be exposed to an understanding of electricity and electrical principles as it happens around them such as in thunderstorms or other ordinary manifestation of electricity.

3.7.2 Discussion of misconceptions developed or reinforced by analogies

When analogies and metaphors are used in instruction, students should be made to understand where the analogy breaks down and is no longer applicable to the concept being discussed. For example when the student talked about water gushing out when a pipe is broken and related this to the arc created by the current when the switch is open is a classic example of a misconception associated with using the water flow analogy. The substantive property attributed to current by water flow leads students to deduce that the circuit, like the pipe, if broken will have current still *flowing* like water would. A proper conception or understanding of current in a circuit would result in students knowing that once the complete path of the circuit becomes broken, whether by a loose connection or opening of a switch, current movement would immediately discontinue. The general rule of current not being present in an open circuit of any kind should be reinforced as often as the water flow analogy is used.

3.7.3 Participant Brad who did not use analogies or metaphors

Based on the definition of the different types of analogies and metaphors used to create the coding framework Brad used no types of analogies or metaphors. From his transcript it was found that he was interviewed using the protocol that had most of the everyday contextual questions. The issue of participants who struggled to explain why someone who was swimming in a pool then went to a vending machine that was ungrounded and got electrocuted was also applicable to Brad. However we found implied comparisons that were not explicit enough to be classified as level one analogies such as *"When you have a--when you have a larger area, there's just,* *they're traveling on more material because the circumference is larger"*. Here it can been seen that there is some comparison being made to how electrons travel given the size of the conductor. However the analogy is not overtly said or discussed.

There were also misconceptions present in Brad's interview assumed to have been reinforced or developed by the substance property that is typically associated with electricity. For example "*So, when that's cut off that flow of electricity is stopped, and there's just sorta' like a - it acts like a volt - or a battery. And it increases voltage until it has a way to disperse it through either an electrical arc to the ground, if it gets high enough. Or, someone touching the vending machine or anything like that*". The obvious misconception here is that even with the removal of a load or the breaking of a circuit, there is a buildup of voltage until there is a way to get rid this excess voltage. The correct reasoning in circuits as it relates to voltage is that the value of the voltage applied to the circuit is constant as it is directly supplied by a source. Consequently, unless the source is manipulated the value of the voltage is unlikely to change regardless of what is happening elsewhere in the circuit. A basic understanding of Ohm's law and the relationship that exist between voltage, current and resistance would expose this idea of voltage build-up as incorrect since the law clearly states that voltage is always constant however the value of the current is likely to change based on the load or resistance value. This finding also provides evidence to the claim that students tend to use voltage and current interchangeably when they lack a proper understanding of the obvious and fundamental difference between these two variables (McDermott & Shaffer, 1992b; Shipstone, 1988) .

CHAPTER 4. A SYSTEMATIC REVIEW OF UNDERGRADUATE ENGINEERING STUDENTS' PERCEPTION OF THE TYPES OF ACTIVITIES USED TO TEACH ELECTRIC CIRCUITS[2]

4.1 Introduction

Traditionally, the design of electrical circuit courses is a lecture format during which concepts are introduced and sample problems solved (Lawanto, 2012; Zirbel, 2006). This lecture approach is often discussed and preferred by engineering professors as the most effective approach to cover vast amounts of content within the time period slotted for the class (Douglas, 2011; Mejias, 2012). An advantage of the use of lecturing is the opportunity to disseminate a great deal of information in a short period of time. However this approach is limited by the fact that it assumes students are "empty receptacles waiting to be filled with knowledge" (Mejias, 2012, p. 1520). In addition, according to Borrego and Bernhard (2011) "lectures are an efficient means of delivering material to large numbers of students, however evidence is mounting that this format does not necessarily promote a high level of learning or retention of knowledge" (p. 19). It has also been argued that "good instruction involves more than just asking students questions or putting them to work on activities; it also means helping to move students toward the

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types of expert thinking that characterize knowledge and practices of a discipline" (National Research Council, 2014, p. 17). Consequently, traditional lecturing has been classified as ineffective in helping students develop critical thinking skills necessary to take up their roles as engineers in more professional settings (Lord, Prince, Stefanou, Stolk, & Chen, 2012; National Research Council, 2014; Turns, Atman, Adams, & Barker, 2005).

In most cases the lecture classes are followed by a laboratory component. For the laboratory sessions students are given a booklet consisting of specific circuit exercises related to the lecture of each given week to be completed prior to the class. During the lab, they are required to construct the given circuit, measure required values and discuss the comparison between calculated and measured values. Consequently, laboratory classes have been described as the point at which theoretical learning about concepts meets practical application. Laboratories have also been classified as "superior to lectures and tutorials in enhancing manual skills, introducing the application of theory to practice and developing inquiry skills" (Salim, Puteh, & Daud, 2011, p. 231). However, the main point of concern that might arise is the fact that lab classes are usually only compulsory for electrical engineering (EE) majors hence non-EE majors are only exposed to circuit concepts during the lecture class. This therefore means within lecture classes professors are tasked with the responsibility of creating opportunities for deep learning of these concepts.

The process of deep learning has been characterized by an interactive exchange whereby students are presented with the opportunity to actively engage with the material they are expected to retain (Laird et al., 2008). To this end, engineering education researchers have suggested for the last twenty years the benefits of implementing active learning approaches to engineering learning environments since various studies have found achievement gains significantly improve when students take a more active role in their own learning (K. A. Smith et al., 2005). This call for more active learning approaches within engineering classrooms, with specific focus on the teaching and learning of abstract concepts such as electricity, has sparked research into innovative ways to engage students without much disruption to the current design. Some of these approaches have been centered on the use of technological devices e.g. clickers students use to respond to questions individually then discuss with their immediate peers (M. K. Smith et al., 2009), interactive learning tools students use within the classroom while solving examples (Anderson et al., 2007; Mejias, 2012; Resta & Laferrière, 2007), instructional videos students are required to watch before or during class aimed at reducing the length of time spent in class on introducing concepts or formulas (Moreno, Reisslein, & Ozogul, 2009; Restivo, Chouzal, Rodrigues, Menezes, & Lopes, 2014; Walter, 2011), among other classroom approaches such as enhanced guided notes which require students to pay direct attention to in-class discussion in order to complete note sheets (Lawanto & Santoso, 2013; Lawanto, 2012). A recent publication by the National Academies of Science (National Research Council, 2014) provides extensive discussion and examples of interactive approaches utilized in large lecture classes and their benefits in not only engaging students but increasing their learning experiences. Though it is recommended learning environments should be designed to actively engage students, professors should also be mindful of how these activities are perceived by the students.

The purpose of this paper is to investigate the types of learning activities used to teach electric circuits and students' reported perceptions of these activities. This systematic literature review is aimed at answering the following questions: "How are engineering learning environments designed to promote students' understanding of electric circuits? What are students' perceptions of the types of activities used in enhancing their understanding of circuit concepts?" Systematic literature reviews, as opposed to the traditional literature reviews, employ a more rigorous and comprehensive approach to reviewing and synthesizing work on a particular topic (Cronin, Ryan, & Coughlan, 2008). According to Mosteller & Colditz (1996), a research synthesis such as a systematic review helps the researcher to create for readers a general overview of previous work done on a topic under study while highlighting new knowledge on a common topic. A systematic approach to synthesizing literature therefore offers three main benefits to the researcher. These are:

1. The opportunity to explore areas among previous studies that can be combined to provide answers to new research questions,
2. The ability to generally summarize many issues of research described by previous studies relating to a common area of study,
3. The opportunity to demonstrate gaps in previous work and highlight areas of little evidence that can be used to support a particular concept (Borrego et al., 2014).

4.2 Method

Cooper (2010) developed a model of a systematic research synthesis which outlines the process of conducting and reporting findings in seven steps: formulating the problem, searching the literature, gathering information from studies, evaluating the quality of studies, analyzing and integrating the outcomes of studies, interpreting the evidence and presenting the results. In addition, Borrego et al. (2014) outlines six steps in developing a systematic review of literature: deciding to do a systematic review, identifying scope and research questions, defining inclusion criteria, finding and cataloging sources, critique and appraisal, and synthesis. For the purpose of this study both frameworks will be referenced as guiding principles to conduct the review. The review will follow the seven steps as described by Cooper (2010) however the Borrego et al. (2014) framework will be used to conduct a deeper exploration of the organization and analysis of the literature selected for inclusion in the review.

4.2.1 Formulating the problem

The research questions "How are engineering learning environments designed to promote students' understanding of electric circuits? What are students' perceptions of the types of activities used in enhancing their understanding of circuit concepts?" were developed to investigate previous work on engineering learning environments, specifically for the topic of electric circuits and the reported findings on increasing students' conceptual understanding of circuit concepts. The active-constructive-interactive-passive, I-C-A-P, framework developed by Chi (2009) discusses the advantage of engaging students in interactive activities over constructive, active and passive activities. The claim of this framework is that students learn more not only when they engage with the learning material but with each other and/or the instructor. These activities are termed interactive activities. Constructive activities are the type that requires students to exert some level of cognitive effort however students engage with the material in silo. Active activities require less cognitive effort while passive activities require little to no participation outside of paying attention in classes. As the overall guiding approach to the selection of literature, this framework was used to classify learning environments in terms of the activities students engaged in and the reported learning gains from each implementation.

4.2.2 Searching the literature

An extensive database search of Compendex and Scopus was conducted using a combination of the following keywords: engineering, circuits, students' perceptions, learning activities, learning environments, scientific concepts. The combinations of these terms and their respective search results are summarized in Table 5. Compendex and Scopus were used because these are the two main databases compiled of engineering and engineering related work.

Table 5 – Summary of keyword and database search and subsequent results

Search terms	**Search results**	**Resulting articles with duplicates removed**
"engineering" AND "learning environments" AND "scientific concepts" (all fields)	Compendex and Scopus – **305** articles *114 duplicates removed*	191
"learning activities" AND "scientific concepts" AND "undergraduate" (all fields)	Compendex – **45** articles *15 duplicates removed*	30
"learning activities" AND "circuits (subject/title/abstract) AND "students' perception" (all fields)	Compendex and Scopus – **32** *16 duplicates removed*	16
"engineering" AND "learning activities" AND "circuits" and "students' perception" (subject/title/abstract)	Compendex – **19** Scopus – 0 *3 duplicates removed*	16

engineering" AND "learning activities" AND "circuits" and "students' perception" (all fields)	Scopus – **11**	11
	412 total	**264 total**

The restrictions applied to the search was that articles had to be in English, they had to be published after 1990 and they had to be full text. Based on the final number of 264 articles a flowchart was created using the PRISMA model (Liberta, Tetzlaff, Altman, & The PRISMA Group, 2009). The figure below demonstrates how the resulting 10 articles used in the study were obtained.

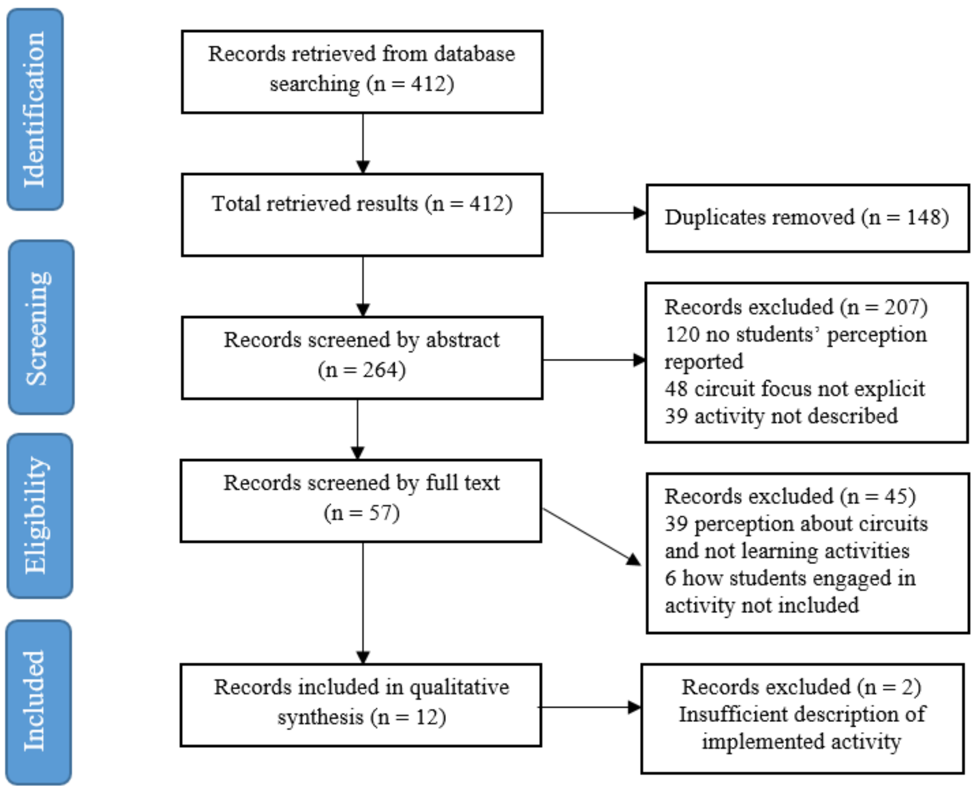

Figure 5 – PRISMA flowchart created using Liberta et al. (2009)

Specific to the research questions and what the study was meant to uncover, an abstract evaluation was done to determine which studies would be included in the review. The inclusion/exclusion criteria were:

i. Published work (conference or journal)
ii. Reported students' perception
iii. Undergraduate circuits course (engineering or science focus)
iv. Description of the activity used

4.2.3 Gathering information from the studies

The main focus of this review was to investigate strategies employed in engineering learning environments and their reported benefits on student learning. To this end the information gathered from these studies came directly from the methods, results and discussion of findings section of the articles selected. Pertinent information on what made the study relevant to the review was determined through an iterative data extraction process. In addition, the classification of the studies in passive, active, constructive and interactive categories of Chi's I-C-A-P framework served as a guiding principle against which information was gathered. A data extraction table was developed to categorize preliminary information from the studies. Based on the work of Cronin et al. (2008), data extraction tables present a summary of information required in a review which are; title of the paper, author, source and year (journal or conference), type of study, setting, data collection method and major findings. Table 15 (appendix A) shows the overall general information drawn from the included studies.

4.2.4 Evaluating the quality of studies

The suitability of each study was determined based on the inclusion/exclusion criteria against which the study was subjected when the initial literature search was conducted (refer to flowchart shown in Figure 5). In addition, the type of intervention utilized in collecting data and how the study was conducted was of importance to determine which study would be included or excluded from the review. For this work, it was important that learning activities be implemented and tested within an engineering or science learning environment and that the activities the students engaged in fell somewhere along the active-constructive-interactive continuum. Upon completion of the data extraction table, the selected articles were read a second time in order to retrieve more specific information. This was captured using a more in-depth table represented by Table 16 (appendix B). The categories used as an organizing principle for Table 4.3 were description of activity, description of data collection, reported students' perception and limitations. These categories were developed using the I-C-A-P framework and conditions derived from the research questions. In creating Table 16, two of the studies were found to be no longer applicable. These studies were excluded because the second round of data extraction uncovered their unsuitability in terms of not having explicitly reported the students' perception and insufficient description of the implemented activity. This phenomena is explicitly explained by Cronin et al. (2008) as a part of the process of being critical in the evaluation of the usefulness of selected articles.

4.2.5 Analyzing and integrating the outcomes of the studies

From the two data extraction tables emerging themes were documented. Supporting evidence for each theme was also retrieved from the studies and a thematic analysis conducted. This approach to data analysis was selected for two primary reasons as discussed by Braun and Clarke (2006): 1. A thematic analysis is most commonly used in qualitative research when patterns within the data are important in answering the research question, and 2. Thematic analysis affords the researcher greater flexibility in pulling out themes from the data that can always be analyzed using other methods such as inductive or interpretative analyses.

4.2.6 Interpreting the evidence

For the studies that were included the category of methods, type of learning activity determined by Chi's I-C-A-P framework, reported learning gains and how the study was executed was used as the organizational tool.

4.2.7 Presenting the results

A discussion of what was found from the literature search and subsequent review is presented based specifically on how previous work done answers the research questions and what future recommendations can be made. The patterns reflected in the data were also discussed to show how the conclusions made from the review are warranted. This paper concludes with a discussion about gap in the literature that the review uncovered and suggestions for future work or directions.

4.3 Findings

At the first stage of data extraction of the 12 selected studies, eight were found to have primarily qualitatively collected data while the other four were quantitative. There were five cases of the activity being implemented in lecture classes, five in laboratory classes and two in a combination of lecture/lab classes. While there were 12 studies that met the inclusion criteria (shown in Table 15), 10 studies (shown in Table 16) were used for the final round of analysis. Of the 10 studies, there were five studies in which interactive activities were implemented, two studies had constructive activities, two had active activities and one had a passive activity.

4.3.1 Structure of studies

There were overall similarities in all the studies based on their structure. In all 10 cases, the researchers described the need to make learning more beneficial to the students by engaging them in activities that went beyond showing up for class and taking notes. The argument was made that by including the students more actively they would experience significant learning gains. It was also expected that students would report a deeper appreciation for the course material and by extension the implemented activity. To this end, nine of the 10 studies used open ended items on surveys or pre- and post-course surveys to measure students' perception of the activity used and how they felt their learning and overall class experience was affected. One study collected data solely from reflective journals the students were expected to maintain. In addition, the four studies that collected primarily quantitative data did so with the use of pre- and post-testing and in two instances concept inventories.

4.3.2 Structure of activities

Table 6 – Summary of findings based on implemented activity

Setting	Number of studies
Lecture classes	5
Lab classes	3
Lecture/lab combination	2

Five of the activities were implemented in lecture settings where the aim was to use an approach that would provide students with the ability to maximize their learning while making the most of the allotted class time. Two of the studies (Dolan, Prodanov, & Taufik, 2011; Rockland, Hirsch, Burr-Alexander, Carpinelli, & Kimmel, 2013) utilized instructional videos the students were required to watch before class while the class time was used for problem solving and conceptual discussions through assignments and reflective documents. In two other studies (Enriquez, 2010; Lawanto, 2012), the students were given the course notes before the start of class while the lecture time was focused primarily on having discussions and solving examples related to the concept being covered. The last of the five studies (Sangam & Jesiek, 2012) utilized an experimental design whereby one of three course sections was taught as an experimental group using a conceptual change framework informed module. While the structure of the class remained the same, the students in the experimental section were instructed using an approach aimed specifically at reducing the possibility of developing misconceptions while presenting the material in a hierarchical conceptual manner.

Three of the activities were implemented in a laboratory class aimed at helping students better understand or visualize the abstract concepts associated with the course. In one of the studies (Walter, 2011) students interacted with simulation software to synchronize schematic diagrams with instructional videos. In the second study (Jansson & Kelley, 2012), students' roles were rotated every week but the primary role that was important to the activity was that of note-taker as a means of actively involving the students individually. In the third study (Simoni, Aburdene, & Fayyaz, 2013), students were given lab exercises to complete in an iterative manner with the objective to develop and increase their conceptual understanding while building on the basic to more complex concepts.

Two of the activities were implemented in a combined lecture/lab setting. In the first study (Sivaramakrishnan & Ganago, 2013) students were introduced to the class material using a range of activities aimed at combining theoretical and practical constructs. Primarily, students used a virtual keyboard to project and modify waves along a frequency spectrum to provide students with the ability to see and hear how changes in frequency can be represented. In the second study (Dori & Belcher, 2009) a holistic approach to lectures, recitations and lab exercises was done through the use of a technology interactive tool to engage students with the material and each other.

4.3.3 Structure of students' response

In the 10 studies students' perceptions were assessed using open-ended survey items, affective evaluation instruments or reflective documents. Nine of the 10 studies discussed students having positive responses on open-ended surveys or reflective documents to the activities that were used. Students also reported the influence of the activities in helping them to better understand the concepts being taught. Most commonly reported was the ability to visualize or having a better conceptual understanding of concepts that would have otherwise been abstract. This was a common theme for the activities that were conducted within the context of laboratory classes. However in one study (Jansson & Kelley, 2012), students actually responded more favourably on the pre-course survey than they did on the post-course survey. Where instructional videos were used, whether in lectures or labs, students reported being able to view the videos as often as they wanted or being able to access just the section they were unsure about as a definite advantage. On the flip side, students reported not being able to ask clarifying questions especially during the lecture time as a disadvantage of this approach.

4.4 Discussion

The benefits of a systematic literature review as previously discussed are: exploring areas among previous studies to provide answers to new research questions, summarizing issues of research described by previous studies that relate to a common area of study and demonstrating gaps in previous work and highlighting areas of little evidence that can be used to support a particular concept. In this section how those benefits were attained in this work will be described.

4.4.1 Using previous studies to answer new research questions

The objective of this study was to synthesize literature on electric circuits learning environments aimed at promoting students' conceptual understanding. More specifically, the focus was the use of activities and how students perceived these activities in enhancing their learning of the content. It was therefore imperative that the studies included in this review met a specific inclusion criteria. This criteria not only ensured that the pool of studies align with the research questions but that clear evidence of the phenomena being investigated was a possibility. The results of this study indicate that within learning environments aimed at teaching electric circuits some steps have been taken to address the issue of increasing student engagement in the learning process. Specifically, the nature of learning activities implemented spanned a wide range of student engagement. For example, one activity required students to watch videos before attending class then engaging in discussions while in class whereas another required students to only complete specific tasks within the class period.

Across the selected studies used in the review the results were aligned well with posits made by I-C-A-P framework. Researchers of active learning have purported that any level of involvement on the part of the student will have positive impact on their learning (Lord et al., 2012; Prince, 2004). However, Chi's I-C-A-P framework explicitly discussed the benefits of interactive, constructive and active learning activities with the recommendation for the implementation of more interactive type activities. This was evident in the selected studies as the cases that reported the most significant learning gains, where statistical analyses were utilized, the type of activity implemented aligned with Chi's definition of interactive activities. In these cases, students were reported to have shown significant increases in their conceptual gains which were attributed to the use of the activity. The summary of the activities categorized by the I-CA-P framework and the corresponding studies and learning environment design is illustrated in Table 7.

Table 7 – Distribution of activities and classroom setting

Activity Type	**Number of Studies**	**Setting**
Interactive	5	4 labs/ 1 lecture
Constructive	2	Lecture/lab
Active	2	Lecture
Passive	1	Lecture

Four of the five activities classified as interactive were implemented in lab classes or a combination of lecture and lab classes. This can be attributed to the fact that interactive activities require students to interact either with each other and/or the instructor. This kind of interaction is most times better facilitated in lab classes as labs tend to be longer than the average lecture class. A larger sample of electrical engineering classes might not yield the same result as lecture classes in general tend to be more instructor-focused. However, the emergence of flipped classrooms and the use of technology-enabled devices such as clickers are now propelling engineering classes toward more active learning activities with very little disruption to their current design. The one lecture class where the activity implemented was classified as interactive incorporated the use of Tablet PCs. In this activity, the students could solve exercises on their own while the instructor monitored their progress from the front of the class and could respond individually to students' concerns. The two activities classified as constructive were implemented in a lecture class and a combination of lecture and lab class. The two active activities were implemented in lecture classes while the one passive activity was also in a lecture class.

The finding of how the activities were perceived by the students related to the second part of the research question. In all but one study, students reported the activity implemented to have increased their knowledge about the concept being taught. Most commonly, students discussed the benefit of the activity as having the opportunity to better visualize concepts of an abstract nature. Visualization of abstract concepts is a very important factor in learning about electric circuits. The nature of electric circuits, especially fundamental parameters such as voltage, current and resistance dictates the use of approaches which allows students to create mental models of the concept. Consequently, the nine studies in which students reported their learning to have increased it was primarily because the activities used required them to go beyond memorization of facts. For example, in one study the students were required to complete lab exercises designed in such a manner that they progressed from simple to more complex problems in the same class. In all the studies, the activities used are considered authentic tasks in that the students were required to solve a problem or explain a concept in an open-ended manner rather than choosing an answer from a set of given responses. This measure caused the students to engage with the material on a deeper level than would have been possible by simply taking notes in class.

4.4.2 Summarizing issues of research described by previous studies relating to a common area of study

The motivation of all 10 included studies was to implement new learning activities within learning environments aimed at teaching scientific concepts. In all cases the researchers reported their study stemmed from the need to help students better understand the complex abstract concept of electricity. This can be considered evidence of the fact that engineering professors are not only conducting research into student learning and using their classrooms as the context but that they have an intent to positively impact their students' experiences. Additionally, this finding indicates the critique of lecturing and calls for more active learning approaches have not gone unnoticed. The literature search was conducted using specific key words and for the purposes of this study there was a strict inclusion/exclusion criteria. Specifically, the intent was to capture the types of activities being implemented and how students perceived these activities. It was therefore important that these two aspects be explicitly discussed in the studies used for the review. However, the number of studies included in the review is small thus it cannot speak for the body of literature that exist about other approaches being implemented in different types of electric engineering classes. This study uncovered the fact that while innovative approaches have been utilized in engineering classrooms to elicit student engagement, there is not much work aimed at capturing students perception or thoughts about these approaches.

4.4.3 Demonstrating gaps in previous work

Analysis of the studies used in this work highlighted the benefits of the activities used to increase students understanding. However common gaps among the studies were found. The common gaps that emerged from the data and will be discussed separately are:

1. How measurement of learning gains corresponds with students reported perceptions
2. Lack of varied learning activities/preferences
3. Use of multiple representations within activities

4.4.3.1 Measurement of learning gains corresponds with students reported perceptions

Six of the 10 studies were done using qualitatively collected data in the form of surveys and attitudinal open-ended items. In most cases where the students self-reported or rated their responses based on the given prompts, there was very little evidence within these studies of actual measurement of their learning. Owing to the fact that students' perception can potentially be subjective, the use of other means of verifying their actual learning is therefore necessary. The four studies that had primarily quantitative data presented, statistically, the increase in students' learning as well as having short attitudinal surveys or open-ended items by which the students' perceptions were recorded. Additionally, the most common method of data collection across the studies was pre-and post-testing or post-surveying. While the use of this data collection method indicates a change in learning or attitude this method, by itself, is not specific enough to identify what exactly was the cause of the change or how the activity stimulated the change.

4.4.3.2 Lack of varied learning activities/preferences

The types of activities implemented were not conducive to varied learning styles or preferences. This was a common theme among all 10 studies. In some cases (can be seen from the limitations column of Table 4.3) students even reported feeling overwhelmed by the requirement of the activity or that working in groups did not attend to their preferred learning approach. It can therefore be argued that the lack in the use of differentiated approaches can work to the detriment of the intervention. It was evident that while the activity was very engaging and aimed at increasing the students' knowledge, the students lost interest due to the magnitude of work or the activity's inability to align with how best they learn.

4.4.3.3 Use of multiple representations within activities

Within the studies selected for this review, there was a lack of discussion on the use of multiple modes of representation to convey knowledge of the concept being taught. The description of the activities was centered on the particular procedures the students had to follow or the stated requirements they had to meet in order to complete the given tasks. However, there was no indication given as to whether or not the concepts were presented using multiple formats such as a combination of qualitative discussions, mathematical solutions and/or graphical representations.

In this paper previous studies on the use of implemented activities in electrical engineering environments aimed at engaging students in the process of learning electric circuits was discussed. The focus was primarily on the students' perception of the activity being used and how their knowledge increased through their engagement with the material contingent upon the requirements of the activity. From the analysis, alignment among the studies that were included in this review and the suppositions of the I-C-A-P framework was found. The most interactive learning activities had the most reported learning gains when compared to constructive, active and passive activities. Most importantly, this study provided evidence for the benefits of conducting a systematic literature review.

4.5 Conclusion

Based on what was found from the 10 studies the following questions, *how are engineering learning environments designed to promote students' understanding of electric circuits? What are students' perceptions of the types of activities used in enhancing their understanding of circuit concepts?* were answered. It was found that though there were varied implemented activities used to engage students in both lecture and lab classes, in all but one case there were reported increase in students' learning. From the data it can be concluded that the suggestions, as made by the I-C-A-P framework, hold true in that the different types of activities implemented in the classes were reported to have significant impact on the students' learning and understanding of circuit concepts. Even though our data set could be considered limited, this study still holds significant implications for engineering professors. Currently, the move for implementing more active learning approaches in engineering learning environments have led to the development of innovative and introductory activities. Professors, should however, be cognizant of the fact that in one particular classroom there might be varied learning styles/preferences. Hence, the implemented activity should appeal to varied learning preferences as much as possible. In addition, the level of demand the activity might have on the students should be considered. The lack of discussion about multiple modes of representation is a significant gap in the previous studies. Abstract concepts, such as electricity, are discussed by conceptual change researchers as best taught in ways that provide the students with multiple ways of considering the content.

The small number of studies found when the initial database search was conducted and the resulting number of studies that were included in this work when the criteria was applied speaks volume to the dearth of work done in this space. In addition, the findings of the small number of studies that actually measured students' perceptions of their learning could be validated by learning gains, indicates a significant gap in the field. For future work, studies could be conducted to measure the impact of an intervention, such as learning activities, but with better assessment of student learning gains that is beyond surface learning. Assessments that would measure knowledge transfer or deep conceptual learning would allow for more in-depth investigation into what professors are doing and what actual difference is being made to students' learning.

CHAPTER 5. COMPLEX CIRCUIT CONCEPTS IN AN INTRODUCTORY ELECTRICAL ENGINEERING COURSE: A DESCRIPTIVE CASE STUDY

5.1 Introduction

Electrical engineering introductory circuit courses are the first context in which students are exposed to simple or direct current (DC) to complex or alternating current (AC) circuit concepts. While students are usually taught basic circuit concepts in physics classes introductory classes tend to go in more depth as these classes form the basis for a specialization in electrical engineering (Sangam, 2012). Research has indicated that despite the addition and application of active learning strategies to the teaching process students still experience difficulties learning these complex circuit concepts (McDermott & Shaffer, 1992a; K. A. Smith, Douglas, & Cox, 2009; Streveler et al., 2008). Previous studies have been focused on the students' epistemological and ontological beliefs about the concept of electricity and how they foster misconceptions (Carstensen & Bernhard, 2007; diSessa & Sherin, 1998; Elby, 2001; Montfort, Brown, & Pollock, 2009; Roth & Roychoudhury, 1994; Sangam & Jesiek, 2012; Streveler et al., 2014). However much of the work that has been done on circuit concepts focus on the difficulty associated with the learning of the concept based primarily on students understanding (Biswas et al., 2001; Holton et al., 2008; Marks, 2012) and to a greater extent on basic or direct current (DC) circuits (Cohen et al., 1983, Duit and von Rhöneck, 1998; Engelhardt & Beichner, 2004 Métioui et al., 1996; Shipstone, 1988).

In addition, an area of concentration has been on the impact learning environment design and the nature of instruction on undergraduate engineering education (National Research Council, 2000, 2012, 2014). Nevertheless there is a lack of studies on the design of learning environments in terms of the decisions made about the teaching of complex circuit concepts and how these decisions are influenced by students' perceived prior knowledge. This is an important area to be researched as it helps to uncover the relationship between the techniques used to express information about these circuit concepts and possible barriers to students' understanding. The general assumptions guiding this study stemmed from the work of Clement (2000) which suggest:

1. There is a target model or desired knowledge state that the instructor wishes students to possess after instruction.
2. Students have pre-existing conceptions that can strongly influence their learning of new material. These pre-conceptions may be in conflict with the target model or they can be useful enough such that they become building blocks for developing the target model.
3. The learning process that takes the students from pre-conceptions to target models might have intermediate levels. In this case students have not attained expert level reasoning but at any given point in time instructional efforts are aimed at moving students from one model to the next.

Work in this space has the ability to explore the alignment of content, the method by which the content is taught, what concepts are emphasized as important for conceptual understanding as well as how great a role students' prior knowledge play in the dissemination of knowledge. This study focuses on the teaching of complex circuit concepts in a compulsory introductory circuit concepts using a descriptive case study approach. The research questions that guided this study were:

a. How are complex circuit concepts taught to students enrolled in a compulsory introductory circuit course?
b. What decisions are made by professors about how to communicate knowledge about complex circuit concepts to students?

In this single descriptive case study with multiple embedded units guided by the pedagogical content knowledge (PCK) framework, the researcher examined three distinct areas: the context of the learning environment through direct classroom observations, decisions about how the content is taught and students engaged through semi-structured interviews with the professors of the course and emphasis on specific concepts through the analysis of course documents. The findings are presented first specific to each unit studied and then collectively across units to answer the research questions. Results from this study indicate the unequal balance between the reliance on mathematical knowledge, graphical and symbolic representations and qualitative discussion about the circuit concepts. These findings align with the previous work of Licht (1991) and Johnstone (1991) based on the importance of having a learning model where students are taught complex concepts using a targeted approach. In this approach the significance of qualitative discussions, graphical illustrations and representation and quantitative reasoning are emphasized. In actuality in both studies (Johnstone, 1991; Licht 1991) the suggestion is that students are first taught the concepts in a purely qualitative manner before graphics or equations and formulas are introduced. The study concludes with recommendations for the design of learning environments that can overcome the barriers to conceptual understanding of complex circuits through the incorporation of an equal use of multiple representations of the concept.

5.2 Literature Review

Engineering students' ability to learn introductory concepts is very important for their success in becoming experts in their respective disciplines or areas of study. More specifically "to develop competence in an area of inquiry students must have a deep foundation of factual knowledge, understand facts and ideas in the context of a conceptual framework and organize knowledge in ways that facilitate retrieval and application" (National Research Council, 2000, p. 16). According to Chi, De Leeuw, Chiu and Lavancher (1994) the process of learning is characterized "in terms of comprehension, skill acquisition, and both" (p. 440). These guiding principles can be applied explicitly to the introductory circuit course studied in this paper that all engineering majors are required to pursue. The practice of learning in introductory classes therefore has implications for the materials presented to students and decisions surrounding the style in which it is presented. In this section of the paper existing literature will be synthesized to explore what counts as foundational knowledge in relation to understanding circuit concepts and how this knowledge is typically communicated in engineering learning environments.

5.2.1 Components of foundational knowledge in electrical engineering

Engineering practice as categorized by Sheppard, Colby, Macatangay and Sullivan (2006) consists of three components:

1. engineering as problem-solving, considering the systematic process that engineers use to define and resolve problems
2. engineering as knowledge, considering the specialized knowledge that enables and fuels the process, and
3. engineering as the integration of process and knowledge (p. 429).

In keeping with these three core areas, the root of electrical engineering expertise can be classified as a working knowledge of basic to complex circuit concepts which is transferred from course to course, advanced mathematical understanding, and the combination of content knowledge and mathematical skills which develops the ability to identify and solve for unknown circuit conditions. These three areas will be discussed separately below.

5.2.2 Working knowledge of basic to complex concepts

At the surface level, the heart of electrical engineering knowledge can be characterized by the ability to identify following conditions:

a. the three basic circuit configurations: series, parallel and series-parallel,
b. the four dominant variables: voltage, current, resistance and power,
c. the four main components of electric circuits: source, control, load and conductors and

d. an understanding of how all of these factors interact to create the desired circuit operation.

Research however has indicated students tend to have difficulty understanding these very basic concepts which then becomes problematic when more complex concepts are introduced (Bernhard & Carstensen, 2002; Biswas et al., 1997, 2001; Holton et al., 2008). The work of McDermott and Shaffer (1992) has been cited as one of the hallmark of research done of investigating difficulty students experience when learning direct current (DC) circuit concepts. In this study, the authors sought to investigate difficulties students experience when learning simple electric circuits that relate to the four conditions discussed previously. The categorized underlying difficulties explored by these authors are summarized in table 8.

Table 8 – Summary of identifies difficulties experiences by students learning simple DC circuit (McDermott & Shaffer, 1992a)

Identified difficulties and definitions	**Sub-categories**
Inability to apply formal concepts to an electric circuit: "*the meaning students associate with a formal concept in physics is often very different from that which a physicist ascribes to that same concept" (p.995).*	Difficulties of a general nature • Failure to distinguish among related concepts • Lack of concrete experience with real circuits • Failure to understand and apply the concept of a complete circuit Difficulties with concepts related to electric current • Belief that direction of current and order of elements matter • Belief that current is "used up" in a circuit • Belief that the battery is a constant current source Difficulties with concepts related to potential difference • Failure to recognize that an ideal battery maintains a constant potential difference between its terminals • Failure to distinguish between branches connected in a parallel across a battery and connected in parallel elsewhere • Failure to distinguish between potential and potential difference

Table 8 continued

Identified difficulties and definitions	Sub-categories
	Difficulties with concepts related to resistance • Tendency to focus on number of elements or branches • Failure to distinguish between the equivalent resistance of a network and the resistance of an individual element • Difficulty in identifying series and parallel connections
Inability to use and interpret formal representations of an electric circuit: *"students often manipulate formulas without relating the algebraic symbols to concepts as well as having difficulties interpreting diagrammatic representation of a circuit" (p. 999).*	• Failure to recognize that a circuit diagram represents only electrical elements and connections, not physical or spatial relationships • Failure to treat meters as circuit elements and to recognize the implications for their construction and external connections
Inability to reason qualitatively about the behaviour of an electric circuit: *"difficulties are not purely conceptual in nature but also reflect an inability to do the qualitative reasoning involved in the development and application of concepts" (p. 1001).*	• Tendency to reason sequentially and locally, rather than holistically • Lack of a conceptual model for predicting and explaining the behaviour of simple DC circuits

Engelhardt (1997) through the use of various literature expanded on the categories and sub-categories summarized in the table above to include:

a. Inability to handle simultaneous change of variable (p. 37).

b. Inadequate use and misuse of analogies (p. 47).

c. Fear of qualitative reasoning – mechanical use of formulas (p. 49).

Similarly, Carstensen and Bernhard (2007) and Streveler et al. (2008) have reported that a basic understating of the relationship among various electrical quantities is an important area of difficulty for students. Students tend to have difficulty envisioning quantities such as voltage, current and resistance acting interchangeably in a circuit yet still performing their own circuit task toward the holistic operation of the circuit (Picciarelli, Di Gennaro, Stella, & Conte, 1991a; Picciarelli et al., 1991b). In each case the recommendation has been made for the use of specific instructional strategies possessing the ability to help students overcome these difficulties. This is based on the premise that students are to not only learn these basic introductory concepts but to be able to apply them to more complex contexts such as other courses and the world of engineering practice. This involves the ability to transfer knowledge however it has been discussed that "one's existing knowledge can also make it difficult to learn new information" (National Research Council, 2000, p. 70). Transfer of knowledge is highly dependent on mastery of initial information which involves deep conceptual understanding rather than the memorization of facts. To achieve this deep conceptual understanding the ability to apply what is being taught, sufficient time to process and explore related connections to other concepts as exposure to various means of representation is a necessity (Bybee & Ebrary Inc, 2002; National Research Council, 2000).

5.2.3 Advanced mathematical understanding

Advanced mathematical understanding and the possession of mathematical skill is very important to learning circuit concepts because of the level of abstraction involved. According to Schoenfeld (1992) "the tools of mathematics are abstraction, symbolic representation and symbolic manipulation" (p. 3). It is on these tools of mathematical knowledge that electrical engineering is highly dependent. This level of dependency is manifested in the pre-requisite knowledge required of students before they can enroll in introductory circuits' courses. The rationale behind this requirement is that as a result of having his mathematical knowledge students will be equipped with the relevant skills to learn circuit concepts. Since Schoenfeld (1992) posit "the language of mathematics is based on rules that must be learned, it is important for motivation that students move beyond rules to be able to express things in the language of mathematics" (p. 4). This is where the use of mathematics in engineering becomes applicable. The work of Cardella (2006) supports this notion by discussing the importance of how mathematics is used in engineering. She hypothesizes that the style employed to apply mathematics knowledge in engineering classrooms can have significant benefits to student learning however there may be obstacles to students' ability to transfer this knowledge. A condition for this transfer is the ability to link mathematical knowledge and engineering practice to real-life situations.

5.2.4 Content knowledge and mathematical skills

The combination of mastery of content knowledge and mathematical skills is very important for problem solving for basic and complex circuit concepts. Students possessing this advanced skill are capable of "seeking solutions not just memorizing procedures, exploring patterns not just memorizing formulas, and formulating conjectures not just doing exercises" (Schoenfeld, 1992, p. 4). There is therefore an expectation of the learning environment and the curriculum to create the opportunities whereby students can develop this degree of mastery. In the book *Learning Science and the Science of Learning* (Bybee & Ebrary Inc, 2002) the place where instruction, curriculum and assessment meet is referred to as the zone of optimal learning. In this approach "students are afforded the opportunity to display components of competence for achieving higher level thinking and deep understanding" (p. 56). This zone of optimal learning encompasses decisions made by instructors to create these opportunities that foster student engagement, the communication of knowledge, transparent methods of assessment and the development of classroom climate whereby students are comfortable seeking clarification of unclear concepts. This unique arrangement is termed effective learning environments (National Research Council, 2000).

5.3 Research Framework

The pedagogical content knowledge (PCK) as framework is used in research to highlight how knowledge and beliefs held by instructors influence their classroom practice. The premise of this framework is that as instructors blend their own knowledge about specific content and their experiences they tend to present content to their students in the form they believe best enables learning (Magnusson et al., 1999). In addition instructors use their PCK to determine what concepts are important for emphasis, teaching strategies that are most effective for teaching specific topics and activities necessary to foster conceptual understanding (Miller, 2007). Though PCK has its roots in science education and is often used as a construct for measuring science teacher's use of their own knowledge to become effective in teaching, PCK can also be used as a guiding principle for data collection and analysis in studies of other disciplines aimed at investigating the nature of scientific content and student learning. For the purposes of this study the five components of PCK as discussed by Magnusson, Krajcik and Borko (1999) were used to guide the collection of data collected in this study. These are:

1. Orientations toward science learning: this involves daily instructional decisions regarding class objectives and content, student engagement and use of curricular materials (p. 97).

2. Knowledge and beliefs about science curriculum: this involves how information about the goals of the class is communicated to the students over the duration of the course as well as the activities and materials used in achieving these goals (p. 104).
3. Knowledge and beliefs about students' understanding of specific science topics: this involves prerequisite knowledge and skills students are required to have, how teachers incorporate individual student ability in the dissemination of class activities and what concepts students find difficult to understand (p. 105).
4. Knowledge and beliefs about assessment in science: this involves decisions made about appropriate means of assessing student learning such as approaches, activities or specific procedures (p.109).
5. Knowledge and beliefs about instructional strategies for teaching science: this involves various approaches used to represent scientific concepts and principles in a manner that best facilitates student learning.

This framework was used because it provides the opportunity to examine decisions made by professors relating to how the content of the course is taught to the students, strategies used for student engagement and how students perceived difficulty in understanding is addressed.

5.4 Research Design

5.4.1 Descriptive Case Study

A descriptive case study is typically used to describe a phenomenon and the context in which it occurs (P. Baxter & Jack, 2008; Yin, 1993). In this type of case study the intent is to highlight overarching connections among different sources of data pertaining to the phenomenon under investigation (R. Tobin, 2010). The main benefit of a descriptive case study lies within its ability to draw data from many sources with each source being of equal importance in providing in-depth information relevant to the topic being studied (Yin, 1993). In addition, findings from a descriptive case study tend to have implications that can be applicable to other cases or fields of study (R. Tobin, 2010).

5.4.2 Context

Linear Circuit Analysis I is an introductory 3-credit circuit course compulsory for all undergraduate engineering majors and is a core course for electrical engineering majors. This course is usually taken by sophomore engineering students. Pre-requisites for this course are ENGR131, PHYS172 and three semesters of calculus one of which can be taken concurrently. There are usually seven (7) sections of the course which consists of five (5) lectures and two (2) distance learning components. The course is offered every Fall, Spring and Summer. During the Fall and Spring semesters the class meets three days a week for 50 minutes. The accompanying ECE207 is the lab component for this course that is compulsory for the electrical engineering majors only. While the other engineering majors may enroll in this course, it is not a requirement. In Linear Circuit Analysis, students interface with theoretical and practical material related to simple to complex circuits and circuit principles. Basic electrical principles such as voltage, current, resistance and power in both DC and AC circuits frame the basis of this course. The main objectives of this course are to expose students to volt-ampere relationships and characteristics, the development of the ability to analyze first and second order linear resistive circuits with DC and AC sources, as well as being able to compute voltage, current, power and impedance values. Since this case study was done on one course the objective of this study is not to generalize across all circuits course but to shed some light on the decision made about the class during Spring 2015.

5.4.3 Case

A single descriptive case with embedded units was used for the design of this study as well as to guide the collection of data. In this study, the case used was the introductory circuit course with three sections chosen as units of analysis. This approach was chosen as "subunits often add significant opportunities for extensive analysis, enhancing the insights into the single case" (Yin, 2009, p. 56). To facilitate this in-depth analysis the same types of data were collected in each unit, each data set were first analyzed separately and then collectively.

5.4.4 Participants

The participants were the professors who instructed the sessions chosen for the study. The professors were recruited based on recommendations from a senior professor who was over undergraduate admissions to the Electrical and Computer Engineering program. A research committee member also suggested possible prospects and set up introductory meeting with these professors and the researcher. Following the meetings, the researcher conducted pilot observations of the professors' classes. The sessions used were selected from the results of two pilot studies. One pilot study was conducted a semester before the actual data collection period while the other was conducted the semester of data collection but earlier in the semester. From the pilot studies, the unique strategies used by the professors were noted and the manner in which they engaged the students. The time of the class periods were also a determining factor. For example since all the classes were scheduled for the same days of the week it was important that there was at least a two hour break between sessions. This was necessary so that the researcher had enough time to reflect on the previous class and write an analytical memo before conducting another observation. Additionally another unique feature about the three sections from which the data were collected is the length of experience of each professor and the size of the classes. The professors' experience ranged from over eight years to one year of teaching the course. In relation to class size, the three sections ranged from large (over 150 students enrolled) to relatively small (60 students enrolled).

5.4.4 Data Collection

The use of multiple sources of data helps the researcher to triangulate findings, provides supporting evidence for the propositions made about the case and strengthens the value of the case study (Yin, 2009). In this study the data sources selected were aimed at providing the researcher data points aimed at collecting different types of information about the course. Multiple data sources facilitates the development of a holistic understanding of the case under study (P. Baxter & Jack, 2008). Using multiple data sources which are analyzed and then combined add strength to the findings of the research as various strands of data are interwoven together to provide a greater understanding of the case (p. 554). In addition, using multiple sources of evidence for a single case has the advantage of developing converging lines of inquiry around a phenomenon (Yin, 2003). These multiple sources of data were collected in each section of the course. For this study, the focus of data collection was primarily on how concepts were introduced and taught in general, how the transition from simple to more complex concepts was made, the role of the student in the environments and how knowledge is communicated. The data used for this study were collected from a variety of sources including direct classroom observations, semi-structured interviews with the professors, and course documents such as syllabus and lecture notes.

Direct Classroom Observations

A pilot study using various observation protocols was conducted in order to determine which protocol was most suitable for the study. Fifteen (15) direct classroom observations, five from each section (unit), were conducted using the Teaching Dimensions Observation Protocol (TDOP) (Hora & Ferrare, 2014). The TDOP was developed with the intent of having a validated observation protocol that can be used to collect information about the various factors that lead to decision making practices such as the teaching of content and specific classroom practices. The protocol consists of six categories namely: teaching methods, pedagogical strategies, cognitive demand, student-teacher interactions, student engagement and instructional technology. Within each category a set of pre-determined codes were used to record data in two minute intervals. In addition to the codes detailed notes were made at each interval and an analytic memo written following each observation. The elements of the Teaching Dimensions Observation Protocol (TDOP) (Hora & Ferrare, 2014) used to conduct and code the direct classroom observations for the three units are summarized in the following table.

Table 9 – TDOP categories and codes used for direct classroom observations

TDOP Observation Protocol Categories and Codes		
Categories	**Codes**	**Definition**
Teaching Methods	L	Lecturing
	LW	Lecturing while writing
	LVIS	Lecturing from pre-made visuals
	WP	Working out problems
	AT	Administrative task
Student-Teacher Dialogue	IRQ	Instructor rhetorical question
	IDQ	Instructor display question
	ICQ	Instructor comprehension question
	SQ	Student question
	SR	Student response to teacher question
Instructional Technology	CB	Chalkboard
	OP	Overhead projector/transparencies
	PP	PowerPoint or other digital slides
	DT	Digital tablet
Pedagogical Strategies	HUM	Humor
	ANEX	Anecdote/example
	ORG	Organization
	EMP	Emphasis
Student Engagement	VHI	Very High (>75%)
	HI	High (between 50 and 75%)
	MED	Medium (between 25 and 50%)
	LO	Low (< 25%)

Context of observations

The observations for this study were conducted in a typical engineering lecture setting meaning the room was arranged in lecture-style seating with the students on various levels and the instructor being on the lowest level at the front of the room. The size of the classes ranged from 60 to 150 enrolled students however attendance to classes is not mandated. Students were encouraged to attend classes but in the event they did not they were strongly advised to take advantage of the extended tutorial hours conducted by teaching assistants assigned to a particular section as well as the exam review sessions conducted by another professor. The structure of the class was a typical lecture approach where there was an introduction of the concepts to be covered, related equations were derived and sample problems worked. Each class section commenced with a review or wrap up of the previous class' content and a description of how the content to follow was related to upcoming exams or homework. In the event of extra time professors would introduce alternative equations or strategies that can be used to solve the given problem. In cases where the professors used more than one approach the most favorable approach was emphasized based on its perceived benefits. In addition students were often encouraged to learn and use that particular method.

Semi-structured Interviews

Interviews as a data collection method for case studies are described as an "essential source of case study evidence because most case studies are about human affairs or behavioral events" (Yin, 2009, p. 108). Using an IRB approved interview protocol (see Appendix C) the three professors of the sections chosen for the study were interviewed. The interviews were intended to gain insight into the decisions made by the professors on how to teach electric circuit concepts, strategies for learning the course material and their personal philosophy of teaching complex concepts. The structure of the interviews and the open-ended nature of the questions ensured that the researcher was able to clarify responses as the professors answered the questions in order to get more in-depth information. Audio recordings of the interviews were taken after which each interview was transcribed verbatim and member checked.

Course Documents

Documents are social products aligned with rules and structure based on collective and organized action (Prior, 2003). The course documents represent an aspect of data that allows for comparison on how students are taught about circuit concepts and their perceived role in the learning environment. The course outline and lectures notes for the period of the class that was observed for each section were collected.

5.4.5 Data analysis

Each piece of data collected in a case study is a part of a big picture or puzzle and as such the most beneficial manner to analyze these pieces of data is to show how they link to other data or initial themes and propositions (Yin, 2009). This study focused on how concepts were taught to the students enrolled in the course. Hence the data collected centered on how concepts were introduced, knowledge communicated and information disseminated. Each unit was analyzed separately (within units) and then collectively (across units) this method of data analysis strengthened the findings of this study in that it provided in-depth information about the phenomenon being studied. Descriptive coding (Miles, Huberman, & Saldana, 2014; Saldana, 2013) was used to conduct the first round of data analysis for each unit (class section) which was then collated in themes. The themes and codes generated from the first round were used to inform the pattern coding used for the second round of data analysis conducted across all three units. The patterns which emerged from the data analysis were then categorized using the five components of the PCK framework used to guide the study.

5.5 Results/Findings

In this section the findings from each unit is presented separately and followed by the findings across all the units. Based on the multiple units embedded framework the results are organized in terms of the emerging themes from the sources of data: direct classroom observations, professor interviews and course documents.

5.5.1 Unit (Section) One Findings

The descriptive analysis used for the three types of data collected for this unit was followed by theming of the data and summarized in table 10 as discussed by Saldana (2013). Following the table additional findings from each data sources will be discussed.

Table 10 – Common themes for sources of data in unit one

Themes	**Observations**	**Interviews**	**Course Documents**
Importance of pre-requisite knowledge	✓	✓	✓
Importance of repetitive practice	✓	✓	✓
Development of problem-solving skills	✓	✓	✓
Instructor-focused teaching strategy	✓	✓	
Conceptual learning over memorization		✓	✓
Use of analogical comparisons	✓	✓	

Direct classroom observations

From figure 6 it can be seen that for unit one a high percentage of the observed sessions were conducted with a heavy reliance on classroom instructional technology and focused on problem-solving. This is evidenced by the 95% of time spent using display tablets (DT), 92% of time spent lecturing from pre-made visuals (LVIS) as well as the 59% and 40% time for overhead projector (OP) and PowerPoint (PP) slides respectively. In addition, 79% of the observed time was attributed to lecturing while writing (LW) and working problems (WP). These two codes, LW and WP, are typically recorded together as a recommendation from the TDOP. The observations uncovered that the classes were highly teacher-focused with very low interaction between students and the instructor. This is confirmed by the low percentage of student-focused dialogue since only 12% of the observed time were student responses (SR) to instructor questions and 3% for student questions (SQ). However, student engagement was very high (VHI) 53% of the observed time. In terms of pedagogy strategies 56% of the observed time was spent emphasizing (EMP) concepts and equation notation.

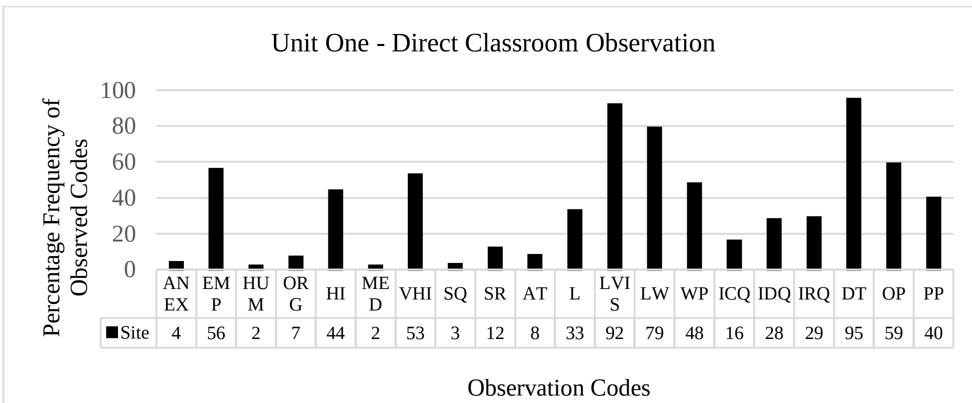

Figure 6 – Percentage of observed codes for unit one direct classroom observations

Professor Interview

The recurring threads that emerged from the coding of the interviews were students' insufficient mathematical knowledge, the importance of repetitive practice, use of analogical and comparative examples, use of strategies for problem solving and dealing with issues related to time constraints such as having to negotiate a balance of how deep to go into content. Most importantly was students' ability to apply mathematical knowledge they have from previous courses and engagement in activities that would provide them with the practice necessary to master the concepts that were discussed as detrimental to students learning the content. Dealing with time constraints was an issue that the professor discussed that was not common for the other sources of data. However this factor has significant impact on decisions such as how deep to go into the concepts being taught or how much time could be spent ensuring students completely understood the information being presented.

Course documents (course outline and lecture notes)

The most prominent themes that were repeated throughout the course outline and lecture notes collected for this unit were the importance of mathematical knowledge, the ability to apply the relevant problem solving skills as well as how repetitive practice is beneficial for deep conceptual learning. A course objective was specific to learning how to analyze different circuit configurations under varied circuit conditions. This was also present in the lecture notes and other documents students were given, such as quizzes, that were used an instructional tools at the end of every topic.

5.5.2 Unit (Section) Two Findings

In table 11, the common themes that emerged after the first round of descriptive analysis were summarized.

Table 11 – Common themes for sources of data in unit two

Themes	Observations	Interviews	Course Documents
Importance of pre-requisite knowledge	✓	✓	✓
Importance of repetitive practice	✓	✓	✓
Development of problem-solving skills	✓	✓	✓
Instructor-focused teaching strategy	✓	✓	
Importance of knowledge transfer	✓	✓	✓
Use of analogical comparisons	✓	✓	

Direct classroom observations

In figure 7 evidence of the vast use of classroom instructional technology is presented by the 99% of observed time in which the professor lectured from pre-made visuals (LVIS). This was also reflected in the combination codes of use of display tablet (DT) 98% of the observed intervals and 73% use of overhead projectors (OP). There was a significant proportion of the observed intervals spent lecturing while writing (LW) shown as 84% and working problems (WP) shown as 57%. This supports the theme that the sessions observed were primarily instructor-focused. In 60% of the observed time the professor would emphasize (EMP) the importance of concepts or equations being covered to either exams or to learn new and upcoming information. Student engagement in this section ranged from very high (VHI) at 42%, high (HI) at 24% and medium (MED) at 31%. This is also evident in the low percentage of student response (SR), 6%, observed.

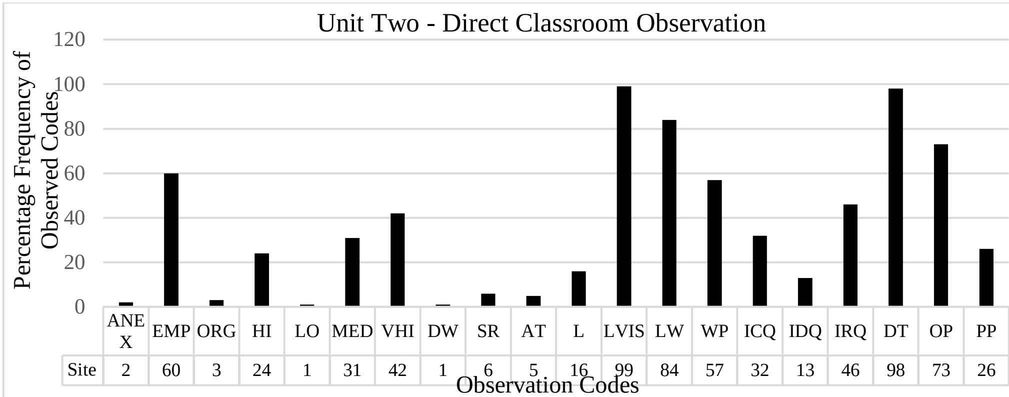

Figure 7 – Percentage of observed codes for unit two direct classroom observations

Professor Interview

Emerging themes from the observations were replicated in the interview such as: challenges faced in delivering the content stemming from students' lack of adequate pre-requisite knowledge, the importance of having students appreciate the deliberated and repetitive practice of working problems inside and outside of the context of the classroom, the need to provide students with the opportunity to develop the necessary problem solving skills and the importance of transferring their knowledge to more complex contexts such as more advanced courses. Similar to unit one, the use of analogical reasoning and real-life examples as well as dealing with imposed time constraints also emerged from the interview and will be discussed in the across units findings.

Course documents (course outline and lecture notes)

The documents collected and analyzed for this section were similar to unit one, this is not surprising as the professor for unit two is mentored by the professor of unit one. There was a strong emphasis on having the relevant pre-requisite knowledge in mathematics and physics concepts before attempting to enroll in the course as well as the importance of repetitive practice for achieving a good grade. The integration of course outcomes and how exams are designed was reinforced in the course documents as well as in the interview with the professor.

5.5.3 Unit (Section) Three Findings

As in the previously described units emerging themes were matched across all the sources of data and are summarized in Table 12.

Table 12 – Common themes for sources of data in unit three

Themes	**Observations**	**Interviews**	**Course Documents**
Importance of pre-requisite knowledge	✓	✓	✓
Importance of repetitive practice	✓	✓	✓
Development of problem-solving skills	✓	✓	✓
Engaging students in the process of learning	✓	✓	✓
Importance of knowledge transfer	✓	✓	✓
Conceptual learning over memorization	✓	✓	✓
Use of analogical comparisons	✓	✓	

Direct Classroom Observations

In this particular unit the primary method of presenting information to the students was the professor writing on the chalkboard while lecturing. This can be seen from figure 5.3, the chalkboard (CB) was used 99% of the observed time as well as the 99% frequency of lecturing while writing (LW) code. Contrary to the other two units, student engagement was significantly higher with very high (VHI) engagement being observed 97% of the time intervals. In addition there were more observed instances of student questions (SQ) at 38% and student response (SR) at 7%. Another interesting observation was the high level of posed instructor comprehension questions (ICQ) which was observed 63% of the time intervals. This indicates there were more student-instructor dialogue than in the other two units observed. There was also more time spent emphasizing (EMP) concepts at 66% of observed intervals which can be attributed to the increase in the dialogue with the students.

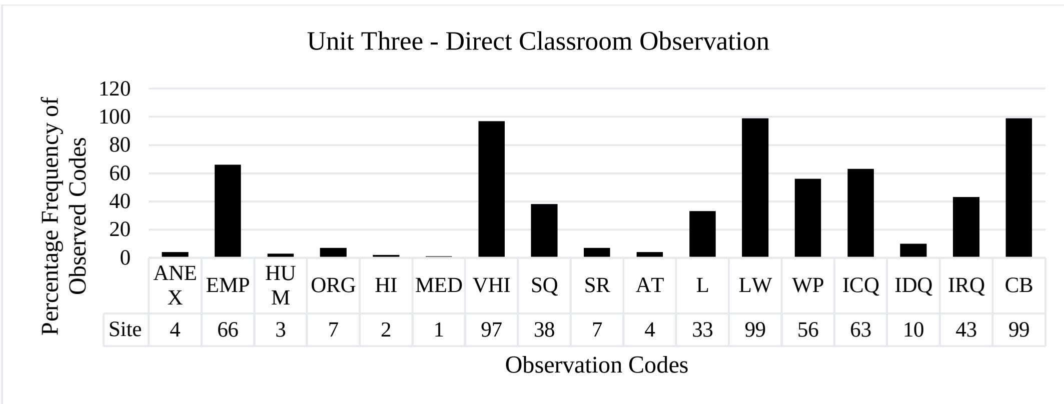

Figure 8 – Percentage of observed codes for unit three direct classroom observations

Professor Interview

The most common theme that emerged from this interview was how the class was designed and information conveyed in a manner intent on teaching students problem solving strategies that would be applicable to more complex courses. This finding was triangulated by the observed time spent on working problems, deriving equations and discussing how these equations can be applied. Other common themes were related to problems with transferring knowledge, use of analogical comparisons and real-life applications to engage students even though with difficulty, the need for repeated practice so as to go beyond memorization as well as problematic pre-requisite knowledge.

Course documents (course outline and lecture notes)

Interestingly the lecture notes for this section consisted of discussions about the concept being covered in the similar manner to the in-class teaching. Rather than mathematical symbols and notations students were presented with material aimed at helping them understand the nature of concepts followed by mathematical principles they could use to prove interaction among variables. Though the need for relevant mathematical pre-requisite knowledge and skills were important factors the idea of discussing why these skills were necessary was made explicit in the course outline and lecture notes.

5.5.4 Across unit findings

The second round of data analysis was conducted based on the findings of the individual unit descriptive coding. The pattern coding approach was used to categorize themes. There were five patterns that emerged across the data set. These were: perceived characteristics of students, perceived characteristics of content, structured problem solving process, student engagement and the impact of time constraints. Table 13 and 14 illustrate how the emerging patterns correspond with themes in each unit and across the data set.

Table 13 – Patterns derived from emerged themes across all three units

Patterns across all three units	Unit One	Unit Two	Unit Three
Perceived characteristics of students			
• Problems with knowledge transfer		x	x
• Lack of sufficient prior knowledge/mathematical skills	x	x	x
• Categorization of students	x		x
Characteristics of content			
• Abstract nature of concepts problematic	x	x	x
• Becomes applicable in more complex courses	x	x	x
• Heavy emphasis on mathematical representation	x	x	
Structured problem solving process			
• Deep understanding over memorization	x	x	x
• Encouraged exploration	x		x
• Importance of repeated practice	x	x	x
Student engagement			
• Difficulty engaging non-EE majors	x	x	x
• Use of analogical comparison to real world concepts	x	x	x
• Lack of learner-centered environment	x	x	
Impact of time constraint on:			
• Problem solving/worked examples	x	x	x
• Addressing deeper content	x	x	x
• Exploring more advanced content	x		x
• Reinforcing content covered	x	x	x
• Negotiating balance between breadth and depth	x	x	x

The cross unit analysis identified on a broad scale some of the decisions made by professors surrounding how to teach the content while dealing with imposed constraints associated with the curriculum, students' prior knowledge and what the course objectives are. These findings indicate there is an overlap between what is an expectation of having pursued this course, the nature of the content being taught and other impeding factors such as what knowledge and experiences the students bring with them to the learning process. In the following table how the emerging patterns were matched across the data set is demonstrated.

Table 14 – How emerging patters were matched across the data set

Patterns across all three units	Direct Classroom Observations	Professor Interviews	Course Documents
Perceived characteristics of students			
• Problems with knowledge transfer	x	x	
• Lack of sufficient prior knowledge/mathematical skills	x	x	x
• Categorization of students	x	x	
Characteristics of content			
• Abstract nature of concepts problematic	x	x	x
• Becomes applicable in more complex courses	x	x	x
• Heavy emphasis on mathematical representation	x	x	x
Structured problem solving process			
• Deep understanding over memorization	x	x	x
• Encouraged exploration	x	x	
• Importance of repeated practice	x	x	x
Student engagement			
• Difficulty engaging non-EE majors	x	x	
• Use of analogical comparison to real world concepts	x	x	
• Lack of learner-centered environment	x	x	x
Impact of time constraint on:			
• Problem solving/worked examples	x	x	
• Addressing deeper content	x	x	x
• Exploring more advanced content	x	x	
• Reinforcing content covered	x	x	x
• Negotiating balance between breadth and depth	x	x	x

Perceived characteristics of the students

The data collected from the three units reinforced the idea that there is a core body of knowledge students must have before they can attempt the material of this course. In all three course outlines there were recommendations for the pre-requisite courses students were expected to have successfully passed before enrolling in the introductory course. However from the observations and interviews, with all the professors, there seemed to be an apparent mismatch between what the students should know based on their prior classes and how they interact with the material in the course. It was discussed in the interviews and repeatedly stated in the observations that there was a certain level of mathematical skill required to be successful in understanding the material related to circuits. However all three professors discussed a primary reason for difficulty encountered by students in the course was their lack of sufficient prior mathematical knowledge. Two of the professors discussed that challenges different students face were dependent on their categorized abilities such as high performing or low performing.

The various categories of students based on their abilities were discussed as influential in the types of examples they would present in class or the kind of questions they would ask, even as far as how they design quiz and exam items. Deep learning, in this class, is marked by the ability to transfer knowledge from one context to another. Two of the professors discussed it was not a case that the students lacked the capability to understand the concepts covered in class; it was more a case of them not being able to take that knowledge and apply it to problems of a different nature. The importance of knowledge transfer was explicit in two of the three course documents and was reinforced in the classes. Time was spent at the beginning of a class in two sections to emphasize concepts that were important for exams or for achieving good grades on upcoming tests. One professor even discussed designing homework and exam problems that required students to think beyond what was explained in the classroom.

Characteristics of content

In addition to the perceived characteristics of the students, the nature of the content was found to be a determining factors in how the course concepts were taught to students. In all three units the abstract nature of the concept was discussed and presented as an area that tends to be problematic. This was evident in the interviews as professors would individually speak to the fact that the concept is abstract and hence reinforce the need for strong mathematical skills. In unit one and two however, this heavy emphasis on mathematical representation was more explicit. For example when a student would ask a clarifying question or in the situations where professors would pose a question to the students, the explanation or justification of the given response would be prefaced by importance of having certain mathematical skills followed by the derivation of equations and other mathematical notation. On the flip side in unit three, student questions would be answered by the use of multiple representations such as a graphic illustration or a qualitative discussion in which the professor would make connections between various sections of the circuit or problem being solved.

Through all the sources of data collected it was observed that in unit three while knowledge of mathematical knowledge and skills were important for understanding the content of the class, they were not the only means by which course content could be conveyed. In all three units the fact that the content covered in this particular course was important for future courses was stressed repeatedly. All three professors discussed in the interviews and throughout the class observations that while the concepts seemed disjointed now they would become applicable as students moved on to more advance classes. It was also discussed in the interviews that the content of this course was meant to give students a broad overview of all the possible areas of study. Hence the manner in which the course is taught is more applicable to electrical engineering majors since their choice is to continue a career in this particular discipline.

Structured problem solving process

The course objectives as presented in the course catalog and outline is to: “1. analyze linear resistive circuits, 2. analyze 1^{st} order linear circuits with source and/or passive elements and 3. analyze 2^{nd} order linear circuits with sources and/or passive elements” (course outline p. 4). In order to help students achieve these outcomes, professors have discussed the use of class examples aimed at helping the students realize the importance of “applying a problem-solving approach much like they would follow a recipe in a cooking class” (professor of unit one) or “being able to apply what tools they have on their belts” (professor of unit two) or “problem-solving skill development” (professor of unit three). This indicates there is an emphasis on students being able to master the process of solving circuit problems that could be of a clinical or real-life nature. The importance of developing these skills were expressed in all aspects of the units included in this study.

In addition to being able to apply this problem solving process, the importance of repetitive practice and developing a deep understanding of the methods of solution were skills students were encouraged to acquire. All three professors discuss that in their own learning of these concepts they developed an attitude of repetitive practice which they found to be helpful to learning the difficult material. Providing opportunities for repetitive practice and bringing students to the understanding of its importance was most explicit in the course documents, in all three outlines the importance of completing homework as a method of repetitive practice was expressed. For example: unit one and two had the following statements “*The homework is very important part of the course. You may read your lecture notes and the text and think that you understand the material.*

However when you attempt to work the homework problems, you will frequently find that you actually did not…you are strongly advised to solve independently as much of the homework as you possibly can. This will serve you well come exam time…to avoid having to memorize formulas, we will provide you some formulas for your use during the exam". In unit three the wording was different but the concept remained the same: *"work the homework: The problem-solving techniques taught in this class are as important as the theoretical material. Memorizing formulas and the understanding the concepts will not be enough to pass the class. You will only learn how to solve the problems if you work the homework"*.

The importance of practiced problem solving was reinforced during the teaching of the content in the classes. In unit three the professor would draw boxes or use asterisks to emphasize equations or solution processes that were important for the students to learn. Additionally it was observed that at the beginning of the classes the professors would emphasize which concepts were the most important to become familiar with as well as a measure of how these concepts related to upcoming tests, exams or future concepts to be taught or explored by students.

Student engagement

The issue of engaging students was discussed by all the professors as hard to achieve especially with the non-electrical engineering majors for two main reasons. First reason was the inability of students to apply the material of this course to their other coursework. Professors explained that while mechanical engineering students (a reference made by all three professors) have some kind of tangible entity with which to associate what they learn in mechanical introductory courses when they come to this circuit course they tend to sometimes feel inept because there is nothing to relate the concepts to. The second reason relates to the fact that the course is compulsory hence students take the course out of obligation and less of actually being motivated to do so. This, they discussed, works to the detriment of their efforts to engage students. The professor of unit three discussed extra credit activities he added to the course as a means of getting students involved in the class, however none of the students expressed an interest. In addition, the fact that this dissertation was conducted in the off semester for EE majors it could be possible that the lack of engagement observed was a result of the other engineering majors that were enrolled.

The use of analogical comparisons to real world concepts such as talking on cell phones, playing sports or music, following a cooking recipe were examples used in the units to make the concepts relatable. All the professors discussed the importance of using analogies but also the limitations associated with their use. Analogies are therefore described as appropriate methods for first introducing the concept but over time the professors hope that students understand the concepts on their own and analogies become no longer useful. The fact that there is a point in which the analogy will break down or is incapable of being exactly aligned with the concept being taught was discussed as a limitation and reason for opting not to use analogies.

The use of instructional technology created an instructor-focused atmosphere that was most prominent in units one and two. In these two classes the professors lectured from pre-made slides and would use a digital tablet to solve problems or to expand on equation derivations. This was observed as a limitation in how the professors could interact with the class as they were basically tethered to the lectern in the room. In addition, students were given handouts with the slides for the class at the beginning of the session. This significantly reduced their participation in the class. Student engagement determined by the observation protocol reflected this fact. In unit three however, the professor wrote on the chalkboard except when having conversations with the students. It was observed that the students in unit three were more attentive to the professor, asked more questions and responded to his questions. This could be attributed to the fact that they were having to pay attention to the lecture and make their own notes. The professor discussed this as a strategy he enforces in his class to not only engage the students to pay attention but to encourage them to think about the concepts being discussed during class and even after when he releases his own lecture notes.

Impact of time constraint

The emerging themes informing this pattern were primary found across the data collected from the professor interviews. The professors discussed, when asked about challenges faced when teaching concepts of this course, restrictions associated with time as one of the main challenges. Decisions such as how much content should be covered in one session, the depth of explanations, discussion on alternative problem solving strategies, exploring more advanced content, reinforcing what was covered in class and “striking a balance between concept and worked problems” were some of the most common discussed. The influence of time constraints is an important finding in that even though professors wished to spend more time reinforcing particular concepts or using more real-life applications the design of the course did not afford them this opportunity.

The nature of the course and, by extension, the lecture classes are constructed to expose students to a wide variety of topics. Consequently, there is not a lot of time written in the course to go deeper into concepts or to spend time ensuring students are exposed to multiple problem solving strategies.

The professors of unit one and three also talked about how they go about working problems in the class is very different than those problems the students encounter on the exams. This is as a result of the fact that within the 50 minute session it is expected that the relevant concepts for that session will be covered and sample problems will be worked. In addition, one of the professor discussed even though it was obvious to him that the students could benefit from having additional discussions and explanation about the concept *"it would not be fair to spend more time of these concepts as there is a risk of the class falling behind based on the collective class schedules".* A coping mechanism discussed, by two of the professors, is to suggest to interested students other projects they can attempt on their own in order to get that deeper experience with the concepts. However the professors acknowledge that this approach only works for the higher performing students.

5.6 Discussion of Findings

The findings from this study indicate that there are various intervening factors such as professors' perception of students' prior knowledge, concepts relevant for emphasis and the overall goal of the course that helped to determine how this introductory course was designed and concepts taught to the students. Through the multiple sources of data collected from each unit it was found that the main emphasis of this course is providing students with the necessary information to develop a structured problem solving process that can be applied to various circuit configurations. It was also found that repeated practice was strongly encouraged as a means of ensuring the students not only understand the content of the class but most importantly for achieving good grades on exams. A third major finding was the heavy reliance on mathematical knowledge and skills that was deemed necessary if the students were going to be successful in the course. All the professors discussed that the students seemingly lack this prior knowledge or their understanding of these very core concepts is insufficient. This perceived inadequate prior knowledge becomes problematic when professors attempt to use mathematical representation to convey information about the abstract concepts covered in the class. The discussion of findings and subsequent implication for this study will be organized using the five components of the PCK framework (Magnusson et al., 1999) namely: orientations toward science learning, knowledge and beliefs about science curriculum, knowledge and beliefs about students' understanding of specific science topics, knowledge and beliefs about assessment in science and knowledge and beliefs about instructional strategies for teaching science.

5.6.1 Orientations toward science learning

In this study it was found that decisions about content covered in the classes were made based on the number of sessions in the course for the semester. Other administrative decisions such as scheduled exams or mid-terms played into the topics that were on exams as well. The fact that all the sections had to follow this rigid schedule offered very little leeway for exploring other concepts or providing opportunity for professors to deviate from the structure even if they wanted to. Consequently, the inflexible nature of the schedule was a determining factor in terms of how much time could be spent in class discussing concepts or working problems or using activities aimed at engaging the students. Two of the professors discussed how they would use end of topic quizzes not for grading but as instructional tools to encourage the students to think about the concepts and try to solve the examples on their own. This method was discussed as useful in getting the students to take some part in the learning process besides making notes. However, in the observations whenever these quizzes were used, professors did not check in with the students to assess if they were in fact solving the examples or how well the students understood the concepts being covered. Additionally, in all the direct observations professors would ask comprehension questions and move on unless a student had specific question. This indicates a lack in the use of formative assessment even when the professors introduced activities or instructional strategies in their classes. This finding demonstrates the importance of the use of formative as well as summative assessment or feedback within the learning environment as a means of not only gauging student engagement but their understanding as well.

5.6.2 Knowledge and beliefs about science curriculum

In the course outline, the outcomes of the course as well as how they align with the accreditation criteria for life-long learning are explicit. In this study, classroom observations were not conducted until after the middle of the course hence it is not possible to determine if time was spent at the beginning of the class discussing the course outline with the students. However when the professors would move to a new topic, at the beginning of that particular class, students were informed of the new concepts to be covered and how the topic related to previous concepts or upcoming exams. In unit three specifically, the concepts to be covered or the goals for the class were actually written on the board. At the completion of concept or the achievement of a goal the professor would actually cross that item off the list. In units one and two, the professors would begin the class with what was labeled as a “motivating example”. When asked during the interview what this meant, it was discussed as a way of showing the students how the concept could be applied and a technique to encouraging the students to pay attention to the concepts that would follow. These findings indicate professors had some outlined goals for each class period such as the content to be covered and related sample problems. In terms of the class content, the notes from which the professors taught were given to the students. In units one and two, students were given the slides for the class upon entering the room whereas in unit three lecture notes were not released until after the class. The levels of engagement were found to be different in these two instances in that when the students had the notes on the handouts in both units one and two they paid less attention to the professors yet in unit three student engagement was observed to be very high. Based on the active versus passive learning debate, it is fair to conclude that in unit three students were more engaged because they had to at least write the notes from the board.

5.6.3 Knowledge and beliefs about students’ understanding of specific science topics

The importance of sufficient pre-requisite knowledge is an aspect of this course that was repeated often. In all three units it was manifested that students lacked the prior knowledge necessary to be successful in the course and that it adds to the challenge of learning the materials of the course. Two of the professors discussed that while they would be willing to go deeper in the content to account for students' insufficient prior knowledge the restrictions on extra time render this feat impossible. In addition, the assumed varied levels of mastery in students' prior knowledge played a role in how learning activities are incorporated in the class. Professors had to make decisions about the level of simplicity used to represent the concept so that the low performing students had the opportunity to catch up without boring the higher performing students. Alternate problem solving strategies and suggestions for learning these strategies were emphasized. The significance for knowing or using alternate problem solving strategies was coupled with a purposeful differentiation in terms of which problem solving approach was easier to recall or apply. There was repeated emphasis on spending time to working through problems, completing homework and as well as trying to understand concepts fully without memorization of formula. This indicated professors' acknowledgement of the difficulty associated with the course material and as such would suggest strategies students could use to overcome this difficulty.

5.6.4 Knowledge and beliefs about assessment in science

Throughout the class, professors would ask the students comprehension questions which they described as aimed at checking in with the students before moving on to the next concept. Though an informal method of assessment, this indicates effort being made to gauge students understanding of the content. Additionally, in units one and two the students were given end of topic quizzes professors discussed as good instructional tools to engage the students in thinking about the content covered previously. However, the mismatch identified in this study was between sample problems worked in the class and the actual exam. Whereas in the class students were taught using a detailed structured solution to the problem, it was found that exams were multiple choice items completed using Scantron sheets. This therefore means students were not assessed based on their problem solving process but rather the response they chose from the available options. The lack of assessment whereby students are afforded the opportunity to demonstrate the skills the course is intended for them to develop is a deficit in this course. This demonstrates that while the focus of the course is on the development of problem solving skills and the ability to apply these skills to unknown problems, assessment was not on students' mastery of these skills but rather their ability to select the right answer. This finding was also evident in the course outlines as it was stated *"you will satisfy each course outcome when your score for the test questions equal or exceeds a value we specify as representing a minimal competency"*. Not only is the definition of competency vague, through this statement it was also found that students have no idea of knowing when they have met the competency requirement or the means by which they can get there. While professors acknowledge they were not measuring students understanding of the problem solving process, the use of multiple choice items and Scantron sheets were discussed as an easier way to deal with grading exams based on the large number of students enrolled in the course.

5.6.5 Knowledge and beliefs about instructional strategies for teaching science

One of the key findings of this study is the lack of multiple representations of concept. This was manifested in all three units where it was found that the method used to convey knowledge about the concepts was quantitative reasoning through mathematical equations. There were some instances where graphical illustrations were used and in unit three the professor would respond to students' questions with use of an illustration as well qualitative discussion. However overall the reliance was primarily on quantitative strategies. When qualitative discussions were used, the method was analogical and comparative reasoning. It was found, as discussed earlier, professors recognized the limitations of analogies however the level of abstractness associated with the content warrant their use. Additionally, the inability of analogies to represent concepts beyond the basic level was another limitation identified.

The value of real-life application and its use in expressing why the concepts were important to learn was found to be lacking in the design of the classes as well. The issue of time constraint and the rigorous schedule class periods had to adhere to was found to be a potential reason this feature was not included in the teaching of the concepts. This raises the question of where then are students exposed to these experiences? The textbook clinical examples worked in the class and presented on exam provide students with the opportunity to learn the theory of circuits. However the current manner in which students are taught does not create an environment where they can also experience the practical application of the concepts taught.

5.6.6 Summary of discussion of findings

The introductory course used in this study is designed with the aim to help students develop problem solving skills that can be transferred to higher level courses. This intent was manifested throughout all the methods used to collect data. It was also found that the primary approach to achieve course outcomes was through the derivation and application of mathematical equations. The nonexistence of qualitative discussion and explanation of the assumed relationship between concepts was quite evident. The work of Johnstone (1991) and Licht (1991) speaks to the significance of having an equal balance between the use of quantitative reasoning, graphical representations and qualitative discussions. Johnstone (1991) suggests the design of learning experience which takes into consideration the alignment and importance of macro (tangible and visible) discussions about concepts, micro (the invisible represented by illustrations) and symbolics (use of mathematical formulas and equations). A model of classroom reform that includes the three areas previously discussed is suggested by Licht (1991) and demonstrates how qualitative reasoning can be introduced when teaching scientific concepts without much disruption to the current design of the learning environment. The five levels of this model and how they can be applied to curriculum design in electrical courses was discussed in length by Pitterson and Streveler (2014) and are summarized below:

1. Phenomenological overview: in this first step concepts are introduced very broadly so that students come to appreciate each feature of the circuit or concept to be explored as integral to the overall topic being taught. At this level students are able to see how all the individual pieces fit as part of the whole.
2. A qualitative macroscopic approach: the emphasis in this step is on the correct use of terminology when discussing circuit concepts and specific variables. In addition information given about circuits at this stage is purely qualitative in

nature such that students are not only able to see the circuit and its various components they are also taught to be able to verbalize circuit operation.

3. A qualitative microscopic approach: at this stage the details about circuits are discussed in more finite details with the use of technical terms and visual illustrations. Since the use of graphical representation is important to the teaching and learning of scientific concepts, it is recommended that their usage be included in the teaching process when students have a clear understanding of why these visual representations are important to learn.
4. A quantitative macroscopic approach: the introduction of mathematical thinking and quantitative reasoning about concepts should be introduced when students have developed an understanding of the concept. The use of formulas and equations is introduced after students have been taught to appreciate the underlying relationships between concepts and variables.
5. A quantitative microscopic approach: at this level, the previously introduced mathematical formulas and equations are expanded and details about how they are derived is conveyed to the students. Students would now have a complete understanding of the underlying theory behind the concepts and the relationships that exist between variables. Additionally at this level instruction would be focused on helping students identify and understand how to select, apply and manipulate appropriate formulae as well as develop the ability to decipher what relationships are being represented by these formulas or equations.

5.7 Conclusion

The goal of this study was to describe how complex concepts are taught to engineering students enrolled in an introductory circuit course. From the findings it has been discussed that while the ideal situation is one which qualitative discussion, quantitative reasoning and visual representations hold equal sway there tend to be a dominance on appealing to students' mathematical knowledge when learning complex circuit concepts. These findings align with the work of Vosniadou and Verschaffel (2004) in relation to how instruction should be designed to incorporate the use of methods to help students develop an exploratory framework for the concept. Another key finding was that while the main goal of the course is to help students develop problem solving skills that can be transferred to more complex courses, students were assessed through the use of multiple choice items on exams. This indicates a misalignment between the goals of the course and the manner in which the course is designed and subsequently executed. The use of varied methods of assessment is discussed in the work of Svinicki (2004) and Hansen (2011). There were no instance where students' mastery of this skill was evaluated beyond their ability to solve and select the correct answer on an exam. In addition it was found students are not exposed to the open-ended problems they might encounter when they move beyond the classroom setting. This therefore breeds the question of how and when are students prepared to deal with constraints since complex courses build on their introductory experience. Another issue that this finding highlighted was the fact that students were given direct steps involved in solving a given problem and encouraged to not only learn but to master these steps. However there was no advice given for what to do when students follow the steps as outlined and yet arrived at the incorrect answer. While the correct use of sign notation was emphasized the nature of the class did not lend itself to much uncertainty.

The implication of this study is centered on the design of learning environments and decisions made about how to teach and assess the students. The issue of time constraint and having to keep to a rigid schedule was an important finding in this study. This indicates the need for an investigation into the number of topics being covered in the course and how the relationships between concepts can be leveraged. This would ensure students are exposed to all the necessary information while still being able to acquire the relevant skills necessary to move forward in their courses of study. This work also has implications for how concepts are taught. The five levels of Licht's (1991) model are simple changes that can be made to the daily delivery on content and can help students better understand complex concepts.

A balanced approach such as the Lesh Translation Model (LTM) (Lesh & Doerr, 2003; Moore, Miller, Lesh, Stohlmann, & Kim, 2013) that utilizes multiple representations of concepts can have significant impact on students overall learning. Using this model allows instructors the ability help students understand complex concepts using a variety of representations. It is also theorized that by having students engage in the process of creating these various representations, for example drawing a schematic diagram of a circuit first, then representing that same circuit in a pictorial or layout diagram, has the power to strongly influence their learning. As students work on creating these different representations or are instructed using this model, they are being providing the opportunity to think about the concept in different ways as well as to develop an understanding of the underlying principles associated with the concept being studied.

5.8 Recommendations for future study

Conducting a comparative case study in the semester when the majority of the students are electrical engineering (EE) majors. In this study the data was collected in the off semester for EE majors who professors explained explicitly tend to exhibit more engagement with the material during classes. A study with this focus could also highlight differences in how professors communicate knowledge to the students as well changes in the learning environment. Another area for future study could be a replication of this descriptive case study in more complex courses using the same methods of data collection and guiding framework. This approach would provide interesting information on the similarity or difference in decisions made about the teaching of introductory and complex courses. Additional data could be collected to gauge student perception of content and learning environment design.

CHAPTER 6. OVERALL SYNTHESIS, IMPLICATIONS AND RECOMMENDATIONS

6.1 Overview

This dissertation was completed using three individual studies each having their own research question however still seeking to answer one overarching question: what are the underlying reasons for students' perceived difficulty in learning complex circuit concepts? This question was used to maintain a line of coherence between the three studies in terms of how their individual questions were structured. These were:

a. Study one: How does students' prior knowledge hinder/enhance learning about complex circuit concepts? How do students use analogies and metaphors to explain circuit concepts?
b. Study two: How are engineering learning environments designed to promote students' understanding of electric circuits? What are students' perceptions of the types of activities used in enhancing their understanding of circuit concepts?
c. Study three: How are complex circuit concepts taught to students enrolled in a compulsory introductory circuit course? What decisions are made by professors about how to communicate knowledge about complex circuit concepts to student

The intent of this chapter is to seek to align the findings of the three individual studies to propositions made from the literature about the nature of complex circuit concepts, students' conceptual understanding and the design of learning environments.

The discussion to follow is aimed at highlighting how the findings of each study validates each proposition as well as to unearth emerging information where they exist. This chapter is therefore divided into two major sections. The first section will discuss the four propositions namely: how students' prior knowledge or experience influence learning, design of learning environment and student learning, student engagement through learning activities and how knowledge is conveyed in the classroom. In the second section the discussion will be centered on how the findings from the study one, two and three collectively confirm or dispel each proposition. The implications of this work, conclusions and suggestions for future study are also discussed later in the chapter.

6.2 Propositions from literature

6.2.1 How students' prior knowledge/experience influences learning

Students' prior knowledge has been described as very influential in learning as it is through these prior experiences and engagement with material being presented students are able to build new knowledge (Ambrose, Bridges, Dipietro, Lovett, & Norman, 2010; M. G. Hewson & Hewson, 1983). In facilitating conceptual change related to difficult scientific concepts, prior knowledge tends to be thought as the first point of reference. Researchers have posited that instruction that utilizes students' prior knowledge has the ability to construct new knowledge and deeper learning of material being presented (Hennessy, 1993; Swafford & Bryan, 2000; Vosniadou, 2007b). The notion therefore is that in learning new information prior knowledge has to be appealed to, in a conceptual manner, through specific and targeted instructional strategies. On the other hand, students' prior knowledge can be thought of as double edged swords in that if prior knowledge is insufficient or inaccurate they can become stumbling blocks for learning. Ambrose et al. (2010) describe the importance of measures employed by instructors to effectively uncover and utilize students' prior knowledge. The main point of their argument centers on the idea that the possession of pre-requisite knowledge by students on its own is not enough to judge students' ability to learn new material. The onus is therefore on instructors to ensure they create opportunities that not only leverage students' prior knowledge but is capable of prompting learning of new material.

6.2.2 Design of learning environment and student learning

Research focused on the teaching of complex and abstract scientific concepts speak specifically to the importance of the learning environment (Jonassen, 1998; Könings, Brand-Gruwel, & van Merriënboer, 2005; Lord et al., 2012; Roth & Roychoudhury, 1994). The emphasis on learning environment design is to create conditions necessary for optimal learning in which students are able to go beyond surface learning to more conceptual learning. It has been theorized " learning is not an activity that occurs only in the head but is also an activity that happens in a social and cultural context" (Vosniadou et al., 2001, p. 382). This suggests in order for effective learning to transpire the design of the learning environment plays a very critical role. In addition, studies have been conducted to explore the types of learning environment that are most appropriate for eliciting lifelong learning (Lattuca & Litzinger, 2014; Lord et al., 2012).

Additionally Bell, Lewenstein, Shouse and Feder (2009) suggests that by examining learning environments the opportunity to explore intervening factors that influences the learning process which can then be used as means by which learning is improved.

The four existing designs that each offer specific benefits to student learning are discussed as learner-centered, knowledge-centered, assessment-centered and community-centered environments. In each design, decisions are made about how material is taught, what is taught and why it is taught (National Research Council, 2000). However these four designs are not and should not be considered as mutually exclusive. In one classroom there is the possibility of the intersection of two or more designs. In actuality it is theorized that the most effective learning environment is one in which there is alignment between all four perspectives. However the combination of designs is usually determined by the manner in which the curriculum is structured and what is determined as important for the students to be able to do at the end of the learning process. The level of importance placed on how learning environments are designed and structured speaks to their direct influence on how well students learn and how much they learn.

6.2.3 Student engagement through learning activities

The discussion around engaging students in the classroom highlights the benefits associated with active learning approaches in that when students are allowed to participate in the learning process they learn more (Slavin, 1996; K. A. Smith et al., 2005). One of the key strategies by which student engagement is achieved in the classroom is through the use of learning activities (Chi, 2009). Where the ability to completely reorganize the design of the learning environment was impractical, research on how to engage students through the implementation of learning activities within the current structure of the classroom was conducted (National Research Council, 2012, 2014). From flipped classrooms, peer interaction, laboratory exercises to the use of technological interventions professors have employed novel, innovative and other proven measures in their classrooms all with the intent of increasing learning gains among students (Enriquez, 2010; Pitterson & Streveler, 2014b, 2015; Rockland et al., 2013; E. L. Smith et al., 1993; M. K. Smith et al., 2009; Stupans, Scutter, & Pearce, 2010). These learning activities organized by level of engagement required on the part of the student and the intensity of cognitive processes (Chi, 2009; Menekse, Stump, Krause, & Chi, 2013) are all proposed to have significant impact on student learning through the use of varied learning activities. In a comparative study of types of learning activities and their abilities to increase learning of content it was found that the most effective learning activities are notably the ones in which students are allowed to interact with each other (Chi, 2009; Johnson, Johnson, & Smith, 2007, 1998).

6.2.4 How knowledge is conveyed in the classroom

The transmission of knowledge relating to complex scientific concepts usually takes the form of deep mathematical representations such as formulas and derivation of relationships using equations and mathematical models (Elby, 2001; Johnstone, 1991; Schoenfeld, 1992). However as more studies are conducted on the nature of difficult and complex concepts, researchers have recommended the use of qualitative discussions and multiple modes of representation to enhance the possibility of making the information more accessible to students (Ainsworth, 2008; Licht, 1991; Pitterson & Streveler, 2014a;

Shipstone et al., 1988). Suggestions have spanned the use of comparative language, such as analogies and metaphors whereby the students are able to relate their prior learning to concepts of a more abstract nature (Brown & Clement, 1989; Clement, 1993; Gentner, 1983), restricting the manner in which concepts are discussed to minimize the reinforcement of misconceptions (Grotzer & Sudbury, 2000; Grotzer, 2000) as well as the use of various mental models all aimed at conveying information about the concepts being taught in various ways (Albe, Venturini, & Lascours, 2001; Beheshti, Fitzpatrick, Hope, Piper, & Horn, 2013; Driver & Erickson, 1983) just to highlight a few. In each scenario, the underlying goal is to ensure that students are exposed to the necessary information deemed important for the specific course of study being pursued in a manner that aligns with the nature of the content.

6.3 Findings from studies

6.3.1 How students' prior knowledge/experience influences learning

The findings of the three studies gave evidence to the influence of students' prior knowledge and experience on their learning. In study one the focus was primarily on how students use prior knowledge to discuss circuit concepts after they had exited the learning experience. It was found that even though the students' academic level spanned sophomore, junior and senior status they would spontaneously revert to knowledge they had garnered in introductory courses or through childhood experiences without being prompted to. Even though the design of study two was to focus on the design of the learning environment and more specifically the types of learning activities used to engage students, the included studies had a common theme surrounding the importance of prior knowledge. The issue of sufficient and accurate prior knowledge was highlighted throughout the articles used. All the 10 studies selected for inclusion in the systematic review emphasized how important students' prior knowledge was for the activity being implemented. One of the selected studies was primarily concerned with repairing misconceptions in prior knowledge through the use of a conceptual instructional approach. Similarly, in study three, one of the key findings was the repetitive emphasis on the importance of students' prior knowledge in that the students were expected to have a core knowledge base before they could even attempt to enroll in the introductory circuit course. Though this was the first time the students would be exposed to concepts of this nature in an electrical engineering context, it was imperative that the students had the necessary physics and mathematics pre-requisite knowledge before pursuing the course.

According to Ambrose et al. (2010, p. 13) "students' prior knowledge can help or hinder learning". This statement resonated through all of the data used for each study and especially across the data set used in study three. In separate interviews all the professors attributed the difficulty associated with the teaching of complex circuit concepts to a lack of or perceived inadequacy of students' prior knowledge. In addition, findings from study one indicated that misconceptions in students prior knowledge was present long after students had learned the introductory material and had progressed in their courses of study. This finding is not surprising since conceptual change researchers study how robust misconceptions associated with prior knowledge and experience will tend to propagate despite exposure to additional and more intense content (Chi, Roscoe, Slotta, Roy, & Chase, 2012; J. P. Smith et al., 1993; Yang, Streveler, Miller, & Santiago, 2009). These studies indicated that where difficult and complex concepts such as electric circuits are concerned, the role of prior knowledge in learning new material is very influential. However it is necessary to assess the status of students' prior knowledge in terms of exactitude and competency in being able to add value or enhance students learning.

6.3.2 Design of learning environment and student learning

The influence of a particular learning environment on the development of curriculum and by extension student learning was resonated mainly in studies two and three. A general finding was that even though the type of learning environment design being implemented or utilized was not explicit, the nature in which knowledge was disseminated aligned with a particular design. In addition there were various instances of the intersection of two or more of the learning environment designs as discussed in the How People Learn framework (National Research Council, 2000). For example in study three the main emphasis was on the development of specific problem solving skills and the ability to apply an engineering problem solving mindset to various types of circuit conditions. This is evidence of the intersection of learner-centered and knowledge-centered designs in that the instruction was dependent on students' prior content knowledge and mathematical skills. The course used for the case in study three was an introductory circuit course that was compulsory for all engineering majors. The purpose of the course is to expose all engineering majors to basic concepts of electricity and electrical circuits. This aligns with a knowledge-centered design in that the "focus is on the kinds of information and activities that help students develop an understanding of disciplines" (National Research Council, 2000, p. 136). Similarly in study two while the activities that were discussed by the selected studies were primarily to engage students, which will be discussed in the following section on student engagement, there was also the intent to increase students' conceptual understanding and working knowledge of the concepts being taught.

In both study two and three there were instances of the intersection of learner-centered, knowledge-centered and assessment-centered designs. In study two the expected outcomes of the implemented activities and instructional strategies were increased learning gains. The use of surveys, pre-and post-testing as well as end of unit tests were used to measure how students' learning increased as a consequence of the various intervention strategies. The main aspect of assessment-centered designs focuses on deep learning and enhanced understanding rather than the memorization of facts or application of formula. This was a common thread in the findings of study two and three. Data gathered and analyzed in study three gave explicit evidence of the need for repetitive practice for in-depth learning and understanding of the course content. The method of inquiry used in study one also supports this indication. The students that were interviewed in that study were done using a think aloud instrument. The purpose of this approach was to go beyond surface knowledge using the supposition that as students verbalized their knowledge about basic concepts they would give evidence of their thought processes and conceptual understanding of the content. Throughout all three studies the importance of alignment between learning environment design and the expected outcome of the learning process was clear. In all instances the intended goal is to provide students with the necessary knowledge and experiences required to develop expertise in electrical engineering concepts. To achieve this feat it is therefore necessary to create opportunities for students to transfer what they are learning currently or have learnt to new and related spaces (National Research Council, 2000).

6.3.3 Student engagement through learning activities

The issue of actively engaging students in the process of learning has been widely studied (Prince & Felder, 2006; Prince, 2004). Svinicki (2010) refers to the endeavour of actively engaging students as without a doubt "the best learning situation for learning the skills of both problem analysis and engineering design" (p. 15). Student engagement is most often achieved through the inclusion of innovative and in some cases experimental instructional strategies (National Research Council, 2014). In most instances, the medium used is primarily learning activities of varying intensity. The focus and findings of study two speak directly to student engagement through the use of learning activities. It was found that while the nature of large lecture classes renders the endeavour for the use of active learning strategies near impossible there were cases where professors attempted to include learning activities aimed at increasing students learning gains but largely to involve them in the process of learning. In nine of the 10 studies included in the review, it was reported that student engagement was a direct result of the type of activity that was implemented in the classes. In addition, in the studies, where students learning gains were measured it was found that students had significant increase in their learning of the content these gains were attributed to their active engagement with the content.

In study three there was a lack of the use of in class learning activities. It was found that the most common ways of attempting to engage students was through the use of instructor questioning and, in two of the units studied, the use of instructional quizzes.

On the scale of active, constructive and interactive learning activities instructor questioning would rank as interactive while the use of instructional quizzes would be constructive. These were only two cases of learning activities that were observed in study three. However it was generally reported as difficult to engage the students especially among non-electrical engineering majors. Collectively the findings of study two and three validate the proposition of engaging students through learning activities however it was not proven on a wide scale in this dissertation.

6.3.4 How knowledge is conveyed in the classroom

The use of analogical reasoning, comparative language, mathematical proofs for equation derivation and graphical representation of concepts were all common components among the three studies. The findings of all three studies supported the use of these processes to convey knowledge about circuit concepts. Most commonly was the emphasis on the importance of having acquired mathematical skills and the ability to appropriately select and manipulate complex formulas. The nature of the content dictates this reliance on the use of mathematical models and graphical representation. However the use of qualitative discussions was lacking in all three studies which should also be seen as a method of conveying knowledge that is of equivalent levels of prominence. In study one, for example, it was found that all participants had a tendency to default to equations and graphs when asked to clarify their thought processes about any particular concept. In addition a core finding of study two was the lack of multiple representation in the activities used in the learning environment to engage the students. Similarly in study three there was a heavy and repeated emphasis on having the necessary mathematical experience in order to be successful in learning the content. Contrary to the findings of the studies research has recommended an approach to the teaching of complex scientific concepts that equally recognizes the importance of mathematical, graphical and qualitative methods to disseminating knowledge (Johnstone, 1991; Licht, 1991).

Second to the importance of mathematical reasoning was the use of analogies and analogical thinking. In studies one and three, the reliance on the use of analogical reasoning was evident. It was found that analogies present the opportunity to discuss and represent abstract concept which have significant impact on students learning. In study one the inadequacy of analogical reasoning was a fundamental finding where participants' use of analogies uncovered misconceptions in their understanding that seemed to have developed in introductory courses and have continued to proliferate. While the professors who participated in study three recognized the limitations of analogies and their ability to develop or reinforce misconceptions their use was described as a necessary evil. These findings strengthen the need to exercise caution when using analogies and ensuring their appropriateness for the concept being conveyed.

Problem solving through the use of varied strategies was another aspect of information dissemination that was evident in all three studies. The focus of introductory circuit courses was described in studies two and three as the means by which electrical engineering students develop the ability to troubleshoot, identify and solve required circuit parameters. In study one some of the items were designed to measure students conceptual understanding about circuit operating conditions while solving problems. Likewise, the focus of the activities where a flipped classroom approach was used was to create more time in the class session for the working on sample problems. In study three it was found that a large percentage of the class session was spent working problems. Jointly the findings of studies two and three emphasized the process of working problems similar to what students would face on exams was one of the main approaches to teaching content.

6.4 Implications of Study

The implications for this dissertation study are specifically for course instructors and course coordinators. The core findings of the three studies independently and collectively have the ability to significantly impact the way future engineers are taught introductory concepts in their respective disciplines. The overarching theme that subsumes the findings of this study deals primarily with the design of introductory courses having alignment between content, assessment and pedagogy which will then influence decisions made about the teaching and application of content, design of the learning environment and how the content is communicated to the students.

6.4.1 Alignment of content, assessment and pedagogy

A course design which incorporates the alignment of content, assessment and pedagogy is reported to have significant benefits to the learning process (Streveler, Smith, & Pilotte, 2012). The findings of this study have indicated the misalignment that exist between the three core areas of learning in course design. An approach to teaching and learning that takes into consideration the important questions of: What is the desired knowledge students are expected to have at the end of the learning process? What is acceptable evidence of them having garnered this knowledge? How are instruction and learning experiences planned so as to achieve this desired knowledge? (Wiggins & McTighe, 1998). The key to course design is the determination of the enduring outcome for the course. In other words what is the set of key outcomes one would like for their students to have possessed at the end of the learning experience or even years after they have exited the learning process? In the introductory circuit course used for study three it was evident that students were expected to have developed a certain level of engineering problem solving skills that could be translated to other complex learning experiences. The emphasis on working problems in the class or the use of learning activities meant to provide more class time for working problems were also reflected in this dissertation study. However in most cases students were assessed using multiple choice items. To this end a deliberate approach to ensuring that the students engage in activities or are assessed using approaches that are directly related to the envisioned outcome is very important. Without alignment of content, assessment and pedagogy complete mastery of the essential attributes of the course cannot be truly determined.

If the intent of the course is the development of problem solving skills aimed at eliciting deep conceptual knowledge that goes beyond simple application of mathematical formula then there is a need for the creating of opportunities where students are assessed on their ability to demonstrate this deep learning. Since the nature of introductory courses is to provide students with the necessary pre-requisite skills and knowledge on which to build their educational model, it is important that content, assessment and pedagogy are properly aligned. The need for alignment between what core concepts are necessary for understanding and future learning, how students' understanding of these core are assessed and how these core concepts are taught is germane. This implication encompasses the argument for a learning environment in which the different design approaches are aligned meaning learner-centered, knowledge-centered, assessment-centered and community-centered perspectives are all taken into consideration. The incorporation of the fourth perspective would add value to the classroom climate in that students would feel comfortable questioning concepts they do not understand as well as having the ability to build relationships with their fellow classmates.

6.4.2 Decisions about teaching and application of content

The findings from this study have indicated the need for the inclusion of real life application in introductory engineering classrooms. The argument can be made that students get exposed to design problems when they are assigned their capstone project or are working on internships. However the nature of electricity or any other complex concept dictates a measure of applicability as abstract concepts are better learned when there is another concept to which it can be compared. In this study it was made explicit that the content of the course and the manner in which it was taught was mostly conceptual with very little to no real life application. The manner in which students are exposed to the concept of electricity in the classroom does not match the actual working environment they will be operating in. The classroom should do a better job of preparing students for the workforce and as such there is a need to include more application type activities. In this instance essential attributes or skills associated with the content of the course could be assessed by students' ability to demonstrate through given tasks their mastery of the content.

6.4.3 Decisions on design of learning environment

The traditional design of engineering learning environments tend to be teacher-centered and this was manifested throughout the dissertation but most transparently in study three. The statistics from the direct classroom observations indicated an average 90% of the class time was predominantly instructor-focused dialogue. This finding indicates the lack of engagement and discussion on the part of the students. While it is accurate that the intent of lecture courses is to expose students to a wide range of concepts in a short period of time a recent publication by the National Academies Press (National Research Council, 2014) proposed simple modifications that can be applied to the structure of classes in order to actively engage students. The ideal learning environment is one in which there is a combination of all four design perspectives (National Research Council, 2000) however in situations where such a design is not possible an alternative design should be considered. If the objective of the learning process is to provide students with relevant problem solving knowledge and skills then at the very least the learning environment should subscribe to a mix of learner-centered, knowledge-centered and assessment-centered design. A design of this nature would put the learners at the heart of its focus while still providing the necessary information and using applicable methods of assessing their consummation of this information. Alignment within the design of learning spaces provides the opportunity to truly ascertain what is being taught and subsequently learned.

6.4.4 Decisions on how the content is communicated to the students

The disparity between emphasis on mathematical knowledge and skills and the lack of qualitative discussions in the classroom warrants the inclusion of more explanation on not just how to apply formulas but why they are applied. This study revealed a lack of qualitative information communicated to the students about the nature of the concepts being taught. The works of Johnstone (1991), Licht (1991) and Bernhard and Carstensen (2002) support this recommendation in that the significance of including qualitative approaches to teaching complex scientific concepts is discussed as essential and highly beneficial. This argument is made on the premise that the use of mathematical principles to express circuit phenomenon differs from the actual physical representation of the concept. Since previous research has highlighted the fact that students ability to identify constructs specific to direct current and alternating current circuits are problematic (Bernhard & Carstensen, 2002) the implication from this study support the call for the implementation of activities that utilize more qualitative scientific reasoning. The current use of traditional mathematical-focused methods are not enough by themselves to create the space for students deep exploration of the concepts that could be advantageous to overcoming conceptual difficulties associated with electric circuits.

This need for use of various representations of content is supported by the Lesh Translation Model (LTM) (Lesh & Doerr, 2003). A recent work by Moore and her colleagues (2013) demonstrated how this model can be used in science learning. In this study, the researchers investigated how the influence of representation and models on students' conceptual learning of temperature and heat transfer. It was found that as students were encouraged to represent the concept of heat transfer in various ways their understanding and ability to verbalize and translate their understanding of the model they had created significantly improved. This approach, the LTM, can be applied to other disciplines where there exists heavy dependence on mathematical models. Subjects such as thermodynamics, statics, fluid dynamics and other highly mathematical focused spaces could benefit from use of this model as students would be exposed to the idea of using multiple representations and being able to see the connections that exist between these different models.

6.5 Conclusion

The findings of each of the three studies have demonstrated evidence of the interaction between students' prior knowledge, design of learning environments and how complex circuit concepts are taught. The model chosen to guide the study in terms of how the three individual studies support each other and align with the overarching research question provide useful information that can significantly improve the methods used to exposed students to complex concepts in introductory courses.

The first key finding was the impact of students' prior knowledge when they were required to discuss concepts learned in introductory courses after they had completed the course and advance in their academic journey. Misconceptions that developed as a result of the use of analogies and metaphors when the concepts were first introduced, were found to be prevalent when students asked to verbalize their thoughts about basic concepts. It was also found that students were more confident in their responses when the sample problems were the typical textbook circuit problems. This indicates students became more uncertain of their knowledge when they had to explain the operation of current and voltage in a real-life concept. This level of difficulty is not surprising as it was found in study three that students are not exposed during classes to open-ended problems they are likely to encounter in the workplace.

Findings from studies two and three suggest students are expected to develop a certain set of problem solving skills and that these skills are reinforced in the learning environment. However students' mastery of these skills are not properly assessed. The use of multiple choice items does not provide the opportunity to give detailed illustrations of the process whereby students arrive to the solution. This means professors have no real way of determining how students arrived at a solution nor are they able to identify where students are having difficulties. In addition there was little to no instances of discussing what to do when the possibility of using the structured problem solving approach led to an incorrect response.

The lack of qualitative discussion or other means whereby students are able to communicate what they understand about how concepts are related or how the relationships between concepts are developed was another interesting finding. The nature of the concepts being taught lends itself to heavy reliance on mathematical concepts, symbols and equations however students were seldom exposed to why these mathematical formulas or equations were necessary or how they relate to each other. This may lead students to think that the operation of electricity and the interaction between variables are purely quantitative.

6.5.1 Theory of difficulty for learning complex circuit concepts

In this study the goal was to answer the overarching question of: what are the underlying reasons for students' perceived difficulty in learning complex circuit concepts. To answer this question, three individual studies were designed having their own research questions, method of inquiry and data.

1. How does students' prior knowledge hinder/enhance learning about complex circuit concepts? How do students use analogies and metaphors to explain circuit concepts?
2. How are engineering learning environments designed to promote students' understanding of electric circuits? What are students' perceptions of the types of activities used in enhancing their understanding of circuit concepts?
3. How are complex circuit concepts taught to students enrolled in a compulsory introductory course? What decisions are made by professors about how to communicate knowledge about complex circuit concepts to students?

Each study focused on a particular lens; study one – influence of prior knowledge, study two – design of learning environment and study three – how the concepts were taught to students. In all the three studies the focus was on an introductory compulsory circuit course taken by all engineering majors. Figure 9 represents the relationship between the studies and how the key findings align with the overarching research question as demonstrated by the color coding of the concepts in the map (larger image included in Appendix D).

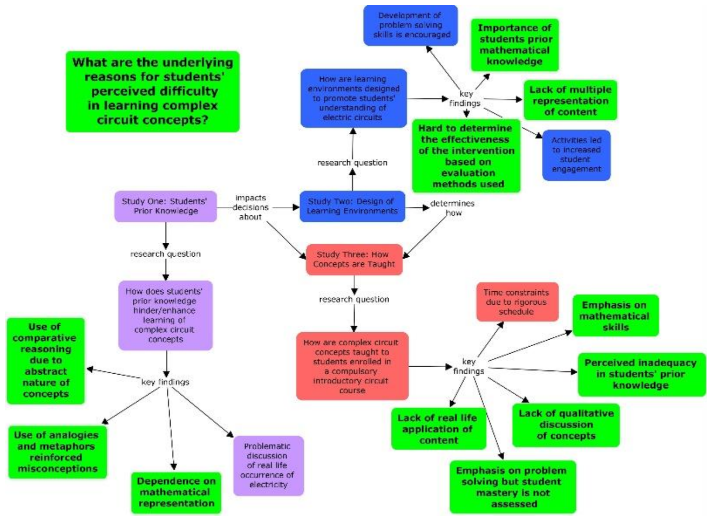

Figure 9 – Relationship between studies and alignment of key findings

The findings from each study were discussed individually in their respective chapters; chapter three – study one, chapter four – study two and chapter five – study three. Previously in this chapter, the findings of each study were discussed collectively in terms of how they validate or dispel propositions made from the literature about the teaching and learning of circuit concepts. Based on the collective findings of the three studies, a theory of difficulty for the learning of complex circuit concepts can be described as the lack of learning experiences and design of learning environments that take into consideration the unique but challenging intersection of students pre-conceptions about electricity, how information about circuit concepts are communicated to students and instructional strategies used to convey this information.

In relation to circuit concepts themselves, there is a level of difficulty associated with the abstract nature of the concepts. It is an expectation that students will need some tangible concept or visible domain with which they can identify in order to develop some understanding of the content being covered. However students' deep-rooted pre-conceptions with which they enter the learning space is detrimental to their learning of formalized information about electricity. If these pre-conceptions are incorrect or incomplete they contribute to the level of difficulty students face in understanding the new material because their pre-existing beliefs are not in conflict with the new information. Most often when faced with cognitive conflict of this nature the easiest option is to refute what is being learned and hold on to the prior formed explanations (Chinn & Brewer, 1993).

The use of mathematical formulas and equations can help to alleviate difficulty in that they provide a means of modeling the abstractness of the concept. However another level of complexity is introduced when students are not made aware of why these formulas are necessary or how the formulas describe the relationship between concepts. This outlines the need for qualitative discussions about the concepts. Students should exit the learning experience with the ability to not only prove mathematically the relationship between concepts but also having the ability to verbalize the means by which these relationships exist and why they do exist. Not having this understanding of how concepts relate and why a simple manipulation of a component value can have significant impact on the operation of a circuit contributes to the level of difficulty students have when they have completed the course and still experience challenges expressing their knowledge.

6.6 Recommendations for future study

This study has successfully brought to light difficulties associated with the teaching and learning of complex circuit concepts in introductory electrical engineering courses. This findings and limitations of each individual study can inform directions for future study that are threefold. The recommendations for future research stemming from this dissertation are:

- Study one: An investigation looking specifically on students' perception and metacognitive thought on their use of analogies and metaphors. The emerging finding in this study related to the participants reflecting on their use of analogies and metaphors and discussing them as useful ways to communicate knowledge about abstract concepts to others even though they did not need them for their own understanding. Further study into this interesting phenomenon can be conducted to uncover how the conflict between tacit and explicit knowledge is manifested when students are instructed to express knowledge about abstract concepts using tools they do not necessarily need.
- Study two: The studies discussed students increased learning gains as a result of the implemented activities however further work could be conducted to measure the impact of an intervention, such as learning activities, but with better assessment of student learning gains that is beyond surface learning. Assessments that would measure knowledge transfer or deep conceptual learning would allow for more in-depth investigation into what professors are doing and what actual difference is being made to students' learning.
- Study three: Conducting a comparative case study in the semester when the majority of the students are electrical engineering (EE) majors. In this study the data was collected in the off semester for EE majors who professors explained explicitly tend to exhibit more engagement with the material during classes. A

study with this focus could also highlight differences in how professors communicate knowledge to the students as well changes in the learning environment. Another area for future study could be a replication of this descriptive case study in more complex courses using the same methods of data collection and guiding framework. This approach would provide interesting information on the similarity or difference in decisions made about the teaching of introductory and complex courses. Additional data could be collected to gauge student perception of content and learning environment design.

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APPENDICES

Appendix A Protocol used for student think aloud in study one

Difficult Concepts in Circuits

Second Round

Prepared by: Ravel F. Ammerman

Question Number	**Acknowledgements**
1: Electric Incident Report Fundamental Electrical Quantities: Charge and Energy	Adapted from: IEEE Industry Applications Magazine, May/June 2005
2: Lightning Strike: Fundamental Electrical Quantities: Charge and Energy	Version 2a: Adapted from: National Weather Service Web Site http://www.lightningsafety.noaa.gov/photos.htm Version 2b: The Denver Post September 4, 1999 Version 2c: Mountaineering, The Freedom of the Hills, 6^{th} Edition, 1997
3: AC Power: Fundamental Electrical Quantities: Charge and Energy	
4: Fundamental Electrical Quantities: Charge and Energy	Conceptual Physics, Paul G. Hewitt, 9^{th} Edition, 2002. Addison Wesley

Question 1: Electrical Incident Case History: A man was swimming at a motel pool while on vacation. The man left the pool to buy a soda from a nearby vending machine. While attempting to insert a coin into the machine, he received a fatal shock. The safety investigation that followed this incident revealed that the vending machine was ungrounded because someone had removed the third grounding prong of the connecting plug. A voltage was observed on the frame of the vending machine.

The pictures shown below illustrate the injuries that were sustained as a result of this electrical shock incident. Explain what happened. What factors contributed to the victim's death?

Question 2a: The following pictures are posted on the National Weather Service Lightning Safety web site. Animals are frequent victims of electrocution by lightning. Explain what happened to this group of cattle. Defend your answer (i.e. explain your reasoning).

Question 2b: The following article appeared in the September 4, 1999 edition of the Denver Post. Animals are frequent victims of electrocution by lightning. Explain how an entire herd of elk could be killed by a lightning strike. Defend your answer (i.e. explain your reasoning).

Dead elk herd may be record

Group of 56 killed by lightning on Evans

By Jim Hughes
Denver Post Staff Writer

Colorado Division of Wildlife

Lightning is believed to have killed these 56 elk on Mount Evans.

A hunter's discovery of 56 elk carcasses near Mount Evans — since determined to have been fatally struck by lightning — has state wildlife officials wondering if the incident could be some kind of gruesome wildlife record.

The elk were discovered by a hunter scouting the area for this fall's upcoming hunting season. He stumbled upon a grisly sight: a cluster of nearly 60 dead elk, already bloated, lying across an above-timberline bench.

"It's rare to see this many animals killed," said Fred Quarterone, a Colorado Division of Wildlife spokesman. "Big game animals probably are struck by lightning every year in Colorado. It's not unusual. What is unusual, though, is to see this many animals struck by lightning. This is a rare incident."

So far, wildlife officials have found only one incident that comes close to last month's mass killing. In 1972, 52 caribou were found dead in Alaska. In Colorado, 11 mountain goats were killed in 1997 by a single lightning strike in the Collegiate Peaks.

"In talking to wildlife biologists and officers in the division, I didn't hear of any recollections of more than this amount of animals killed in recent history," Quarterone said.

Whether any elk survived the deadly strike, which biologists estimate came down during the second week of August, is not known. Any animals jumping over rocks, for instance, or were far enough away from the place where the lighting bolt actually struck, could have survived, Quarterone said.

The bizarre slaughter will have little impact on management of the region's elk herds, he said.

"The state's elk population is very healthy, and in that particular area, the population is in good shape, too," he said. "We estimate there are more than 2,400 elk in the Mount Evans area. We don't see that this loss is going to substantially hurt hunting opportunities nor the watchable wildlife opportunities in the area."

Question 2c: The picture below shows the preferred body position and location during an electrical storm.

A mountaineering guidebook makes the following suggestions of what to do in the event you are caught in an electrical storm while hiking.

- Never lie down.
- Do not put your hands down.
- Put your elbows on your knees.
- Crouch on the soles of your feet.
- It is better to stand on dirt than rock and avoid water.

Why do these suggestions improve your chances of surviving if lightning strikes nearby? Defend your answer (i.e. explain your reasoning).

Question 3: The majority of electrical energy used in North America is transmitted and distributed in a three-phase alternating current form. One of the advantages to this approach is that fewer lines can be used to deliver power to the customer. If fewer lines are required then the power loss in the system will be reduced improving the efficiency of energy transmission. Why is power lost when current flows through a transmission line? Carefully explain your reasoning.

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Appendix B Data Extraction Tables used for Study Two

Table 15 - First round of data extraction for primary sources

Title	Author	Source	Purpose of study	Type of Study	Setting	Data collection	Major Findings
Student perception of lecture video use as a means to increase time for in class problem solving applications	Dolan, Dale S.L., Prodanov, Vladimir I. Taufik, T.	ASEE Conference Proceedings, 2011	To examine students perceptions of lecture video as a means to increase available time for in class problem solving in a teaching and learning context	Qualitative	Lecture	Pre and Post Online surveys	Results indicated strong support for the format of the course and students perceived they were better able to learn the material.
Levels of practical skills in basic electronic laboratory: Students' perceptions	Salim, Kamilah Radin, Puteh, Marlia, Daud, Mohd Salwani	IEEE Global Engineering Conference, 2011	To investigate students' perceptions on the practical skills acquired after conducting laboratory experiment for one semester.	Qualitative	Lab	Online surveys	Results indicate some variations in students' perceptions with regards to their ability in recognizing the electronic components, constructing the circuit, operating the instruments and interpreting measurement.
Learning outside of the classroom - Flipping an undergraduate circuits analysis course	Rockland, Ronald H. Hirsch, Linda. Burr-Alexander, Levelle. Carpinelli, John D. Kimmel, Howard S	ASEE Conference Proceedings, 2013	To document the process of how videos for an introductory course was developed and how the structure of the course was rearranged to accommodate the use of the videos and students' report of the effectiveness of this endeavour	Qualitative	Lecture	Reflection documents	Students reported enjoying being able to revisit challenging concepts through the videos. Overall the approach received mostly positive assessment owing to the fact that students were able to use videos repeatedly to prepare for exams

Title	Author	Source	Purpose of study	Type of Study	Setting	Data collection	Major Findings
Analog-circuit - based activities to improve introductory continuous-time signals and systems courses	Simoni, Mario. Aburdene, Maurice. Fayyaz, Farrah	ASEE Conference Proceedings, 2013	To present a series of analog-circuit based activities that can help students visualize complex mathematical concepts and gain better appreciation for how concepts are useful in real-world situations	Quantitative	Lab	Surveys	The activities used in the laboratory was reported to have given students an opportunity to relate the highly mathematical concepts with real-world problems through the use of hands-on activities. Students reported gaining a more application-oriented appreciation but did not feel their confidence in learning the material improved much.
Using Tablet PCs to enhance student performance in an introductory circuits course	Enriquez, Amelito	ASEE Conference Proceedings, 2010	To show how Tablet PCs and wireless technology can be used during classroom instruction to create an Interactive Learning Network that is designed to enhance instructor's ability to solicit active participation from all students during lectures, to conduct immediate and meaningful assessment of student learning, and to provide needed real-time feedback and assistance to maximize student learning.	Qualitative	Lecture	Surveys	Results of student surveys shows "overwhelmingly" positive student perception of the effects of this classroom environment on their learning experience. Additionally the interactive classroom environment developed using wireless Tablet PCs has the potential to be a more effective teaching pedagogy in problem-solving intensive courses compared to traditional instructor-centered teaching environments.
Audio-visual lab tutorials to develop independent learners	Walter, Deborah	ASEE Conference Proceedings, 2011	To describe the development and use of audio-visual lab tutorials to outline pertinent circuit concepts to novice students aimed at developing independent learners	Qualitative	Lab	Surveys	Results indicated the use of the lab tutorials reduced the time students were in the lab, accommodated varied levels of experiences and learning styles, developed students' capacity for independent learning and are preferred by most students over text-based resources.

Title	Author	Source	Purpose of study	Type of Study	Setting	Data collection	Major Findings
Augmented reality to improve STEM motivation	Restivo, Teresa. Chouzal, Fatima. Rodriques Jose. Menezes, Paulo. Lopes, J. Bernardino	IEEE Global Engineering Conference, 2014	Aims to characterize student involvement using an augmented reality application as well as its use as an additional experimental tools, to characterize how students perceive their experience and learning through use of this application	Qualitative	Lab	Surveys	Preliminary results show induced student satisfaction and revealed very good student perceptions about learning perspectives. This application showed good potential for application in teaching DC circuits.
Increasing hands-on laboratory equipment experience via rotation of notebook recording duties	Jansson, Peter Mark. Kelley, David	ASEE Conference Proceedings, 2012	To show how the pedagogical strategy of having the role of note-taker within a group in a lab setting helped students to increase their competency in using laboratory equipment and learning subsequent circuits	Qualitative	Lab	Pre and Post surveys, Notebook assessment and in class observations	Results showed skills and competencies was significantly improved over the course of the semester. On post survey students reported a great appreciation for the use of this approach to improve their knowledge about circuits and use of lab equipment
Teaching strategy focused on sensory perception, students' interest and enjoyment	Sivaramakrishan Sudarshan. Ganago, Alexander	IEEE, 2013	To create a learning environment that would engage students' senses; provide hands-on experience to which they can easily relate, and to stimulate intuitive understanding of EE concepts.	Qualitative	Lecture/ Lab	Multiple choice survey	Findings indicate positive results and experiences on the part of student learning, understanding and interest. Students also express a deeper appreciation for EE concepts in real world contexts.
The use of enhanced guided notes in an electric circuit class: An exploratory study	Lawanto, Oenardi	IEEE Transactions on Education, 2012	To evaluate students' learning performance after their participation in lectures using enhanced guided notes in an electric circuit's course.	Quantitative	Lecture	Concept Inventory	Results indicated significant increase in student performance and reported gains in students' understanding of concept based on method used.

Title	Author	Source	Purpose of study	Type of Study	Setting	Data collection	Major Findings
How does Technology-Enabled active learning affect undergraduate students' understanding of electromagnetism concepts?	Dori, Yehudit J. Belcher, John	Journal of the Learning Sciences, 2009	To analyze the effects of a unique learning environments of the TEAL project on students' cognitive and affective outcomes. Students' conceptual understanding before and after studying electromagnetism in a media-rich environments	Quantitative	Lecture/ Lab	Pre and post standardized tests, multiple choice and open ended items	Test scores indicated increased performance on the tests. Students also reported an appreciation for the learning experience and that their understanding was significantly impacted by the innovative approach used.
Conceptual understanding of resistive electric circuits among first-year engineering students	Sangam, D Jesiek, B.	ASEE Conference Proceedings, 2012	To discuss the details of an instructional module implemented and present findings on its effect on student learning as well as to report students' perception of the module in increasing their understanding	Quantitative	Lecture	Pre and post concept inventory test, open ended survey items	Test scores indicate significant increase in students learning which can be attributed to the different learning module that was applied. Students' open-ended response indicated their agreement to the instructional method that influenced their understanding.

Table 16 – Second round in-depth data extraction

Study title	Description of activity	Description of data collection	Reported students' perceptions	Limitations	I-C-A-P
Student perception of lecture video as a means to increase time for in class problem solving applications *(Dolan, Prodanov and Taufik, 2011)*	A portion of face to face to lectures were replaced with pre-recorded instructional videos assigned as homework. The scheduled lecture time was then used for problem solving	A survey was developed to assess the students' perception of the videos. Instrument included 15 sets of five level Likert items students were expected to respond to. 90 students were surveyed from two electrical engineering courses: a required sophomore level course and a senior technical elective	The survey results indicated a general appreciation for the approach. Students reported the videos as a faster means of covering lecture material, a major advantage reported was the ability to go through the lecture material at their own pace and having the ability to review the material. Students preferred solving problems in class but also expressed the need for having face to face lectures as well.	Students reported missing the ability to ask clarifying questions	Active
Learning outside of the classroom - Flipping an undergraduate circuits analysis course *(Rockland, Hirsch, Burr-Alexander, Carpinelli and Kimmel, 2013)*	A series of instructional videos were created for a junior level circuit's course. Students were expected to review videos for the week before attending classes. The main difference with this activity as opposed to other approaches is that the videos were made into learning objects 10 minutes long	In addition to the videos the students were assigned weekly assignments required to be uploaded before the class. These assignments were an assessment of the quality of the learning objects by means of a questionnaire and an assessment of the learning objectives for the course for that week. Students were also required to submit a reflection document in which they would express problems or concerns along with positive results of the week's learning and assignments.	The activity was met with mixed feelings by the students. While the students appreciated being able to access the videos repeatedly as an aid in developing their understanding there was also the comment of there not being enough information in the short duration of the videos. Students also reported being able to watch the videos, paused where necessary to reference the text and class notes when more information was needed.	Students reported that the activity used did not cater to their learning styles as they would have wanted more face to face interaction with the material in the classroom. Students also felt the examples used in the videos could have been more challenging.	Active

Study title	Description of activity	Description of data collection	Reported students' perceptions	Limitations	I-C-A-P
Analog-circuit - based activities to improve introductory continuous-time signals and systems courses *(Simoni, Aburdene and Fayyaz, 2013)*	Students work on a series of hands-on laboratory exercises designed to connect theoretical concepts to real-world practical applications. Students are given a lab document that outlines theory lab is meant to illustrate, a step by step procedure of activities to be conducted prior to lab session, procedure for completing the lab activity and a set of questions to be answered after the activities are completed.	Two types of data was collected for the project. A 13 item survey was administered to measure students' perceptions about the concepts, the exercises and their overall confidence with the material. Students' cognitive learning experience was measured using a concept inventory.	Statistical analysis revealed that students reported positive benefits to the implementation of the laboratory exercises. Students overall agreed that the activities helped them to understand the concepts they were previously taught. Additionally, the results of their performance on the concept inventory indicated that the students’ cognitive knowledge was also increased.	Based on the manner of data collection it was impossible to determine if the change in the students learning gain can be completed attributed to the change in curriculum. Students also reported feeling overwhelmed by the nature of the activities and were unsure how they were related to the material of study.	Interactive
Using Tablet PCs to enhance student performance in an introductory circuits course *(Enriquez, 2010)*	A computer interactive learning environment where students use a set of Tablet PCs to access class material. Through the use of an interactive learning software the instructor was able to gauge the students' understanding and respond to their queries on a one to one basis.	During lecture classes focused on introducing students to new concepts and applying them to simple exercises then moving on to more complex examples students work individually or in groups on their Tablet PCs. Instructors are then able to monitor the students' progress through the instant surveys they complete when they have completed an exercise. A comparative case study was conducted to assess students increased learning through pre and posttests. Students were also assess through an attitudinal survey	Statistical analysis indicated overwhelmingly positive attitudes to the use of the interactive learning software and the Tablet PCs in the experiment group. Students reported the tools to have helped them improve their understanding, instructor's teaching efficiency and improved learning environment. Students also exhibited increased learning gains.	Results indicated increase in students' knowledge in both groups even though the students who used the interactive learning environment had significant differences in their learning gains.	Interactive

Study title	Description of activity	Description of data collection	Reported students' perceptions	Limitations	I-C-A-P
Audio-visual lab tutorials to develop independent learners *(Walter, 2011)*	Students are exposed to a dynamic innovative learning experience whereby they have access to instructional videos as they complete hands on lab activities. A Tablet PC is attached to a computer providing students with the ability to have the instructors video be synchronized with schematic diagrams and other lab tutorial materials	A post-class survey was used to capture students preference for the video tutorials compared to other text-based resources. Students were also instructed to self-report their video access each week.	Students reported preference for the use of the videos in that they were able to sufficiently prepare for the lab before the class. This they indicated gave them more time in class to focus on the required activities. Result indicated students had positive attitudes towards the use of videos over other text-based resources.	There was no determinant for which student accessed which video most hence conclusions cannot be made about student performance in direct relation to how often they watched the videos. Results indicated students tested differently when assessed individually even though they performed well in the lab groups.	Interactive
Increasing hands-on laboratory equipment experience via rotation of notebook recording duties *(Jansson and Kelley, 2012)*	To circumvent the equal dissemination of work in a lab group, this study describes the rotation of a lab notebook to actively involve students in the lab activity. Each member of the group is assigned a particular role that rotated each week.	Data was collected from students' rating of their role as note taker for the group as well as through the use of pre and post course surveys. Questions were designed to capture students' perception of the activity on their learning of the concepts being assessed as well as their self-reported appreciation for the teaching strategy.	There were very little statistically significant differences between students' pre- and post-course surveys. In most categories students reported the same attitude to the concepts being tested in the pre and post survey. Students in fact responded more favourably on the pre course survey.	Students reported an overall general dislike for the requirement of keeping and maintaining a notebook.	Interactive

Study title	Description of activity	Description of data collection	Reported students' perceptions	Limitations	I-C-A-P
Teaching strategy focused on sensory perception, students' interest and enjoyment *(Sivaramakrishan and Ganago, 2013)*	In a lab class aimed at covering the concept of Fourier series students were engaged in activities aimed at appealing to their sensory perception. Students were given a range of activities moving from learning theory to making hard wired circuits. In every lab students were instructed to use a series of notes on a virtual keyboard via keyboard or to modify the waveforms as a means of teaching the students to appreciation the distinction in what they saw or heard.	A set of comprehensive surveys were designed specifically for each lab. The surveys comprised of both multiple choice and open ended items aimed at collecting both quantitative and qualitative data.	Students' responses on the survey indicated an increase in their overall interest in the concepts. They also reported feeling like they had enough time to focus deeply on what they were doing in the lab. More than half of the sample reported great appreciation for being able to see and hear the change in the frequency of the waves they were working with. This they reported made the abstract concept not so grasp.	The concept of music was the focus of the application used in the lab but since the sample was made up of students from various engineering disciplines music might not have been an area that interested them.	Constructive
The use of enhanced guided notes in an electric circuit class: An exploratory study *(Lawanto, 2012)*	Students are presented with course notes before class with the intent on having the students engaged in the class discussions without being distracted by having to take verbatim notes. The instructor creates a set of note sheets that not only requires students to fill in blank spaces but to complete activities, answer conceptual questions and formulate conclusions.	Both quantitative and qualitative data was collected through the use of a circuit concept inventory (pre and posttests) and students' response to the Learning Experience Questionnaire.	Statistical results showed significant improvement in the students learning gains as well as their appreciation for the EGN. Students reported the activity helped them understand the concepts discussed in class, improved their problem solving skills and actively engaged them in the learning process.	The use of this approach could be at the expense of students feeling the need to refer to or read their required text before attending classes.	Constructive

Study title	Description of activity	Description of data collection	Reported students' perceptions	Limitations	I-C-A-P
How does Technology-Enabled active learning affect undergraduate students' understanding of electromagnetism concepts? *(Dori and Belcher, 2009)*	In a typically large introductory physics circuits course this tool TEAL utilizes a set of carefully structured min-lectures, recitations and laboratory exercises. Students work in small groups interacting with simulation software aimed at providing visualization to abstract concepts.	Both cognitive and affective data were collected through the use of pre and post testing as well as observations and surveyed focus groups at the end of the course.	Students reported an appreciation for the discussions they could have with each other while they completed lab exercises or problem sets. Their improved understanding was collectively attributed to differentiated perspectives facilitated by social interaction. Statistically there were significant improvement in students' conceptual understanding among the students in the experimental group as opposed to those in the control groups.	There is a constant concern when students are placed in groups and encouraged to learn together in that this might not sit well with their learning styles. In addition some of the students reported sometimes feeling overwhelmed as they were uncertain if their understanding of the concepts were in fact right.	Interactive
Conceptual understanding of resistive electric circuits among first-year engineering students *(Sangam and Jesiek, 2012)*	Three sections of students were tested using a concept inventory for pre and post test scores. One section however was taught the instructional module using a specially designed based on recommendations of conceptual change research.	Data was collected using pre and post concept inventory test as well as an evaluation survey. Students were tested before the module and then again after the module was completed. They were also required to complete the module evaluation survey.	Among the three sections of students, section one (the experimental group) showed the most overall increase in students' grades. Students who were taught using the conceptual change instruction rated their interest and understanding in electrical engineering to have improved after the module.	The sections were all taught by different instructors which could have had some influence on how the students rated the module. In addition there might be marked differences in how either section was taught.	Passive

Appendix C Data gathering documents for study three

Appendix C 1 – Interview Protocol

Study title: Exploring undergraduate engineering students' conceptual understanding of alternating current (AC) circuits

Interview Protocol

Contingent on the consent form you have signed, this interview will be audio recorded solely for memory purposes. Only the researchers/key personnel on the IRB approved list will have access to these records which will be destroyed after transcription and you have verified your discussion was properly captured. The consent form in short states that all information will be confidential, your participation is completely voluntary and as such you can choose to withdraw from this study at any time and your participation in this study will be of minimal risks.

This interview is set to last no more than 45 minutes. We have a few questions we would like to answer, however based on your response to any particular question the interviewer might ask you a few clarification questions not represented in this document.

Introduction

You have been selected to speak with us today because you have been identified as someone who is interested in using research to inform your practice of teaching and you were recommended by other faculty members as a good resource. This research project is aimed at uncovering how information about electric circuits is passed on to the students. We are particularly interested in how students are instructed on abstract concepts and with this we hope to explore some of perceived difficulties students have learning the material. Our study does not aim to evaluate your techniques or experiences. Rather, we are trying to learn more about teaching and learning, and hopefully learn about faculty practices that help improve student learning.

How long have you been:

_______ in your present position?

_______ at this institution?

1. Could you explain some of the difficulties you have seen your students experience over the duration of the time you have been a professor of this course?
    a. Why do you imagine the students have these difficulties?
    b. Did you experience any difficulty in your own educational experience when you were learning these concepts?
        i. If yes, could you share some of these difficulties?
    c. How did you learn these concepts?
    d. What are some strategies you have employed to make this concept easier to understand for the students?

2. Have you ever used analogies to help the students understand abstract concepts?
    a. If yes, could you share some examples of these analogies
    b. If no, could you say why not

3. Do you think there are limitations in the use of analogies?
    a. If yes, could you share what some of these might be
    b. If no, could you say why not

4. Could you share some of the decisions you make when developing your course materials about what examples to use when you were teaching about AC circuits?
    a. Do you see value in the use of real life applications? If yes, could you elaborate?
    b. Do you try to use real life applications in your classroom? If yes, could you explain a few of these?

5. How do you engage students in the classroom?

6. What do you think is the hardest electrical circuit concept to teach?
    a. Can you share why you think this is the hardest concept?
    b. Do you face any challenges in your attempt to teaching students these concepts? If yes, what are some of these challenges?
    c. How do you deal with the constraint of being tied to a specific schedule of topics and exams?
    d. Do you feel this affects your ability to go deeper in the discussion of concepts? Could you elaborate?

7. Could you share your own personal philosophy of teaching complex concepts such as circuits?
    a. Are there any special strategies you use for problem solving in your classes? If yes, could you give some examples?
    b. Do you feel the problem solving strategies assist students in understanding how to solve these problems?
    c. Do you usually use more than one approach to problem solving? Yes or no, could you say why?
    d. Is there anything else you think I should know about how you approach teaching this course?

8. Closing statements or clarifying comment.

Post Interview Comments and/or Observations:

For IRB Use Only

Appendix C2 – Consent Form

RESEARCH PARTICIPANT CONSENT FORM

Exploring undergraduate engineering students' conceptual understanding of alternating current (AC) circuits

Dr. Ruth Streveler, Associate Professor

School of Engineering Education

Purdue University

<u>What is the purpose of this study?</u>

The purpose of this study is to explore the design of engineering learning environments and the dissemination of knowledge about electric circuits in an introductory circuits' course.

<u>What will I do if I choose to be in this study?</u>

Participation in this study will mean allowing the research to observe a number of lecture classes and consenting to a follow up interview after the period of observation is complete. You will also be required to share your course materials such as syllabus, course notes and PowerPoint slides with researcher strictly for the purpose of data. The researcher will record audio of the interviews and take hand written field notes of the discussion of concepts in the class. Following the interview and transcription of audio you will be asked to review the transcript and will have the opportunity to request that anything you are uncomfortable with be removed before analysis. You are not obligated to participate in future tasks related to the study

<u>How long will I be in the study?</u>

The duration of the interview should not be more than 45 minutes and the researcher will work with you to ensure this is done at a time and place of convenience to you. Your participation in the study will conclude after you have reviewed the interview transcript.

What are the possible risks or discomforts?

The audio recording are strictly for memory purposes and will not be shared with anyone besides key personnel on the approved IRB application. Breach of confidentiality is a potential risk you might encounter but the researcher will endeavor to ensure that your identity remains private and all audio recordings will be destroyed after transcription. The interview questions will ask you to speak to your philosophy of teaching and how you make decisions about teaching abstract concepts. If at any time a question makes you uncomfortable, you reserve the right to decline to answer or alert the researcher of this.

Are there any potential benefits?

There are no direct benefits to participating in this study but as an indirect benefit this study has the potential to help you reflect on your approach to teaching and what you can do differently. Other indirect benefits may include the possibility of learning a new method of teaching circuits which has the ability to elicit more interaction and engagement of the students.

Will information about me and my participation be kept confidential?

No data will be directly connected to you as a study participant and your interview responses will remain anonymous. Research data will be held for three years after the study is complete. Written field notes and interview transcripts will be stored in a locked file cabinet and accessed only by the research team. This study's research records may be reviewed by the National Science Foundation, Office for Human Research Protections and by departments at Purdue University responsible for regulatory and research oversight.

What are my rights if I take part in this study?

Your participation in this study is voluntary. You may choose not to participate or, if you agree to participate, you can withdraw your participation at any time without penalty or loss of benefits to which you are otherwise entitled.

Compensation

No compensation will be provided for participation in this research project.

Extra Costs to Participate

There is no cost for you to participate in the study.

Who can I contact if I have questions about the study?

If you have questions, comments or concerns about this research project, you can talk to one of the researchers. Please contact Dr. Ruth Streveler at 765-427-5316 or rastreve@purdue.edu. You may also contact Nicole Pitterson at 432-788-7097 or npitters@purdue.edu.

If you have questions about your rights while taking part in the study or have concerns about the treatment of research participants, please call the Human Research Protection Program at (765) 494-5942, email (irb@purdue.edu) or write to:

Human Research Protection Program - Purdue University
Ernest C. Young Hall, Room 1032
155 S. Grant St.,
West Lafayette, IN 47907-2114

Documentation of Informed Consent

I have had the opportunity to read this consent form and have the research study explained. I have had the opportunity to ask questions about the research study, and my questions have been answered. I am prepared to participate in the research study described above. I will be offered a copy of this consent form after I sign it.

______________________________________ _________________________

Participant's Signature Date

____

Participant's Name

___________________________________ ____________________________

Researcher's Signature Date

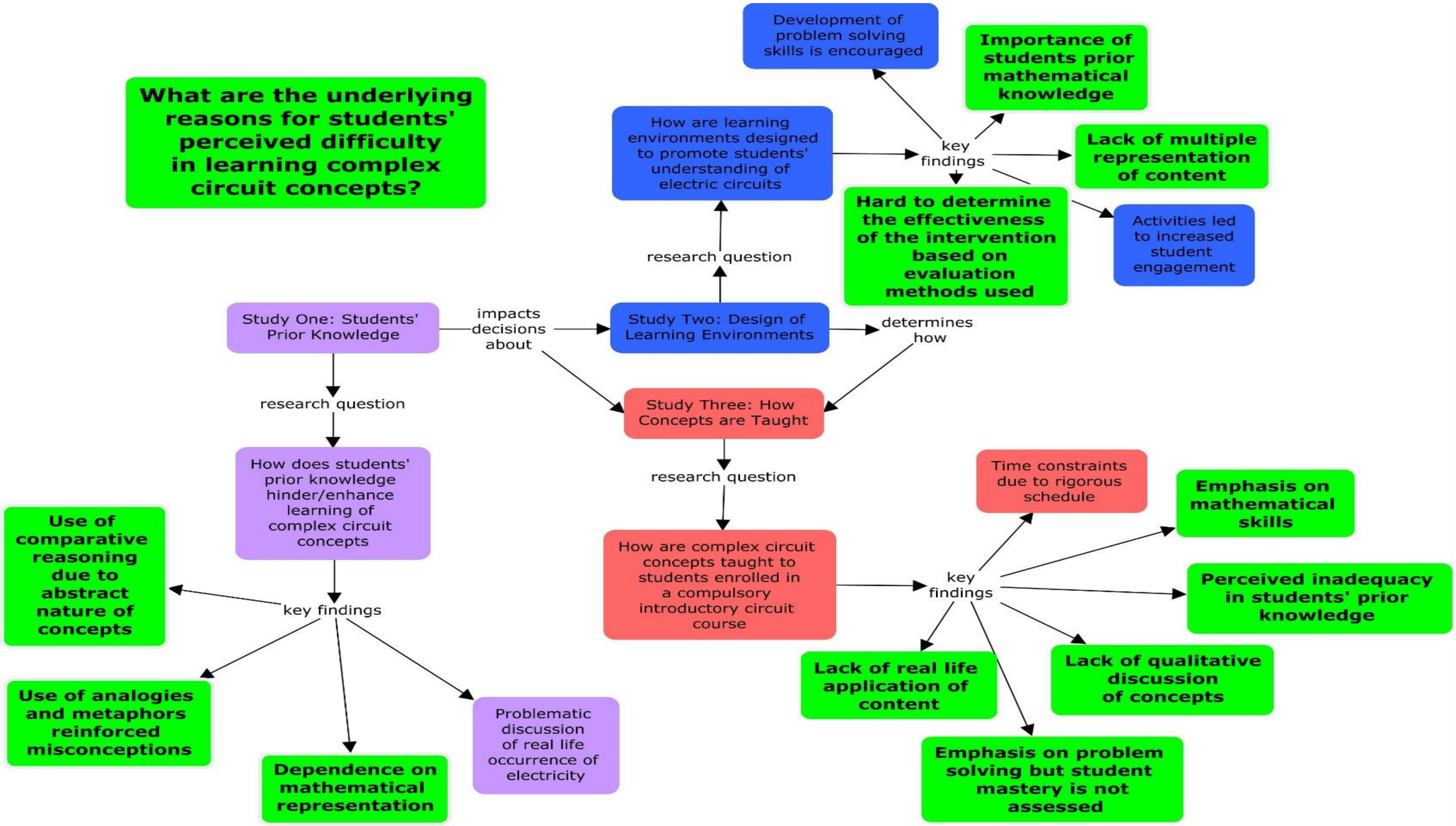
Appendix C3 – ECE Course Schedule

ECE 201 - Fall 2015 Schedule

LECTURE NO.	TOPICS	Reading Assign. SECTIONS	HOMEWORK SET **DUE**
1	General circuit element, charge, current	1.1 – 1.2	--
2	Voltage, sources, power	1.3 – 1.6	1
3	Resistance, Ohm's Law, power, dependent sources	1.7 – 1.8	2
4	Kirchhoff's Laws	2.1 – 2.3	3
5	Resistor combinations; voltage & current division	2.4 – 2.6	4
6	Dependent sources in resistive circuits	2.7 – 2.9	5
	NO CLASS –LABOR DAY	--	--
7	Nodal analysis	3.1 – 3.3	6
8	Nodal analysis, Mesh analysis	3.4 – 3.5	7
9	Mesh analysis	--	8
10	Linearity and superposition	5.1 – 5.3	9
11	Source transformations	5.4 – 5.5	10
12	Thevenin's and Norton's Theorems	6.1 – 6.4, 6.6	11
	Review Session #1 (7:00-9:00 pm; LILY 1105)	--	--
13	Thevenin's and Norton's Theorems (cont.)	--	12
	EXAM #1 (8:00 – 9:00 pm; CL50 224, EE 129, LILY 1105)	--	--
	NO CLASS – EVENING EXAM	--	--
14	Maximum power transfer	6.7	13
15	Inductance and inductors	7.1 – 7.2	14
16	Capacitance and capacitors	7.3, 7.5	15
17	Inductor/Capacitor combinations	7.4	16
18	First-order circuits: zero input response	8.1 – 8.3	17
19	First-order circuits: step response	8.4	18
	NO CLASS – OCTOBER BREAK	--	--
20	Linearity/Response classification	8.5 – 8.6	19
21	Waveform generation/Instabilities	8.7	20
22	Second-order circuits: LC undamped case	9.1 – 9.2	21
	Review Session #2 (7:00-9:00 pm; LILY 1105)	--	--
	EXAM #2 (8:00 – 9:00 pm; CL50 224, LILY 1105, PHYS 114)	--	--
	NO CLASS – EVENING EXAM	--	--
23	Second-order circuits: RLC source free case	9.3	22
24	Second-order circuits: RLC source free case or constant inputs	9.4	23
25	Second-order circuits: RLC with constant inputs	--	24
26	Op-Amp basics: dependent source models	4.1 – 4.4	25
27	Analysis of circuits containing Op-Amps	--	26
28	Thevenin/Norton equivalents for circuits with Op Amps	6.5	27
29	RC Op-Amp circuits	8.8	28
30	Complex forcing function	10.1 – 10.4	29
31	Phasors: Ohm's phasor law, KVL & KCL	10.5 – 10.6	30
32	Impedance/admittance of 2-terminal devices	10.7	31
33	Sinusoidal steady-state (SSS) analysis	10.8	32

34	SSS analysis (cont.)	--	33
35	Frequency response	10.9 – 10.10	34
36	Instantaneous and average power	11.1 – 11.2	35
	NO CLASS – THANKSGIVING VACATION	--	--
	NO CLASS – THANKSGIVING VACATION	--	--
37	Average power and effective value	11.3	36
	Review Session #3 (7:00-9:00 pm; WTHR 200)		
38	Complex power: reactive & apparent power; conservation of power	11.4 – 11.5	37
	EXAM #3 (8:00 – 9:00 pm; EE 129, LILY 1105, PHYS 114)		
	NO CLASS – EVENING EXAM		
39	Power factor improvement	11.6	38
40	Maximum power transfer	11.7	39
41	Review	--	40
	FINAL EXAM (*To Be Announced*)		

Appendix D Concept map showing relationships among studies and alignment of key findings to overarching research questions



VITA

VITA

NICOLE P. PITTERSON, Ph.D., M.Sc., B.Sc.

EDUCATION

Purdue University, W. Lafayette, IN, USA
PhD **December 2015**
Engineering Education
Advisor: Dr. Ruth A. Streveler
Major Courses Include:
Engineering Education Inquiry, Leadership, Policy and Change in STEM, Theories of Development and Engineering Thinking, Content, Assessment and Pedagogy, History and Philosophy of Engineering Education, Research Procedures in Education, Introduction to and Advance Qualitative Research Methods, Conceptual Change in Engineering, Race, Class and Gender in Engineering Education

Western Illinois University, Macomb, IL, USA
M.Sc. – Master of Science **2007 – 2009**
Manufacturing Engineering
Major Courses Include:
Process Quality Control, Automated Industry Production I and II, Work-cell Integration, Automatic Identification, Process Controllers, Programming using Microsoft Visual Basics

University of Technology, Kingston, Jamaica
B. Sc. Electrical and Electronic Engineering **2003 – 2007**
Major Courses Include:
Electrical Installation I and II, Electrical Motor Control, Electrical and Electronic Drafting, Electrical Blueprint Reading and Drawing, Solid State Electronics I and II, Applied Electronics, Electronic Communication, Digital Electronics, Electrical Principles I and II, Network Analysis I and II

RESEARCH INTEREST

Rigorous research in engineering education, difficult concepts in engineering, increasing students' conceptual understanding of electric circuits, promoting collaboration through active learning, developing and fostering communities of practice, design of learning environments and student achievement

RESEARCH ACTIVITIES

Research Assistant **2012 – Present**
School of Engineering Education, Purdue University

- Under the tutelage of Dr. Ruth Streveler on use of emergent process to effect conceptual change in engineering undergraduates.
- Collaboration with other research groups within the department on projects related to the development of communities of practices and the scholarship of integration.
- Development of coding framework for analyzing electrical engineering students using think aloud interviews.
- Analyze interview transcripts using a priori coding scheme to measure students' use of emergent language
- Collection of data through direct classroom observations, interviews, document analysis

Research Coordinator **2009 - 2012**
Waterford High School, Portmore Jamaica

- Investigation into the factors that causes increased dropout rates among Grade 10 and 11 students
- Development of strategies for identifying students at risk of drop out
- Development of students' academic progress reporting format

REFEREED PUBLICATIONS AND PRESENTATIONS

Streveler, R., **Pitterson, N.,** Ortega Alvarez, J,D., Hira, A., Rodriguez-Simmonds, H., (2015) *Learning about engineering education research: What conceptual difficulties still exist for a new generation of scholars?* Presented at the Frontiers in Education Annual Conference, October 24, 2015, El Paso, TX.

Pitterson, N., Streveler, R., (2015) *A systematic review of undergraduate engineering students' perception of the types of activities used to teach electric circuits,* Presented at the ASEE Annual Conference and Exposition, June 16 – 19, Seattle, WA.

Allendoerfer, C., Streveler, R.A., **Pitterson, N**., Perova-Mello, N., Clarke Douglas, T.S., Smith, K.A., (in preparation) *The long term impact of rigorous research in engineering education (RREE) program.*

Pitterson, N., Perova-Mello, N., Streveler, R., (review) *Electrical engineering students' use of analogies and metaphors.* IEEE Transactions on Education

Pitterson, N., Perova-Mello, N., Streveler (2015) *How engineering students talk about their knowledge of electric circuits,* Poster presented at Graduate Research Symposium, March 17th, Purdue University ***(Received honorable mention)***

Pitterson, N., Perova-Mello, N., Streveler (2014) *How engineering students talk about their knowledge of electric circuits,* Poster presented at Big 10 Grad Expo October 19, Purdue University

Streveler, R., Brown, S., Matusovich, H., Montfort, D., Herman, G., Adesope, O., **Pitterson, N.,** Perova-Mello, N., (2014) *Thinking about theories: Emerging results from secondary analysis of clinical interviews to assess conceptual understanding across several engineering domains.* Poster presented at NSF PI's Conference, Washington, DC

Pitterson, N., Streveler, R. (2014). *Increasing students' conceptual understanding of alternating current (AC) circuits: An application of Licht's model*. Paper presented at the 2014 ASEE Annual Conference and Exposition, June 15-18, Indianapolis, IN.

Pitterson, N., Streveler, R. (2014). *Actively constructing interactive engineering learning environments*. Paper presented at the 2014 ASEE Annual Conference and Exposition, June 15-18, Indianapolis, IN.

Streveler, R., Miller, R., Perova-Mello, N., **Pitterson, N**., Denick, D., Magana, A., Santiago-Román, A., Yang, D., & Fayyaz, F. (2014). *Talking about diffusion: Can word usage be an indicator of conceptual understanding?* International Conference of the Learning Sciences (ICLS), June 23-27, Boulder, CO.

Perova-Mello, N., **Pitterson, N**., Denick, D., Fayyaz, F., & Streveler, R. (2014). *Can "emergent language" serve as an indicator of conceptual change?.* Poster presented at AAAS Annual Meeting, February 13-17, Chicago, IL.

Streveler, R., Miller, R., Perova-Mello, N., **Pitterson, N**., Denick, D., Magana, A., Santiago-Román, A., Yang, D., & Fayyaz, F. (2013). Can "emergent language" serve as an indicator of conceptual change? Paper shared at EARLI Conference for Research on Learning and Instruction, August 27-31, Munich, Germany.

Dringenberg, E., Denick, D., Fayyaz, F., Nelson, L., **Pitterson, N**., Tolbert, D., Yatchmeneff, M., & Cardella, M. (2013). *STEM thinking in informal environments: Integration and recommendations for formal settings.* Paper presented at ASEE 2013 IL/IN Sectional Conference, April 6, Angola, IN.

PRESENTATION AND INVITED TALKS

Rochester Institute of Technology	October 1, 2015
College of Technology Research Seminar	April 16, 2015
School of Engineering Education Research Seminar	Nov. 20, 2014

AWARDS

- School of Engineering Education Outstanding Graduate Student Service Award **2015**
- Wilbert Nunez Award - Most Outstanding Performance in Electrical Power Courses **2006**

PROFESSIONAL EXPERIENCE

Purdue University, W. Lafayette, IN
Gifted Education Resource Institute

STEAM Labs Instructor **June – July 2015**

- Work with gifted students in Grades 8 to 11 to design and build a Rube Goldberg chain reaction machine.
- Introduce students to STEAM concepts through the use of innovative and real life examples.

Minority Engineering Department
Summer Engineering Project Lead **May – July 2015**

- Design and deliver electrical engineering projects to Grades 9 and 10 intent on introducing students to basic electrical engineering concepts and the engineering design cycle.

School of Engineering Education
Apprentice Faculty **Spring 2014**
Content, Assessment and Pedagogy

- Assisted first year PhD students with the design and delivery of curriculum project based on students' interest, met on a weekly basis with six students to give direct feedback on their work
- Assisted with the dissemination of information about alignment of content, assessment and pedagogical approaches to learning, suggested the addition of a new textbook and a lesson plan as part of the course design for the class.

Minority Engineering Department
Physics Tutor **2013 - 2014**

- Assist first year engineering students with physics assignments and exam preparation, during one hour sessions for eight weeks of the Fall and Spring semester.
- Supplemented lecture and laboratory sessions with four students on a weekly basis students in a one to one consultation format

Summer Camps Project Manager **May – August 2014**

- In preparation for their summer camps that spanned June 16th to August 8th comprising of students from grade 6 to 12, tasks included developing, reviewing, and finalizing engineering-related project curriculum appropriate for the particular grade level three weeks prior to the start of the camp.
- Meeting parents of the various groups of students (about 20 students per grade) at orientation to give presentation about the projects their children would be working on and what engineering skills we hope they would develop. Another presentation was made at the close of each camp to give parents insights on what the students did and how well they performed.
- Assigned, managed and supervised project assistants by visiting projects while being delivered and assessing students on competition day.
- Supervised student project assessment

- Work alongside instructors to develop material lists and source relevant information from the administrative staff of the MEP department.
- Provide weekly updates in senior staff meeting to instructors, counselors and MEP administrative staff.

Summer Camps Program Assistant **July 2013**

- Assist instructor with conduction of project design and dissemination of information to a group of 25 grade 9 students working on an electrical projects
- Assist two groups of five students with design and creation of project providing design revision and information about circuit operation where necessary.
- Helped instructor with the testing and assessment of students' design on competition day

Caribbean Vocational Qualification Unit, Kingston Jamaica
National Council on Technical and Vocational Education and Training **2011 – 2012**
Assessor and Item Writer

- Conduct practical assessment of students for certification in regional examination
- Developing practical examination scripts for levels I and II assessment
- Developing test items for levels I, II and III theory assessment

Waterford High School, Portmore Jamaica
Grades 10 and 11 Teacher of Electrical and Electronic Technology **2008 – 2012**

- Prepare students for the regional high school certification exam
- Supervise students' laboratory work for professional certification by governing body

Western Illinois University, Macomb, IL **2007 – 2008**
Graduate Assistant for the Department of Engineering Technology
Duties included:

- Preparation of laboratory activities for undergraduate and high school students – Electrical and electronics and AutoCAD
- Design programmable logic controllers for workshop production
- Stress testing of machine parts

Technical Information Consultant in the University Computer Support Service Department
Duties included:

- Provide technical support for email accounts, students accounts, computer systems

Kingston Technical High School, Kingston, Jamaica

Student Teacher and Lab Assistant **2007**

- Develop laboratory exercise, instruct and supervise students at work

Papine High School, St. Andrew, Jamaica
Student Teacher **2004**

- Team teaching of Grades 9 and 10 students

Jamaica Alcoa Company, Clarendon, Jamaica
Summer Intern **2005 and 2006**

- Preparation and update of machinery maintenance schedule
- Development of safety action plan for power systems division
- Conduct weekly inspection of generator room
- Develop cross sectional designs of motors and piston valves

PROFESSIONAL SERVICE

Graduate Student Representative
Engineering Education Graduate Committee, Purdue University **2013 – 2015**
- Work with committee members to inform departmental policies on proposed courses and other educational issues, admission of new graduate students, represent the voice and opinions of the graduate student body

Chair, Social Networking Committee **2013 – 2015**
Co-chair, Multicultural Committee
Engineering Education Graduate Student Association, *Purdue University*
- Organize one multicultural and one social event per month for graduate students to provide support and to engage them in broader diversity conversations with other departments on campus.
- Coordinated and planned two successive ENE Department Holiday Cookie Exchange Party for students, staff (administrative and academic), post-doctoral students and families.

Graduate School Recruiter at Professional Conferences **2013 – Present**
College of Engineering, *Purdue University*
- Engage underrepresented groups at College Fairs (SWE 2014, NSBE 2013, 2014 and *potentially 2015*, Big 10 Grad Expo 2014) to consider graduate programs at Purdue.
- Actively recruit and offer insights on graduate programs, funding opportunities and admissions process from a student's perspective
- Serve on four student panels for parents and HBIs visits in 2013 and 2014.

Co-chair, Awards and Recognition Banquet **2013 – 2014**
Black Graduate Student Association, *Purdue University*
- Organize recognition banquet, April 12, 2014 to showcase the achievement of black graduate students to various stakeholders
- Connected with corporate and university sponsors to raise funds for event
- Supervised sub-committees to decorate, advertise, design programme booklet and communicate with department heads of students, other student support organizations and the hotel
- Currently serving on committee in an advisory role for the upcoming banquet on April 11, 2015

Mentor
Minority Engineering Program/National Society of Black Engineers **2013 – Present**
Purdue University
- Work with the MEP/NSBE to fulfill their mission of supporting black and other minority students by connecting them with graduate students as mentors
- Served on committee that paired 10 undergraduate students with seven graduate students

- Currently mentoring one undergraduate student through bi-monthly one on one meetings aimed at helping student with current projects or finding support through student organizations or other graduate students.

Graduate Liaison
Caribbean Students Association, *Purdue University* **2013 – 2014**
- Work with undergraduate Caribbean students to connect with graduate students, faculty and staff to build their professional network
- Assist in the planning of monthly dinner meetings with a group of eight undergraduate students, seven graduate students, two professors and two staff members aimed
- Fostering communication among the group through bi-monthly emails

Volunteer
Reviewer for Journal of Engineering Education **December 2014 – Present**
- Reviewed appointed journal paper and made recommendations for revision and acceptance

Volunteer
International Weeks of Welcome, International Students and Scholars, **2013 - Present**
Purdue University
- Work with immigration counselors to help new international students in the Spring 2013, Fall 2014 and Spring 2015 cohort enroll and register their MyPurdue accounts such as updating personal information, inputting emergency contacts, scanning their immigration documents, speaking with members from the Purdue Student Health Centre and getting their student identification cards made.
- Provide support for new international students at the Weeks of Welcome orientation session in accessing pertinent resources related to starting their course of study at Purdue (students were 25 to a group per session with approximately six sessions per day over a two week period in the Summer and Spring).

Volunteer
BOILER Outreach, Understanding Teamwork, , **2013 – Present**
International Students and Scholars
Purdue University
- Work with community personnel on service projects such as after school homework programs, volunteering at the local animal shelter (Almost Home Humane Society), book sorting at the West Lafayette Library and food packaging at the Food Finders Bank.

Volunteer
Reviewer for Frontiers in Education **2013 – Present**
- Reviewed 12 papers and recommend acceptance/rejection for annual conference

Volunteer
Reviewer for ASEE Educational Research Method and Student Division **2012 – Present**
- Reviewed papers and ranked for the 2012 Student Division Best Paper Award
- Reviewed papers and recommend for acceptance/rejection for annual conference

Volunteer **2014 – Present**
Reviewer for NARST

- Reviewed papers for Strand 1, part E and recommend acceptance/rejection for annual conference

Volunteer
Waterford High School, Portmore Jamaica
Sports Committee, 2010 – 2012
- Providing guidance and seeking sponsorship for athletes in various sporting activities

Assistant Coordinator
Graduation and Co-Curricular Committee, Waterford High School 2010 – 2012
- Promotion of co-curricular and service organizations
- Preparing and assessing students for graduation and post high school engagements

Mentor
Western Illinois University TEAMLEAD 2007 – 2008
- Working with high school students in the selection of service organizations to get involved

Volunteer
International ambassador program 2007
- Engage international and local students in cultural conversation

Volunteer
University of Technology, Jamaica Editorial committee 2005 – 2007
- Review students' union yearbook, soliciting of articles and department reports

Faculty of Education and Liberal Studies Student Services Representative 2004 – 2005
- Working with students to resolve academic and other social issues with Faculty Administrators

PROFESSIONAL MEMBERSHIPS

- American Society of Engineering Education (ERM, ECE, Student and MIND divisions) **2012 – Present**
- Women in Engineering Program **2012 – Present**
- Graduate Mentoring Program **2012 – Present**
- National Association of Black Engineers (Chapter, Regional and National) **2012 – Present**

CERTIFICATIONS/LICENSURE/TRAINING SEMINARS

- CITI training required by Purdue University Institutional Review Board for Ethical Research **2012**
- Fire, first aid and safety training certified **2011**
- Level I and II certified in E-Learning methods and approaches to class and course delivery **2010**