EXPLORING THE EFFECTS OF COMPUTER SIMULATIONS IN DEVELOPING CONCEPTUAL UNDERSTANDING OF GRADE 10 LEARNERS IN DIRECT CURRENT CIRCUITS

By

Rudolph Gadzikwa

209538457

Submitted in partial fulfilment of the academic requirements for the degree of Master of Education (Science Education) in the School of Education

School of Education,

College of Humanities,

University of KwaZulu-Natal,

Supervisor

Professor Nadaraj Govender

November 2018

Abstract

Physical sciences are perceived as difficult by learners in high school in South Africa and beyond. One of the challenging topics in Physical sciences is the topic of electricity. The Physical sciences National Further Education and Training examiners' reports over the years have highlighted that learners in this topic scored less marks compared to other topics in national examinations. The researcher was then curious to find out why learners have difficulty with the topic of electricity. The project intends to explore if there are any better ways to learn the topic of electricity. In the process, the researcher intends to make possible recommendations on how best to plan for and teach the topic of electricity.

A study was then undertaken at a school in KwaZulu-Natal to determine if the use of computer simulations can enhance the understanding of this topic of electricity. First, all participants were exposed to traditional instruction and then a conceptual test was administered to determine the alternative conceptions they had on the topic of electricity. After the test, participants were split into groups. One group was treated to computer simulations and another group continued with traditional instruction. During the administration of the computer simulations, video data were collected to examine the behaviour of learners during an intervention with computer simulations. In order to understand the depth of the alternative conceptions and to have an insight into learners thought processes, interview data were also collected to triangulate the concept test data and video data. Therefore, this study followed a mixed methods design where quantitative data and qualitative data was collected at the same time. Quantitative data were collected using a concept test and qualitative data were collected using video and interview schedules.

An analysis of the test scores before implementation of computer simulations showed that participants held a number of alternative conceptions on the topic of electricity. A post-test analysis showed that the group exposed to computer simulations had a significantly high average score compared to the group that continued with traditional instruction. Details of the reasons for the improved scores after using computer are discussed in detail in this report. One of them, among others, is the greater visualisation that PhET simulations bring when analysing direct current circuits. Teachers and curriculum developers would gain a lot of insight on how to plan and teach the topic of electricity more effectively by going through this research report.

Declaration

Work in this dissertation was carried out in the School of Education, Science and Technology cluster at the University of KwaZulu-Natal under the supervision of Professor N. Govender.

Ethical Clearance was granted for this study by University of KwaZulu-Natal Research Office. The ethical clearance approval number is: HSS/1529/013M

I, **Rudolph Gadzikwa** declare that:

(i) This study represents original work of the author except where otherwise indicated and has not been submitted in any form for any other qualification to any tertiary institution.

(ii) Ideas, concepts and opinions from other sources are acknowledged properly in text as well as the reference section.

(iii) Data, sources, pictures and graphs are the original work of the researcher and if they not, they are duly acknowledged.

(iv) An errors by commission or omission can only be attributed to me and not participants or the supervisor of this research.

Signed ____________________ Date____________________

R Gadzikwa

209538457

March 2019

Acknowledgements

Doing research is no easy task. Putting together these chapters and making sure everything is in place is again no easy task. Let me thank therefore my supervisor Professor Nadaraj Govender whose expert advice and guidance made this project possible. He never gave up on me. My greatest gratitude goes to him.

Let me thank high school teachers who made it possible to realise this project through piloting exercises so that we come with a sound and reliable Electricity Concept Test (ECT). The research required that we interfere with the normal running of the school. I would also want to thank them for contributing towards the construction of a sound Electricity Concept Test (ECT) by checking appropriateness of language and content. I am sincerely grateful to them.

Let me thank the grade 10 participants for their enthusiastic participation in the project. They came with young and curious energy that made gathering of data manageable. They did not show fatigue and boredom in this demanding research project that took them off their normal school program. They wholeheartedly devoted to writing the ECT and participating in long interviews. I am truly grateful. It is my hope they will gain from this research and realise the value of their contribution in understanding the topic of electricity better.

List of Tables

List of Figures

Abbreviations and Acronyms

AC	Alternating Current
CB	Circuit Builder
CAPS	Curriculum Assessments Policy Statements
CCK	Circuit Construction Kit
CHAT	Cultural Historical Activity Theory
DBE	Department of Basic Education
DC	Direct Current
DIRECT	Determining and Interpreting Resistive Electric Circuits Test
DST	Department of Science and Technology
EET	Electricity Concept Test
ETA	Electricity Design Automation
FET	Further Education and Training
GET	General Education and Training
LOI	Language of Instruction
MCQ	Multiple choice Questions
NCS	National Curriculum Statement
NCS	National Curriculum Statement
NDP	National Development Plan
OBE	Outcome Based Education
PhET	Physics Education Technology
SPSS	Statistical Package for Social Science
QUCS	Quite Universal Circuit Simulator

Dedication

I dedicate this research to my late father and my mother for their continued support in my educational endeavours. I also dedicate this research to my children Tatenda, Rukudzo and Chiedza for their patience in taking time away from them in persuit of the project. Thank you.

Table of Contents

Chapter 1

1.1 Introduction

This chapter starts by giving the background to the research topic. This background description gives the context in which the study was derived. This is then followed by a description of the problem being studied. A brief theoretical framework is then considered to show how the study was designed. Aims and objectives of the study are discussed and finally, the research methodology used in the study will be briefly described.

1.2 Background to the study

The basic function of any society is based on the ability to extract energy from the environment, to, transport people, feed citizens trade with other societies, to communicate, motivate and maintain the health of its citizens. The industrial revolution of the 19^{th} century witnessed unprecedented growth in innovation and technology and this brought massive improvements in the manufacturing of goods and services and the impact is still felt today. Demand for such goods and services have led to ways to deliver these services to citizens efficiently, which places a high demand for people with scientific and mathematical skills to complement the ever increasing demand for industrial growth and innovation as shown by the economic trajectory of most developed nations.

For almost 200 years (1750 to 1950), Britain, Germany, USA and France have had the greatest discoveries, inventions and innovations and their economies have depended heavily on science and technology for their development (Dosi, Freeman & Fabiani, 1994). These nations lead in automobile production as well as aerospace innovations. Also notable in these developed nations, is the way they have embraced information technology. The advent of the computer and the internet has improved connectivity. Software has also improved since the invention of the computer. As a result, goods have been produced much faster and more efficiently. All this happened due to an increased understanding in material science. An increased understanding of material science has led to improved rail, road and air travel. This has led to an increased exchange of goods and services between nations. As a result, global trade and investment has greatly improved.

Food security is one important aspect of any nation. Science and technology has also increased options in which crops and animals can be grown faster and reach the markets beyond borders. Biotechnology has played a major part in agricultural production. Recombinant crops in agriculture have improved food production and provided citizens with a stable supply of food. Biotechnology has notably improved the area of genetic engineering which had an impact beyond the laboratory such as criminal forensics. It is no doubt that in the 21st century, science and technology are now seen as sources of national power and security. Nation states have designed deliberate science and technology policies.

South Africa has not been left out of the race in the advancement of science and technology. National economic demands and the need for global competitiveness have made it imperative for South Africa to pursue science and technology initiatives. The establishment of the Department of Science and Technology (DST, 2016) is a clear demonstration that the country has a definite policy to address the issues of science and technology. A brief overview of the department shows four active projects being undertaken by the department. These are technology innovation, bio-innovation, research & development and socio-economic innovation partnerships. Technology innovation deals with space science, energy issues, robotics, nanotechnology and indigenous knowledge systems. Bio-innovation department deals with drugs and vaccines, research and development caters for infrastructure and knowledge economy. The socio-economic innovation partnership project serves to identify niche technological interventions in relation to other organizations (DST, 2016). Other departments that need the input of science and technology include the Department of Health, the Department of Agriculture, and the Department of Defence. All these departments need specialised technicians such as medical doctors (Health), crop and animal scientists (Agriculture) and pilots (Defense and Aviation). An integration of these departments produces a robust economy capable of addressing food security, national security and economic growth which then addresses trade imbalances, which in turn improve self-reliance on goods and services in the country (Muwanga-Zake, 2001)

In order to pursue careers in health, agriculture, defence and infrastructural development, one must take studies in medicine, veterinary science, crop science, soil science, engineering and aviation. These courses require high literacy and a good competency in high school mathematics, Physical sciences, biology and geography. Central to these studies, is a good conceptual understanding in physics and chemistry which are all under the Physical sciences in the South African school curriculum. It is therefore important to study Physical sciences in order to realize South Africa's national strategic goals. In the National Curriculum Statement for Physical sciences (Education, 2011), it is stated that one of the goals for studying the subject was to contribute to economic development, improve social well-being and contribute to sustainable environmental management. Passing Physical sciences at school is therefore imperative. However, as will be discussed below and in more detail in chapter 2, passing Physical sciences is still a challenge in South Africa.

Demand for people with technical and scientific skills is high in South Africa. This has placed pressure on schools to produce high school graduates with good grades in mathematics and Physical sciences. As explained above, the importance of doing Physical sciences cannot be over-emphasized. However, very few learners take Physical sciences in high school and when they do, very few pass with good grades. The low pass rate in Physical sciences needs interrogation. Let us look at why there is lack of enthusiasm among learners to take Physical sciences in high school.

There are several factors why learners do not choose to do Physical sciences in high school. The first reason is the dominance of traditional instruction. The traditional model of instruction includes chalk and talk, lecture model and teacher centred approach (Taber, 2011). Secondly, Physical sciences is presented to learners as a collection of dry incoherent facts (Zacharia, 2003). Thirdly, science classes are also accused of lacking spontaneity, creativity and innovation. Fourthly, Physical sciences is perceived abstract and therefore difficult. This perception of Physical sciences being difficult has been subject of research for many years which indicates this is a perennial problem that needs attention. Learners, for these reasons and many others explored in chapter 2, shows the problem of low enrolment is also compounded by failing Physical sciences in national examinations. One of the factors cited above, is lack of innovation and creativity in the classroom (Hodson, 2008). Traditional instruction is therefore a default method used by many teachers that disadvantages learners. Innovative classrooms now include computer software programs such as PhET (Physics Education Technology) simulations that are in synchronisation with a technologically savvy generation. Besides a lack of embracing technology in the classroom, a review of research shows that embracing technology in the classroom in addressing alternative conceptions is still a challenge (Akilli, 2007).

A concept is considered central and important to the learning of science and it is defined as an organized unit of thought which can fit into different mental categories (Tas, Cepni, & Kaya, 2012). Teachers and educators struggle with alternative conceptions. Some scholars (Guzzetti, Snyder, Glass, & Gamas, 1993) even labelled them tenacious and resistant. Why these alternative conceptions are considered tenacious? One of the many reasons is that learners bring to class their naïve beliefs about phenomenon. They derive these beliefs from their everyday experience and this is compounded by textbooks and teachers who also have an unclear conceptual understanding about certain topics in Physical sciences. In order for a concept to be effectively understood, it must be similar to the one that scientists have (Potvin, 2013). Those that do not fit into the scientific model are known as alternative conceptions, erroneous ideas, preconceptions, personal models of reality, spontaneous reasoning and intuitive beliefs (Bahar, 2003). Some of the research (Guzzetti et al., 1993) used these misconceptions referring to them as naïve conceptions that learners have. However, this term has been criticized for not respecting the knowledge of the learner. This is because it is reasoned that it is not the fault of the learner to misunderstand a concept but rather the way they view the world around them and the way they are taught. This study therefore, will use the term alternative conceptions to describe misconceptions (Driver, 1989).

Many factors have been proposed as central to the tenacity of alternative conceptions and shall be considered in detail in chapter 2. School leadership with a low appreciation of science is one of them. It is thought school leaders do not provide an environment, strategy and deep insight on how to improve science scores (Wambungu and Changeiywo, 2008). Other barriers include the quality of teachers teaching Physical sciences, relevance of content to everyday life, lack of practical work, nature of the content of science and lack of use of technology as a teaching tool. The tenacity of alternative conceptions in Physical sciences is well documented and several strategies are recorded in research to confront them and one of them is the use of analogies to address alternative conceptions.

A study (Gilbert, Bulte & Pilot, 2011) explains analogies and how they are used in science education. Analogies will be described in more detail in chapter 2. Their use in the classroom have been extensively recommended as effective in confronting alternative conceptions. Another attempt is the use of hands on practical activities and visual aids. These included the problem solving approach, the mastery approach, multiple representation approach, conceptual modelling, concept mapping and analogies. However, despite all these innovations, poor conceptual understanding still remains a problem. What is important to note is that there has not been a strategy that is a panacea to the problem of alternative conceptions. One of the ideas indicated above are that learners of the current generation are exposed to computers and smartphones on a daily basis. Perhaps it would be useful to explore using computers and smartphones to enhance learning of Physical sciences. One of the latest software that has been developed that has found its way into the science classroom is computer simulations.

A computer simulation is defined as a representation of reality and an imitation of the real thing (Blake & Scanlon, 2007). Their interactivity makes it possible for one to change variables and explore scientific phenomenon through inquiry. One main advantage is they enable visualization. This means learners are able to see the invisible. Computer simulations are a modern way of engaging in education, especially in a generation which is surrounded by technology. Computer simulations have been used in the classroom to address alternative conceptions in many different topics of science. Physics education technology (PhET) simulations were developed by a physics team at the University of Colorado and they cater for a wide variety of topics. A simulation used in this study is the PhET direct current construction kit. This is also known as the circuit construction kit (CCK). This kit enables learners to construct any circuit of their type and observe the behaviour of current in relation to potential difference, resistance and other circuit variables. They show the movement of charge, the brightness of the bulb and make the necessary computations. This kit is described in more detail in chapter 2. One disadvantage of practical activities in the topic of electricity is that learners cannot see what is happening inside the conductors and hence, make erroneous assumptions about the behaviour of current and other circuit variables. Advantages of PhET simulations shall be discussed in more detail in chapter 2. However, at this point, it is important to note their numerous advantages were identified as useful in confronting alternative conceptions in the topic of electricity.

1.3 The problem

The topic of electricity in Physical sciences presents a challenge to both teachers and learners. Although this challenge cuts across many grades and even into university, there are reasons why this study chose grade 10. Firstly, grade 10 serves is the introductory phase of the FET phase in high school. Secondly, getting to know the problems of the topic and possible intervention strategies at this stage could be helpful. Thirdly, failure of grade 12 learners in Physical sciences cannot be blamed squarely on them. It could be they did not understand the basic concepts in grade 8, 9 and 10. Hence, studying alternative conceptions in grade 10 will be helpful to establish baseline problems of the topic before learners reach grade 12. An examination of embryonic literature on alternative conceptions (Freddette & Lockhead, 1980; Osborne, 1983; Riley, Bee & Mokwa, 1981; Shipstone, 1984, 1988) reveals that for decades learners have too many alternative conceptions on the topic of electricity. Details of these alternative conceptions are found in chapter 3 and 4. It is important, at this stage, to highlight that most learners do not understand the behaviour of current in relation to other variables such as potential difference and resistance. My observations when teaching the topic of electricity is that most learners are keen to identify a formula and make substitutions without a deep understanding of the underlying scientific processes and concepts. This indicates a lack of qualitative understanding of the topic. This over-emphasis on Ohm's law and algebraic manipulations are some of the problematic issues investigated in this study. One of the findings described in the study, which also came as a surprise, was the erroneous thinking that a battery is a source of power. This alternative conception was further reinforced with thinking that a battery goes flat because all the charges have been used up. Research also exposed participants thinking that current is a primary concept and that potential difference and resistance are dependent variables. Detailed results of the study will be explored in more detail in chapter 4. This study explores these kinds of alternative conceptions and uses computer simulations to see if it is an effective tool to confront them.

1.4 Statement of the problem

Learners in high school struggle to pass Physical sciences. They have difficulty understanding topics such as electricity, forces, work, energy and power. The topic of electricity as reported above (DBE, 2016) presents the greatest challenge as most learners have more alternative conceptions in this topic. This problem is compounded by lack of innovative teaching methods as most teachers rely on traditional teaching approaches such as chalk and talk. This study investigates a teaching approach of using computer simulations to see if they have an effect in understanding in the topic of electricity.

1.5 Theoretical framework

The project design is informed by Vygotsky's social constructivism as well as Hewson's conceptual change theory. Conceptual change theory emphasizes that for conceptual change to take place, learners should be dissatisfied with the current concept. The new concept being introduced must therefore be plausible, intelligible and fruitful (Posner, Strike, & Hewson, 1982). As will be explained in more detail in chapter 3, a conceptual test will be given to learners to check their baseline understanding of concepts in the topic of electricity. The aim is to indicate to learners which alternative conceptions they have and challenge their current understanding. Computer simulations are used to expose their erroneous thinking and a post-test is then used to establish if there has been any conceptual change. Social constructivism (Vygotsky, 1978) emphasizes that learning takes place from the social to the individual, that learners can construct their own knowledge and a teacher can only facilitate. This framework helped design conditions in which participants would experiment with computer simulations. Some of the conditions are working in groups, and sharing of skills and ideas while exploring computer simulations. Effectiveness of these theoretical lenses shall be evaluated against evidence gathered in chapter 4. As indicated above, in order to identify the level of alternative conceptions before and after intervention with computer simulations, quantitative data were collected using a questionnaire. Social constructivism was used to design qualitative data instruments such as interviews and video recordings. This would enable the researcher to check how participants behaved around computer simulations. Therefore mixed methods design was used. More details on this research design are found in chapter 3.

1.6 Rationale for the study

The researcher investigated the school he was teaching. This school fell under quintile 2. This means it was a non-fee paying school. Most of the parents in the school are low income earners. Learners at the schools were exposed to highly trained teachers and they had a moderate understanding of computers. This school is situated in a semi-urban area but cannot be classified as a rural school. The pass rate in the school was low overall and much lower in Physical sciences and mathematics. Hence, the school was classified as a low performing school. The need to investigate the low pass rate in Physical sciences and ways to intervene were necessary. Not only will results and analysis inform pedagogy, but improved teaching methods of the topic which are research based could be beneficial. The initiative to undertake this project was also motivated by the idea that an international review of literature shows that most studies on alternative conceptions came from American and European countries with few from the African context. Bernstein (2005) pioneered research in the use of computer simulations in the classroom in South Africa. This was followed by other scholars (Govender, 2012) who investigated the effect of computer simulations in understanding photo electric effect and (Mhlongo, Kriek, & Basson, 2011) who investigated the effect of computer simulations in understanding simple DC circuits. One extensive research was done by Dega (2012) in Ethiopia. This shows that computer simulations, as an educational tool, are not extensively researched in Africa in general and South Africa in particular. This study will widen the context of alternative conceptions in the topic of electricity by making a contribution to the South African context especially describing high schools. Most studies investigate university contexts. Studies (Moosa, 2015; Ramnavain & Moosa, 2017) investigated understanding of DC circuits using computer simulations in grade 10 in the Gauteng province of South Africa and did not focus in other provinces. Kotoka and Kriek (2014) used computer simulations to investigate the topic of electromagnetism on grade 11 learners of the Mpumalanga province. Since this research will be conducted in KwaZulu-Natal, it would be interesting to gain insight on a different context. Again, this research will be unique in that it uses mixed methods design yet similar research in the South African context used quantitative or qualitative design only. One such was done by Moosa (2015). Another study (Kriek & Basson, 2009) investigated teachers using computer simulations on the topic of DC circuits. Use of technology in the classroom is a fairly recent teaching strategy, especially computer simulations. Computer simulations are widely used at university and rarely used in high school as a learning tool in South Africa. A study by Mautjana

(2015) investigated grade 12 learners understanding of DC circuits without the use of computer simulations. This makes this study significant in adding to the rare literature on computer simulations as an intervention tool in understanding DC circuits. Most of the studies were investigating the effectiveness of analogies in secondary schools and rarely did they talk about computer simulation. This is a gap that this study intends to fill as computer simulations are rarely used as an intervention tool to improve instruction in Physical sciences. Additionally, teachers also do not research their own practice. In study, the teacher happens to be researcher. This study might add value by motivating teachers to research their own practice. Research on alternative conceptions on the topic of electricity started long ago and the topic is has matured but is not exhausted. However, there is still a possibility that more alternative conceptions can be found in the study, and therefore contribute more to the field physics education.

As indicated above, alternative conceptions are tenacious. A focus on grade 10's alternate conceptions of electricity makes a unique contribution to literature as most studies are spread in their sample. Most range from high school to university in their samples and questions are not specific to grade 10. Textbooks are not written with a misconception focus in their approach. This study might highlight the need for textbooks to be written with an awareness that learners have alternative conceptions. Since computer simulations are recent innovations, this study will be invaluable, especially in the South African context. These motivations highlighted above were then used to develop the following aims and objectives of the study.

1.7 Aims and Objectives of the study

Although authoritative research has been completed on the topic of alternative conceptions on the topic of electricity, especially an extensive study by (Engelhardt, 1997), it will be useful to see if these alternative conceptions will be reproduced if similar questions and similar questionnaires (modified to suit grade 10) are used. Questions will be identified that would expose the alternative conceptions of the grade 10 learners. These would be further analysed in chapter 4 to check if there are similar patterns with prior research or there are new emerging patterns.

1.8 Research questions

To accomplish the aim, the following two research question were formulated:

What are Grade 10 learners understanding of electricity concepts prior to the implementation of computer simulations?

In order to answer this research question, a questionnaire with alternative conceptions is administered to participants. After the prevalence of alternative conceptions are measured, one group will receive the computer simulation intervention and another will not receive the intervention. The same questionnaire will be used after the computer simulations have been administered. This is measured by answering the following research question:

What are Grade 10 learners understanding of electricity concepts after the implementation of computer simulations?

This research question will also be complemented by the development of hypotheses to see if there is a significant difference in scores between the pre-test group, the control group and the post-test group. A t-test will be used to analyse data by comparing if the difference in means of the groups is significant.

Behaviour of learners during an educational experience is important in informing how we should design the curriculum in order for effective instruction to take place. It is therefore important to observe the behaviour of learners and how they would engage with technology. As noted earlier in this chapter, theories inform classroom discourse however, computer simulations are a new technology in the classroom. Observing behaviour during experimenting with computer simulations might give important insight on learning with technology. This might help in revising theories to inform classes that use computer simulations often. To help in this endeavour, the following research question was formulated.

How do learners in Grade 10 engage with computer simulations activities about electricity?

There are certain things that the conceptual tests would not be able to obtain from learners such as the way they think. Learners get answers wrong but we are unable to know why, especially from a questionnaire. Understanding the thinking patterns of learners assists in the formulation of effective pedagogy. Interview questions were then formulated as a follow up to the following research question:

Why do Grade 10 learners engage with computer simulations on electricity the way they do?

1.9 Research Methodology

As will be described in more detail in chapter 3, the first two research questions gather quantitative data and the last two gather qualitative data. This means no one method will adequately answer the research questions. This means that the quantitative approach or qualitative approach alone will not be adequate to address these research questions. Hence, a mixed methods research was appropriate to answer these research questions. A questionnaire was then developed to gather quantitative data and an interview schedule were then developed to help gather these data and this was accompanied by observational data gathered by use of a video. Reliability and validity of these instruments will be discussed in more detail in chapter 3.

1.10 Conclusion

Although this introductory chapter briefly looked at the contextual background, statement of the problem, the rationale for the study, the theoretical framework and aim of the study, more detailed chapters are to follow in this report. A detailed description of literature on some of the aspects examined in this introductory chapter will be in chapter 2. Chapter 2 will give an extensive review of the main ideas and themes concerning alternative conceptions and computer simulations on the topic of electricity. Chapter 3 will look at the research methodology in detail describing why mixed methods research is more appropriate for this study and how variables were controlled. Chapter 3 also discusses sampling method, sampling strategy, data collection instruments, reliability, validity and ethical issues of the study. Chapter 4 will describe results of the research for both the quantitative and qualitative instruments. Chapter 5 will discuss the findings, recommendations and conclusions of the research.

Chapter 2

Literature Review

2.1 Introduction

This chapter deals with a review of literature on computer simulations. To give a solid background to the chapter, a brief discussion of the importance of science education is discussed. This part illuminates the critical relevance of science education in general and Physical sciences in particular. A discussion on why learners do not take Physical sciences as a subject then follows. This section describes both national and international perspectives on why there are low enrolments in physics and Physical sciences. This is followed by general and specific barriers to learning of physics. Sources of alternative conceptions in the learning of Physical sciences are then discussed with special attention to how they affect conceptual understanding.

Traditional instruction has dominated science instruction for a long time. Alternative methods and strategies to teaching physics and Physical sciences have been developed over the years. These instructional innovations to aid in conceptual understanding are then debated with a special focus on justifying the use of computer simulations in the classroom. These justifications include among other things, a wide review of the literature related to the merits and demerits of computer simulations as an instructional innovation. Detailed descriptions of alternative conceptions that learners have about electricity are then considered. This is followed by a review of studies that specifically focused on simulations related to the topic of electricity. The chapter also discusses theoretical frames that have been used to inform studies using educational technology which includes constructivist theory, information processing theory, activity theory, systems theory and conceptual change theory. The topic ends with a justification why constructivism and conceptual change theory were used to inform this study.

2.2 Relevance of science education

Scientific endeavours span centuries from early Greek civilization to date and these scientific endeavours have had a fair share of controversies. They have always challenged conventional thinking of contemporary time. One remarkable character in history of science is Galileo. Brecht, Vesey and Vesey (1974) details how the discovery and use of a telescope by Galileo revolutionised the way contemporary scientists of his generation viewed and perceived the solar system. At the time, when the world had a poor understanding of the universe, Galileo was almost hanged for suggesting the earth was round and that it was the earth that rotated around the sun and not the sun rotating around the earth. He stood trial for such radical scientific ideas (Wiens, Graham, & Kozak, 2008). A few centuries later, Europe underwent the industrial revolution and the contribution of science was immense during the industrial revolution. Nearly every aspect of society was transformed. From print media, transport, defence, medicine to food production (Dosi, Freeman & Fabiani, 1994). Scientific ideas were part of this social transformation. In the 19th and 20th century, scientific developments improved the speed and volume of production. Technological developments were now synonymous with national security and power. Therefore, each nation state has seen it imperative to have a strong scientific base in terms of research and development. Critical in this, is a citizenry that has a high mathematical and science literacy and central to this, is the subject of Physical sciences. The South African curriculum, has two disciplines of Physics and Chemistry combined to form Physical sciences. Many tertiary degrees in science such as engineering, medicine, aviation, agriculture and defence are dependent on the understanding of this subject.

2.3 Importance of Physical sciences

Passing Physical sciences in the national examinations in South Africa is important. Industries mentioned above need people who have passed mathematics as well as Physical sciences. The Curriculum and Assessment Policy Statement for Physical sciences (Education, 2011) clearly states that the subject is critical in economic development, social well-being, sustainable environmental management and disease prevention.

This is augmented by the National Development Plan (NDP, 2011) which clearly states the invaluable contribution that science and the study of Physical sciences in particular, would have on national development. This document envisions that the country needs to effectively fight diseases, provide citizens with access to computers and cell phones, and expand infrastructural development. Technological development is not left out of this vision. Prime value is put on economic development which is premised on technological development. This is intended to increase the quality of life of people. In order to achieve this, the NDP (2011) proposes that investment in quality education of youth is essential. This includes quality education in mathematics and science. Political pressure has also mounted due to comparative studies (Mallis, Martin & Foy, 2007) which places South Africa as one of the lowest performing countries in mathematics and science. The increased pass rate locally and internationally is therefore imperative to put South Africa ahead in mathematics and science literacy. However, there are a few challenges hampering this initiative. There is a low enrolment for Physical sciences nationally in South Africa and learners fail the subject. In fact, the school that the researcher is based at was rated as an underperforming school by the Department of Basic Education's UThukela District in the year 2011, 2013 and 2014. Several factors have been identified resulting in a low enrolment and pass rate in Physical sciences.

2.4 Causes of low enrolment and low pass rate of Physical sciences

Factors that affect low enrolment and the low pass rate of Physical sciences in high school are related. These factors can be split into those that affect the whole school and those that are subject specific. General factors impacting on the pass rate include school leadership, the quality of teachers, teaching strategies, curriculum policy, and the resistance to educational reform, contact time, the size of the school, home culture, quality of textbooks, and the language of instruction. Assessment strategies also contribute to low enrolment. These factors are considered below.

There is lack of instructional and transformational leadership in South African schools (Mergerndoller, Bellisimo, & Maxwell, 2006; Taylor, 2007). The most problematic schools were found to have inefficient work habits and a low expectation on performance. In a positive and recent development in educational reform in South Africa, promotional posts which include principals, deputy principals and head of departments have been created and reserved for educators with science degrees (Taylor, 2007). This is a recognition that school leadership with a poor appreciation of science has affected the pass rate in mathematics and Physical sciences. Some schools do not have a laboratory. This is a clear indication that learners are not exposed to science experiments and hence, performance in the subject is affected. Encouragement by school management to engage in science extra-curricular activities such as Olympiads and science clubs can enhance interest in Physical sciences. These initiatives can be facilitated by school administrators with an insight into how to learn science. This lack of insight into how to manage science learning is fuelled by unqualified science teachers who are in contact with learners every day.

Some teachers are not qualified to teach the subject. This means that they lack the adequate content knowledge required to make learners pass. Lack of content affects confidence in which a lesson is delivered and this affects learning outcomes. Teachers project perfectionism when teaching the subject (Waks, 1994). In turn, perfectionism intimidates learners as they may think that in order to pass and understand physics, one should not make mistakes. This scares away learners who are curious and want to try things on their own (Hodson, 2008). Making mistakes is part of learning and some teachers lack training in this. Primary and elementary school teachers add to this problem by laying a poor foundation for learning science. Science in primary school is taught in concrete style to facilitate learning, and a concept taught in this fashion becomes hard to remove when they reach high school. In a study by Zacharia (2003), it was discovered that primary school teachers do not teach science with enthusiasm. This study found out that primary school teachers use less creative approaches to teaching science such as chalk and talk. This negative attitude and lack of motivation causes learners not to choose Physical sciences when they reach high school.

In the traditional setting of teaching, the teacher is the centre of instruction. Traditional teaching is also lecture based where learners take on the role of listening (Gunstone & Tao, 1999; Jimoyiannis & Komis, 2001). Additionally, traditional instruction is also based on textbooks and demonstration and has been recorded as an ineffective teaching method (Wells, Hestenes & Swackhamer, 1995). Chalk, board and talk are the essential resources of this approach and this makes science unattractive (Taber, 2011; Zacharia, 2003). Classrooms are still rigid, bureaucratic, clumsy, linear and traditional in approach (Akilli, 2007). Hence, science education initiatives which use a traditional approach have been perceived as less able to address alternative conceptions. What is the other picture of science presented by teachers in the classroom?

Teachers present science as isolated dry list of facts which are not relevant to everyday life. Presenting a science that is not contextualized and isolated leaves learners with a deep sense of frustration and confusion (Taber, 2011). It is suggested that teachers should expose learners to market demands as well as career prospects when they graduate and other contextual awareness surrounding the learning of the subject which they will face when they graduate (Pey-Tee & Subramaniam, 2011). This approach to science as relevant to community and national development initiatives motivates learners. Contemporary society at large and learners in particular, are immersed in technology. Computers and smartphones are found everywhere nowadays. They are highly flexible and interactive where teachers can creatively use them in the classroom to enhance the understanding of scientific concepts. Recognising this paradigm shift can transform science pedagogy (Akilli, 2007). It is well documented that poor pedagogical skills results in poor performance by learners (Bahar, 2003; Mallis et al; 2007; Taber, 2011). All these ways in which science is taught and approached create a particular perception in learners.

Learners perceive science as difficult and abstract (Kelly, Bradley, & Gratch, 2008). This perception places a psychological block in learners and this affects their performance and eventually enrolment. Roth and Lee (2003) assert that science education is designed in such a way that it is accessible to only a few in society such as the upper middle class. This perception has reinforced the assumption that science knowledge is only available to the elite. Another assertion is that science require a high level of intelligence and for one to succeed in science, they must possess special mental skills that are above the abilities of an average person (Roth & Lee, 2003). This has made science an exclusive and inaccessible enterprise. In addition, science is perceived as value free and isolated (Roth & Lee, 2003). This is in contrast with social concepts which are subjective and ambiguous. This specific and objective nature of scientific concepts makes it difficult for most learners to articulate. Socialization plays an important role. At home, learners have rare encounters with mathematics and Physical sciences. Learners experience other subjects such as music, history and geography at school, on the radio and television. These subjects are an everyday experience and are conveyed extensively in various media unlike science. Science in general and physics in particular is experienced at school. This means that learners do not have enough exposure to science at home and in the societies that they live in. The lack of extensive scientific socialization impacts negatively on performance at school. In a study by Lyons (2006), family background plays an important role in the selection of subjects at school. Lyons (2006) further claim that most parents are not literate in mathematics and science. This makes them less capable of assisting their children at home and at school. They might not be fully aware of the dynamics and conditions that enable effective teaching and learning of mathematics and science.

The lack of role models at home and in communities indirectly impact on the enrolment and performance of science at school. This problem is further complicated by science textbooks.

Science textbooks have a contribution to performance at school. According to Schultz (2000), science textbooks present specialized language and symbols. Technical jargon used in science textbooks makes it inaccessible to most learners. To comprehend content, learners need to master the scientific jargon and its symbols first. This is an active barrier because learners spent most of their time trying to comprehend the scientific symbols used by most science textbooks. This leaves most learners frustrated and demotivated with the way content is presented in textbooks. What is more? Teachers fail to deliver content.

In a study by Muwanga-Zake (2001), teachers displayed a lack of content knowledge. A further investigation by Muwanga-Zake (2001) also revealed that some teachers could not name some apparatus and chemicals. Most of the practical's came out as cook book investigations which served to verify existing laws (Muwanga-Zake, 2001). This practice ignores the ability of learners to hypothesise and formulate investigative questions to novel situations and this has contributed to rote learning. Furthermore, some learners with an aptitude for practical work are frustrated as this is not examined in the national examinations and this researcher has also noted the same during his experience as a science teacher since 2002. In the South African context, this barrier is further made worse by the constant shift in syllabi by the Department of Basic Education since 1994.

The Physical sciences curriculum has changed several times since 1994 in South Africa. There have been curriculum changes such as OBE, NCS and CAPS in the space of ten years. This constant change of syllabi has had an effect on the performance of learners as some teachers were unfamiliar with new content. In addition, teachers resist educational reform and impacts negatively on learner performance (Muwanga-Zake, 2001; Potvin, 2013; Zacharia, 2003). Moreover, most schools are overcrowded. Curriculum delivery then becomes challenging and affects learner performance as there is little contact time between the teacher and individual learners. This problem is further compounded by the fast pace of the curriculum in which teachers are forced to finish the syllabus in order to be in line with assessment dates and reporting deadlines. This is despite the fact that some challenging topics such as electricity need more time to cover the syllabus. The pressure to perform further rests on teachers where there are high expectations from government officials, parents and school principals. In an order to keep up with this expectation, most teachers find no time to assess the deep understanding of concepts in their subjects. This race with curriculum reduces valuable educational experiences to mere rituals (Bahar, 2003). As a result, learners perform poorly in tests and examinations.

The language of instruction impacts on learner performance. English, which is used in most schools as the language of instruction (LOI), is not the home language for the majority of learners at schools in Africa (Brock-Utne & Hopson, 2005). This has an effect even in science where some learners fail to understand questions due to the language barrier. Bahar (2003) asserts that most learners have reading and writing problems. This makes learning process difficult as learners are expected to express themselves in English when they write in tests and examinations. Although the above discussion focuses on the general barriers to learning there are barriers that are specific to the learning of Physical sciences.

2.5 Problems associated with the learning of Physical sciences

Factors discussed above impact on the performance of learners including Physical sciences. However, there are factors which are unique to the subject. Physical sciences requires that a learner display a unique combination of skills. As discussed above, learners need to master the language of instruction at home language level. This means that learners should have good reading and writing skills. Furthermore, a learner should be fluent in mathematics in order to be competent in Physical sciences. Learners have numeracy problems in South Africa (Mallis et al., 2007) and this is a problem in a subject that expresses concepts using mathematical language and symbols. Understanding and expressing ideas in Physical sciences requires that one is fluent in algebra and geometry and this is problematic. An over-emphasis of mathematical formalisation forces learners to engage in algorithmic problem solving without a deep understanding of the content material (Redish, 1994). Learners in the Physical sciences have an inclination to use formulas and calculations than qualitative reasoning of concepts (Millar & King, 1993). This imbalance between quantitative and qualitative reasoning in Physical sciences needs attention. There should be more emphasis in qualitative reasoning in Physical sciences as not all concepts require mathematical manipulation of calculations, substitution and getting the correct numerical answer (McDermot & Shaffer, 2000). Mathematical formalisation is problematic. It encourages learners to memorize formulas and definitions in order to pass assessments instead of thoroughly understanding concepts (Chen & Howard, 2010). Not only do learners memorize definitions and formulas, but they also come with their own scientific beliefs in the sciences which are not in line with the accepted view of scientific principles.

Beliefs about science have an impact on understanding. Most learners see the learning of physics as a transition and conflict from their indigenous culture to western civilisation. The difficulty that learners face with a conceptual understanding is cultural (Aikenhead & Jegede, 1999). This researcher also alludes to this assertion in his Physical sciences classroom experience, especially when engaging learners in grade 10 on the origins of lightning. Indigenous African culture holds strong to the belief that lightning is caused by witchcraft. Explaining this concept in terms of charges might create problems and the concept of charge is often received with disbelief when explaining the phenomenon of science.

The assertion that science is taught as dry facts was discussed above and authors (Wells et al., 1995; Wieman, Adams, Loblin, and Perkins, 2011) allude to this and further assert that learning of physics relies on concepts as the building blocks of scientific knowledge. This means that a learner needs to master preceding concepts and ideas of a unit before proceeding to the next. Furthermore, it is important to highlight Physical sciences concepts are intricately interwoven and coherent. Physical sciences is a subject that is highly ordered and sequential (Wambugu & Changeiywo, 2008). Therefore, haphazard presentation of concepts can be problematic. Conceptual clarity therefore becomes important.

As indicated earlier, concepts in Physical sciences are presented as precise, objective, specific and clear. This level of precision and clarity presents an intellectual challenge to learners and most fail in problem solving as well as the application of concepts because they lack interpretive framework for concepts which is coherent. This is made worse by teachers of Physical sciences as they bring to the learning experience their own alternative conceptions (Gaigher & van der Merwe, 2011). This problem is compounded by textbooks which are not misconception focused (Abimbola & Salihu, 1996). This combination of factors makes the learning of Physical sciences difficult. However, over the years, there have been significant efforts to understand how to address these difficulties and this is examined in the section below.

2.6 Major alternative conceptions on the topic of electricity

Research on alternative conceptions in the topic of DC (direct current) electric circuits has been a subject of research, both in physics and science education for decades. The number of alternative conceptions uncovered has been increasing and this has been complemented by innovations to confront them.

2.6.1 Conservation of current

Researchers (Ates, 2005; Shipstone, 1984) uncovered that learners did not conserve electrical current in a circuit. Learners incorrectly reasoned that current is more at the source and less away from the source. This misconception has proven to be resilient over the years and has been confirmed by other researchers (Engelhardt, 1997; Engelhardt & Beichner, 2004). In a related incorrect reasoning, learners thought that after passing through a component, current is used up and current measured after the electrical component is less than that before the component. This kind of thinking was termed attenuation model (Osborne, 1983).

2.6.2 Incomplete circuit and direction of current

In their continued inquiry into alternative conceptions (Brna, 1988; Osborne, 1983; Shipstone et al., 1988) went on to reveal that learners thought that for a bulb to light up, there was no need for a complete circuit. Alternative understanding was revealed that bulb light up due to positive and negative charges travelling from the battery and clashing to produce light (Osborne, 1983). This mode of thinking was termed clashing current model. Answers from participants showed that a bulb would light up with one wire from the battery to the bulb. This form of thinking about circuits was labelled the unipolar model. This was confirmed in preceding research (Engelhardt & Beichner, 2004)

Learners also thought that at a junction in an electrical circuit, current is shared and divided equally irrespective of the circuit configuration. Researchers (Osborne; 1983; Riley et al., 1981; Shipstone, 1988) termed this kind of thinking the shared current model. This shows that behaviour of current in parallel and series is not understood with clarity by learners.

Cohen et al. (1983) has also established that learners have a problem understanding the direction of flow in a DC and AC circuit. Lack of clarity on these terms showed that learners thought that current in a DC circuit changes direction after passing through a component such as bulb or resistor (Shipstone, 1984).

2.6.3 Confusion of concepts

The confusion of concepts is another difficulty that learners are faced when engaging with the topic of electricity. Electrical energy, electrical power and electrical charge are interchanged without a problem as they are used in their everyday life. An example of this is found in IsiZulu language use where power means the same as energy and charge. Not only has research established this, but the researcher in his teaching has seen this in tests written by learners that this misconception is active. Learners and teachers lack clarity on these terms. Term confusion extends to the concepts of current and potential difference as learners fail to define these terms with clarity (Engelhardt, 1997; Hussain, Latiff, & Yahaya, 2012; Shipstone et al., 1988). One other related misconception was learners associating the behaviour of current as that of water (Roland, 2006). This was highlighted above in addressing the weaknesses of using analogies in teaching.

2.6.4 Functional dynamics of the battery

It was also established that learners do not understand the functional dynamics around the battery. The most profound being the inability to identify the purpose of the battery highlighted in the CAPS document (DBE, 2011). Related to this, was inability of learners to recognize that a battery is a source of energy. Everyday use of a battery is associated with being a source of power and learners bring this into classroom. Explaining that a battery is a source of energy is then problematic.

Related to the alternative conception above is one that is widely recorded in examination reports (DBE, 2011, 2013, 2014) as well as in the study (Osborne, 1983) that a battery supplies constant current irrespective of circuit configuration. This alternative is also alluded in the policy document (CAPS, 2012). Embryonic research (Cohen, Eylon, & Ganiel, 1983; Riley et al., 1981) revealed that learners thought that a battery is a constant current source. This misconception is premised on the thinking that a battery supplies the same amount of current irrespective of the arrangement of the external circuit configuration.

2.6.5 Circuit configuration

Concepts and questions around battery proved problematic. Termed battery superposition (Engelhardt, 1997), learners could identify and explain the behaviour of bulbs in a series but had difficulty doing the same for batteries in parallel. Related to this, is the finding that learners and teachers had difficulties interpreting series and parallel circuits (Gaigher & van de Merwe, 2011). Although isolated studies have examined these alternative conceptions for decades, Engelhardt (1997) gave a comprehensive report on most alternative conceptions that have been studied and in the process, distinctively revealed more. Battery superposition, explained above, was one distinctive finding of the thesis. This was alluded to by studies (Shipstone, 1984; McDermot & Shaffer, 1992) who also revealed learners have difficulty interpreting parallel circuits.

2.6.6 Combined circuits

Another difficulty was the inability of learners to interpret combined circuits. Learners are able to interpret series circuits and parallel circuits when they are asked separately. Combining these circuits showed that learners only think that the change effected on the circuit affects the part or area changed and not the whole circuit. This model of thinking was termed local thinking (Shipstone, 1984). In order to interpret these combined circuits, learners are expected to show global thinking. Visualizing the microscopic nature of circuits, especially conductors, have not been reported by earlier research and (Engelhardt, 1997) reveals that learners have a problem understanding the nature of circuits as the don’t understand the microscopic and magnetic properties of circuits. This researcher relates to these findings during teaching as learners fail to define current with clarity during class activities.

2.6.7 Properties of resistance

Properties of resistance and potential difference in a circuit were problematic in research reports (Cohen et al., 1983). Most learners were reported to think that among other concepts such as potential difference, emf, power, and resistance, the most important and prime concept was current. This means that for resistance to be there, current must be there first and the same for potential difference (Shipstone, 1984). If there is no current there is no potential difference (Engelhardt & Beichengner, 2004; Hussain et al., 2012; Rankumise, 2012). This is due to learners' inclination to quantitative thinking and they pay less attention to qualitative thinking in the topic of electricity.

2.6.8 Qualitative thinking

On the topic of electricity, participants are inclined to calculate without first reasoning qualitatively. This has been discussed above but also cited in literature (Brna, 1988; Engelhardt, 1997; Millar & King, 1993; Taber, 2011). Most learners engage in quantitative reasoning more than qualitative reasoning and cannot easily solve a problem on the topic without engaging in calculations or using ohm's formula. Therefore, it has been revealed that Ohm's law as a concept is not deeply understood by learners (Liegeois, Chasseigne & Mullet, 2003; Liegeois & Mullet, 2002). Part of this, as discussed earlier in chapter 1, is due to qualitative reasoning receiving less attention in formal assessments such as national examinations yet it affects their overall understanding of the topic at higher levels.

2.6.9 Short circuits

Most learners accessible have difficulties with interpreting short circuits. A short circuit is where a circuit has a conductor that prevents current from flowing throughout the circuit by proving a path of low resistance and other circuits' components will not receive current, hence they switch off. It was reported (Ates, 2005; Engelhardt, 1997; Engelhardt & Beichner, 2004; Freddette & Lockhead, 1980) that most learners thought that current is shared instead of shorted back to the source cutting off the rest of the electrical components.

There are other alternative conceptions that the researcher has uncovered during teaching such as energy conversions. Learners find it difficult to reason that a circuit converts energy. Even when current is not flowing, learners thought that there is no energy. This means learners have a low appreciation of the law of conservation of energy. Furthermore, the concept of opening and closing of a switch is also problematic to learners, especially in combined circuits. Some learners reason in assessments that opening a switch in a combined circuit stops current flowing at all in the whole circuit. This a major flaw when reasoning with circuits and this discussed in more detail in chapter

5. As noted earlier, these alternative conceptions have been the subject of research for decades and research shows that they are tenacious and very hard to remove. The most used intervention to confront these alternative conceptions was analogies. This study will explore if computer simulations will be able to change these alternative conceptions and aid better understanding of the topic.

2.7 Different ways of teaching Physical science for understanding

From the late 70s to date, most science education research has been committed to conceptual change research to challenge the traditional approach to teaching and learning. Pioneers of conceptual change research (Posner, Strike & Hewson, 1982) have described the idea extensively. Their work has been labelled the classical conceptual model. In summary, for conceptual change to take place, they suggest that the new concept must be intelligible, plausible and fruitful. If the new concept satisfies these criteria then conceptual change would take place and the learner abandons the old concept and replaces it with the new one. This learner now acquires an expert status in the practice of science. However, this conceptual change model has been criticized as ‘weak’ and ‘naïve’ as it oversimplifies and fails to expose the complex reality of learning (Potvin, 2013). Gaps in the conceptual change model have been suggested. One of them being that it is not simply the replacement of the old concept. There is a suggestion that cognitive conflict is precedes conceptual change. These critical voices have facilitated the emergence of new ways of confronting alternative conceptions.

According to Potvin (2013) cognitive conflict assumes that there is a prior concept before the new concept but this is not always the case. In some instances, learners do not have the initial concept. In his paper on neuro-education and psycho-pedagogy, Potvin (2013), found out that a study of physics experts can provide useful insights into conceptual strategies. Experts were found to have the ability to inhibit the initial concept. They use a strategy known as inhibition strategy. This strategy allows the experts to resist distracters and any form of interference. What this seems to suggest which is contrary to the classical conceptual change model is that the original misconception is not abandoned but is rather structured parallel to the new concept. The expert only inhibits the old concept. What are the instructional implications? Since the concepts are said to co-exist (both scientific and non-scientific), teachers should actively show learners where an application of their concept or misconception can lead to an error without necessarily having to go through cognitive conflict. This is designed to raise the status of the new concept to that of the misconception and even higher for inhibition to occur (Potvin, 2013).

As indicated above, culture has a part to play in the acquisition of physics concepts (Aikenhead & Jegede, 1999). Transition from family micro-culture to school culture can be smooth, manageable or hazardous and at times, impossible (Aikenhead & Jegede, 1999). A smooth transition shows a similar school and home culture and an impossible transition is when the home culture and school culture are not aligned. What are the implications for instruction? For a smooth transition to take place, instruction should show flexibility and playfulness. In other words, lessons should be as engaging and relevant as possible. As explained above, one of the reasons why physics concepts are difficult is because concepts are taught in isolation. Physics concepts should be taught as a coherent unit in order to facilitate conceptual understanding (Cobern, 1996). Learners face learning problems because they receive a lot of information in short space of time. In order for this information to be retrieved easily, it has to be organized into a structure which is easy to recall and use in a particular physics context (Aikenhead & Jegede, 1999) claim that there are three knowledge structures. Knowledge can be networked, fragmented and hierarchical. The latter, they claim, is more effective in organizing knowledge. Hierarchical knowledge structure has the merit of introducing concepts in a linear fashion which makes it possible to master simpler concepts before much more complex concepts. This sequential approach helps learners to articulate concepts. Another approach used to confront alternative conceptions is the problem solving approach.

Problem solving is one important factor used to measure conceptual understanding in physics. Traditional teaching limits problem solving to the ritual of substituting formulas and producing a numerical answer (Wells et al., 1995). Problem solving has elements that need to be looked into in order for it to be effective. Stages in problem solving should just go beyond identification of the right formula. Rather, problem solving is a systematic approach. More time should be spent in analysing the question, in identifying the principle or concept under examination, in identifying the goal, describing the situation with diagrams and appropriate symbols, identifying the known from the unknown, and in choosing sub-problems within a problem (McDermot & Shaffer, 2000).

Use of problem solving approach should be applied with caution. When problem solving is not applied properly, it can lead to the reinforcement of alternative conceptions (Dega, 2012). The problem solving approach has its own disadvantages. This approach has been criticized for being too stereotypical and avoids the subtle parts of the scientific process (Saleh & Khine, 2009). Dufresne, Gerace, and Leonard (1997), argue that most learners fail in problem solving because traditional instruction makes it too algorithmic and procedural. They further assert that most problem solving models in textbooks are not good as they emphasize the selection and manipulation of equations without a deep understanding of the concepts. Most learners select an equation without checking its appropriateness and then apply it without understanding its content. This results in learners having a low skills base for problem solving failing tests and examinations. An additional approach in addressing alternative conceptions in science education is the inquiry method.

The National Curriculum Statement for Physical sciences (DBE, 2011) recommends inquiry learning as one of the teaching methods of effectively teaching science. This is supported by high school grade 10 Physical sciences textbooks (Geduld, Green, Mkwanazi, Mzolo, & Whitfiled, 2007; Kelder, Repsold, Bridgeman, Finnemore, & Daniels, 2008) as the appropriate approach to teaching and learning science. What is inquiry learning? Inquiry involves hypothesizing, testing, observation, drawing conclusions, rejecting and accepting hypothesis and is a method that is known for engaging learners leading to positive achievement by learners (Zacharia, 2003).

Mastery approach is another educational effort used to address alternative conceptions. In a study by Wambugu and Changeiywo (2008), learners were made to master one unit before moving to the next. They recommend breaking the topic into several units with each unit with its own objectives. A learner has to master each unit in a sequential order before they move to the next. They called this approach the mastery approach. Results of their study showed cognitive gains. Another approach proposed is mental modelling.

Learners usually perform badly in physics because they lack appropriate mental templates or models. Templates and models provide references for interpreting phenomena (Taber, 2011). Models are seen as thinking tools in science and physics in particular as they show the concept closer to the expert scientific understanding. Models such as the visual image of electrons flowing in a circuit should not be shown but learners must, through careful guidance of the educator, be able create their own. The ability to create models enables learners to see that knowledge is not fragmented or isolated but rather coherent (Wells et al., 1995). Modelling method in teaching and learning proved superior to traditional instruction, and increased cooperative inquiry and mathematical modelling (Treagust, Chittleborough & Mamiala, 2002). This is because these methods lack the full picture of describing a concept which is found in most modelling tools. Linked to conceptual modelling is concept mapping. Concept mapping was also suggested as a potent way to restructure learners schema of physics, especially those learners that are visual learners as they show the relationship between ideas and concepts (Novak, 2002; Tas et al., 2012).

Another suggested approach is multiple representations. Multiple representations have been suggested as a way of making physics more attractive to learners. Multiple representations increase learner's flexibility when attacking problems as they can access different thinking resources (Cheng & Gilbert, 2009). Teachers should represent a problem in several ways using diagrams, graphs, free-body diagrams and images in order to help learners understand the idea at hand (Ainsworth, 1999; O'Keefe, 2014).

Analogies are also another strategy used by physics educators to make physics concepts accessible. They are the most widely used intervention tool to confront alternative conceptions in literature. According to Yener (2012), analogies are used by learners to understand abstract concepts and other complicated scientific ideas. They compare the unknown and the unfamiliar to the known and familiar. The unknown idea or process becomes the target and the known is the analogue (Heywood, 2010). Matching the analogue to the target is key to conceptual understanding and features of the analogue which does not fit into the target need to be spelt out so as to avoid introducing a misconception (Yener, 2012). However, use of analogies has the potential to reinforce alternative conceptions if not used carefully and especially when the analogue does not match the target concept or idea.

Innovative ideas discussed above have their disadvantages or at least there seem not to be a panacea as to which approach is the most appropriate in addressing alternative conceptions. Recently, technology has found its way into education. These include online surveys, student e-mails, blogs, clickers and interactive computer simulations (Thacker, 2003). The technological tools have been found to be helpful in enhancing conceptual understanding. The impact of interactive computer simulations on conceptual change will be discussed in detail later in the following sections of this chapter as well as in chapter 4. It is beyond the scope of this study to describe all the innovations investigated in science education. The innovations described above are widely reported in literature and as noted earlier, each intervention has its weaknesses. Other innovations in physics teaching that enhance conceptual understanding include word associations in tests, a structural communication grid, interviews on events, a diagnostic tree, and journal writing. A study by Wandersee, Mintzes and Novak (1994) explains these strategies in detail. However, it is worthwhile to note that despite all these suggestions and innovations, conceptual understanding in the topic of electricity is still a problem. Let us consider the major alternative conceptions that learners have on the topic of electricity.

2.8 Alternative conceptions in electricity: South African high school context

The Department of Basic Education examination reports from 2008 to 2016 showed the topic of electricity posed a challenge to learners in the examination and were reported having more alternative conceptions than other questions in paper 1. Physical sciences are a combination of physics and chemistry. Paper 1 has the physics component and paper 2 has the chemistry component. Table 1 below shows the pass rates of Physical sciences from 2008 to 2016. There is a small number that gets above 40% each year. Those that get above 40% are the ones that access tertiary education where they will study degrees such as medicine, engineering and science. This reveals that an average of 60% each year for eight years from 2008 to 2016 did not access tertiary education.

Table 1: Physical Sciences Pass Rate from 2008 to 2016

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016
>30%	54.9	36.8	47.8	53.4	61.3	67.4	61.5	58.6	62.6
>40%	28.8	20.6	29.7	33.8	34.6	42.7	36.9	36.1	39.5

An analysis of the Department of Basic Education (DBE) diagnostic reports revealed that the question on electric circuits got an average mark of 22% nationwide in 2011. The same question on electricity circuits got 41% in 2015 and in 2016 the average score for the question was 34%. This reveals that the topic of electricity is poorly taught and poorly understood in South African schools. Learners confuse the concept electromotive force with that of potential difference, have an inability understanding of electrical power, an inability in interpreting series and parallel circuits, an incomplete understanding of internal resistance, a weak appreciation of Ohm's law, weak problem solving skills, and the inability to manipulate formulae and equations (DBE, 2012, 2014, 2015, 2016) . These reasons are alluded to by UMALUSI (2011) , which states that there are problems in conceptual understanding of charge and that learners failed to perform complex problem solving questions. As it was noted that most students were having issues with problem solving, it was recommended that teachers do extensive practice on such questions so that when learners come to the examinations, they have problem solving skills (DBE, 2016). The application of Ohm's law was also noted as problematic and it was recommended that learners have to practice more questions on Ohm's law (DBE, 2011, 2015, 2016). Interpretation of series and parallel circuits was problematic for learners. It was therefore recommended that teachers and learners practice more (DBE, 2013, 2014). Learners were confused with terms such as power, potential difference, internal resistance and work. Diagnostic reports (DBE, 2015, 2016) suggested that these concepts should be explained better and should be understood more by learners. This could be achieved by revisiting concepts in Grade's 10 and 11. Learners were also reported to struggle with interpreting graphs especially when interpreting circuit experiment results. It was therefore recommended that more experimental work should be undertaken as per the CAPS policy and that graphical interpretation of results should be emphasized. However, despite these recommendations, Table 1 shows that learners still performed poorly in Physical sciences over eight years from 2008 through to 2016. A closer look at the diagnostic reports shows that learners have not mastered basic concepts of charge, potential difference and power. This is similar to international studies (Engelhardt, 1997; Hussain et al., 2012; Shipstone, 1988) which also found that learners struggled with the same concepts.

2.9 Considering computer simulations in conceptual understanding

It is important to note that innovations in the teaching of physics are still continuing. These alternatives to the conceptual change model have been criticized by Potvin (2013) as unsuccessful in bringing viable conceptual change as they are deemed as variations of the conceptual change model, and that they only work in a specific set of content knowledge domains. However, the quest for a viable conceptual change strategy continues. The recent entrance of computer simulations into education needs a separate discussion as a form of educational reform.

As indicated above, technology has become part of our life and schools are seeing the introduction of computers in teaching and learning. According to Akilli (2007), although instructional technology entered into the classroom in the 1970s, it is the mass production of the micro-computer in the 80s that has had a profound effect on instructional design in education. In the past two decades science pedagogy has been influenced by rapid technology movement, photo typing, a booming electronic system and access to internet. Hence there has been a shift towards creative teaching methods which react to different educational contexts (Akilli, 2007). Instructional technology comes in different forms. It can be hard or soft technology. Computers are part of hard technology. Computers come in with many advantages such as high speed of data processing, huge memory capacity, and good storage functions, have high quality pictures and have good presentation capacity. These attributes of a computer are being exploited in instructional technology. According to Nelson (2014), instructional technology is the communication to learners delivered by any form of equipment and its associated procedures. For some time, computer simulations have been used in physics education to drive instruction and aid in conceptual understanding. A simulation has been defined as the representation of reality and an imitation of the real thing (Blake & Scanlon, 2007; Khan, 2011). A simulation is also defined as a model of the real world designed to simplify and explain processes and mimic dynamically systems of objects in a real or imagined world (Luxman & Chin, 2011) . According to Akilli (2007), a simulation is defined as a model of some system or computer program that is able to change variables of a system, value or action. He also added that a simulation is an interactive representation of a system that is based on a dynamic set of relationships with variables that change over time. There are many definitions of simulations but a detailed presentation is given by Greddler (1996) where he asserts that computer simulations have a surface structure and a deep structure. Surface structure involves the observables such as data and variables that learners would work on. Deep structure includes the intangibles such as the psychological effect, motivation, interest, engagement and visualisation that the simulations naturally come with (Greddler, 1996). Although similar to computer games in some of their functions, they also involve working and undertaking serious responsibilities, are non-linear in their function and they contain a system that responds to the relationship between variables over time (Greddler, 1996).

A further classification of simulations also shows that there are two types of simulations. These are experiential simulations and symbolic simulations. In experiential simulation, the learner is part of the system and can influence the outcome of the process (Greddler, 1996). They are usually designed to represent situations or processes that are hazardous in the real world or which are costly to undertake. In this type of a simulation, the learner is immersed and is an element of the situation. One such kind being the medical simulation in which a medical student is giving a possible diagnosis of a patient which may result in the patient surviving or dying. There are four types of experiential simulations: diagnostic, data management, crisis management and social process simulations (Greddler, 1992). Social process simulations are used to investigate possibilities of a social problem and how to find a solution. Crisis management simulation is qualitative in nature and is used to find a solution to a crisis situation. Diagnostic simulations are basically problem solving in nature and looks at possible ways of arriving at a solution. Diagnostic simulations are usually used in medicine. Data management simulations are quantitative in nature and are used as business models to find a solution to resource management in public and private practice of large organisations.

Another type of simulation is the symbolic simulation. This is a dynamic representation of some situation, process or system. A learner in this case, is not a functional element of the situation and the results are usually independent of the manipulator. The learner only manipulates variables. According to Greddler (1996), the primary purpose of symbolic simulations is to discover and experiment with scientific relationships of principles, explain events and confront alternative conceptions. Another purpose of symbolic simulations is to help in solving scientific problems as well as assist in predicting phenomena. Symbolic simulations come in four types. The first one is the data universe simulation. These simulations use mathematical models and are used to test students. The second one is the systems simulation. Systems simulations help in showing and explaining how components of a system work. This is usually used in industries to show how a component of a mechanical or chemical system works. The third one is the laboratory research simulation which is basically problem-solving and used in chemical industries to show how to speed up chemical reactions. The fourth and last is the process simulation. This is used to show, explain, predict and observe naturally occurring phenomena in biology, physics and chemistry. They enhance the interaction of learners with phenomena at a qualitative level and according to Greddler (1996), process simulations address specific interactive phenomena which is usually not well understood by learners in the classroom. PhET simulations are therefore part of the process simulations and are used in this study.

In order to use simulations in the classroom effectively, certain preconditions have to be met. It is suggested that learners should have a very strong prior content knowledge, be competent in inquiry skills such as hypothesis generation, and they should be able to reason and represent an abstract concept of the domain being learnt or investigated. It is recommended that simulations should not be used be novices trying to learn something. Greddler (1996) recommends that the gap between the learner's capabilities and the tool to be used must be matched to avoid learner frustration with the task at hand. This means that learners must have a minimum level of computer literacy when dealing with computer simulations.

Instructional technology is not without its critics. According to Akilli (2007), educational technology has been labelled challenging because classroom practitioners used to and are still using old teaching methods with new educational media and that current models and methods of instructional technology are insufficient to meet the paradigm shift from the industrial age to information age. As indicated elsewhere in this paper, research is still behind in instructional technology and there are still a few plausible theories to explain and model teaching with technology. This probably justifies why games and simulations are the least used methods in science education (Akilli, 2007). Most teachers are uncomfortable with the use of technology and according to Mandinach and Cline (1992), most teachers cannot manage classrooms which involve computers as the set-up is different from the traditional class they are used to. Learners in this information age push themselves into a situation without knowing anything and prefer to be active, learning by trial and error and discovering things on their own without being told what to do or by listening. This complicates matters for the traditional teacher. There is also the assessment dynamic. Teachers cannot easily assess learning with computers. Learners learn with technology but they are assessed without technology in most situations. Another problem is that there is less literature on simulations and according to Akilli (2007), there is a need to answer the following questions in order to enhance learning with simulations: 1.) How do we incorporate simulations into the learning environment? 2.) How do we differentiate simulations from other learning platforms? 3.) How do learners learn best with simulations? Much of the literature is comparative and does not address these salient questions. Hence, there is a lack of reference on how to use computer simulations for teachers which removes the confidence they may have in working with computer simulations as an instructional innovation in physics and science education. However, computer simulations come with a lot of advantages that can be helpful in the classroom.

2.10 Advantages of computer simulations

Computer simulations have several advantages when used in the teaching and learning of physics. One of the components of a learning environment is motivation. According to Keller (2000), motivational elements include relevance, attention, confidence and satisfaction. Attention includes the ability to induce curiosity and interest in learners. Relevance is when learners see value in the activity they are performing. Confidence in motivation is achieved when the task is achievable. Satisfaction is when we recognize learners for good performance. Motivation helps to keep learners on task. Scholars (Bernstein, 2005; Chin-Liu 2002; Huppert, Lomask, & Lazarowitz, 2002; Ronen & Eliahu, 2000) assert that computer simulations are good as motivation tools in teaching and learning, especially in inducing attention. This high motivation could be due to high picture superiority and the heightened presentation that computers have (Chin-Liu, 2002; Strauss & Kinzie, 1991). Learners are motivated if they feel they own the learning process. Having control over the task at hand is an important motivational element. Computer simulations give learners control of their learning process unlike other pedagogic approaches such as traditional teaching which are teacher centered. This is because when using computer simulations, learners are actively involved in the learning process (Kluge & Bakken, 2010). Other scholars (Chen & Howard, 2010; Ellington, Addinall, & Percival, 1981) also add that since computer simulations are motivating and they cultivate a positive learning environment. Not only are computer simulations motivating and interesting, but they are also deemed engaging (Blake & Scanlon, 2007; Nesbitt-Hawes, 2005). Engagement in class is correlated to the teaching method. The engaging nature of computer simulations is attributed to the interactive nature of the simulations (Bulger, Mayer, & Almeroth, 2008). Interactivity of computer simulations, an inherent attribute of them, is due to the learners' ability to manipulate variables during an activity. Scholars (Eckhardt, Urhahne, Conrad, & Harms , 2013; Gunstone & Tao, 1999; Kelly et al.,2008; McFarlane & Sakellariou, 2002; van Jooligan,

& van der Veen, 2012) among many others, note the interactivity of computer simulations as a distinct and unique advantage compared to other teaching innovations. Computer simulations have the ability of simulations to have multiple representations (Roberts, 1994; F. Wang, Kinzie, McGuire, & Pan, 2010).

Another merit of computer simulations is that abstract concepts are made concrete. Macro-concepts such as astrology and the micro-concepts such as flow of electrons are made accessible and visible (Finkelstein et al., 2005; Lin, Hsu, & Yeh, 2012; Richards, Barowy, & Levin, 1992; Sauter, Uttal, Rapp, Downing, & Jona, 2013; Yu-Fen, Guo, & Juho, 2008). Associated with making abstract concepts visible and accessible, is the ability of computer simulation to aid in conceptual modelling. Another merit of computer simulations that is linked to conceptual modelling is conceptual understanding. Physics is considered difficult by many learners (Mingireanu & Breharu, 2013). Hence, when learners come to the learning situation they bring with them a lot of alternative conceptions. Scholars (Gubuz & Birgin, 2011; Jaakola, Nurmi, & Veermans, 2011; Wieman et al., 2011) described computer simulations as useful pedagogical tools in conceptual understanding which challenges these naive conceptions. Computer simulations are also considered to complement practical work in that there is danger when working with chemicals and delicate apparatus is avoided. In literature, an ethical dimension is added when working with simulations. Simulations are considered an advantage when dealing with animals especially in dissections. Some students are uncomfortable killing animals and others don't like the smell of blood. In this case, learning dissections with computer simulations becomes handy (Strauss & Kinzie, 1991).

Feedback is important in the learning environment. Knowing what you do not understand when it is given timeously contributes to meaningful learning. Assessing existing knowledge is very important and lack of feedback makes a minimal contribution to learning (Chickering & Gamson, 1987). Giving quick feedback on the task at hand is the strength of computer simulations compared to other traditional teaching methods such as laboratory work. When working with variables, computers simulations provide immediate feedback (Blake & Scanlon, 2007; Jimoyiannis & Komis, 2001). Laboratory equipment is expensive and most schools and universities cannot afford to prescribe experiments. At times, learners share equipment therefore, when it comes to laboratory work, computer simulations are seen as a cheap alternative, especially when the apparatus is inaccessible and expensive to run (Pyat & Sims, 2011; Rutten et al., 2012). Working with time scales that are large or too small is a challenge in a laboratory setting. Computer simulations can expand and minimize time scales (Lindgren, 2010; Lindgren & Schwartz, 2009; Ronen & Eliahu, 2000) and this facilitates learning.

Inquiry learning is seen as one of the teaching methods that enhance the learning of science. Elements of inquiry learning include the ability of learners to ask questions, formulate hypotheses, test the hypotheses and make necessary conclusions. Part of this inquiry learning is controlling for variables and getting results. Manipulation of variables, control of variables and immediate feedback of results of the exploration are enabled features of a computer simulation (Campbell et al., 2010; Kelly et al., 2008; Kluge & Bakken, 2010; Limson, Witzlib & Desnarnais, 2007). A laboratory situation is unable to control for certain variables and if controlled there is a degree of error that is unavoidable. According to Chin-Liu (2002), computer simulations are good at eliminating extraneous factors when working with variables. Hence, this allows learners to focus on important and critical information. Rutten et al. (2012), describes this as cognitive focus. Computer simulations are also known as facilitating collaborative learning. Collaborative learning places more emphasis on classroom interactivity and importantly, ICT teaching tools such as slides, projectors and preloaded web pages. However, these innovations lack interactivity and serve as an extension of traditional teaching as the teacher is the one that firmly remains in control of the classroom activities (Beauchamp & Kenwell, 2010) . In their submission on collaborative learning, Beauchamp and Kenwell (2010) further assert that classroom collaboration comes first at a conceptual level where learners in groups are exploring ideas, second at a technical level where learners are using technology and third, at a physical level where learners are manipulating variables. This learning environment where learners are working in groups on a given task is collaborative learning. Authors (Chin-Liu, 2002; Huppert et al.,2002; Kluge & Bakken, 2010; Wieman et al.,2011) assert that computer simulation activities foster collaborative learning.

2.11 Disadvantages of computer simulations

The disadvantages of simulations are rarely noted in literature. In some studies, the disadvantages of using simulations were discussed however, not in great detail (Gubuz & Birgin, 2011; Jaakola et al., 2011; Nesbitt-Hawes, 2005; Wieman et al., 2011) The main criticism is about how they are used without discussing their inherent disadvantages. Computer simulations can easily introduce alternative conceptions if they are not carefully used (Swain, 2012). This is alluded to by Greddler (1996), who notes that simulation exercises need to be properly designed to make computer simulations effective and further asserts that computer simulations are not effective in transmitting information compared to traditional instruction. Another demerit is that computer simulations need a lot of scaffolding in order for them to be effective (Khan, 2011). Lack of studies focusing on the demerits of computer simulations suggests of an area that needs further research. The numerous advantages of using computer simulations compared to demerits in literature reveals that computer simulations can be a useful in aiding conceptual understanding in Physical sciences, especially in addressing alternating conceptions in direct current circuits.

2.12 Computer simulations in direct current circuits

It has been noted earlier in chapter 1 as well as in the preceding sections that alternative conceptions are pervasive in the topic of electricity. Section 2.7 gave a detailed account of the types of alternative conceptions encountered when they are learning direct current circuits. Attempts to address the problem have been made through the use of analogies, concept mapping, problem solving, mathematical modelling, multiple representations and conceptual change strategies. However, it is noted in literature that alternative conceptions are tenacious (Gunstone & Tao, 1999). The question is, "Have computer simulations been tried before to address the problem of alternative conceptions in the topic of direct current circuits?"

During the 1980s and early 1990s, use of computer simulations in direct current circuits was rare. Embryonic research on simulations and direct current circuits was undertaken with confirmatory simulations and not interactive simulations. Confirmatory simulations are simulations in which a learner does not have the flexibility to change variables. Current and other variables are already determined and a learner works to confirm and not explore (Carlsen & Andre, 1992). These confirmatory simulations work like textbooks as they have an inability to address alternative conceptions (Wang & Andre, 1991). There has been an effort, however, to address the inadequacies of confirmatory computer simulations in addressing alternative conceptions in the topic of electricity. This has led to the development of interactive simulations such as EET (Electricity Exploratory Tool), CCK (Circuit Construction Kit), CB (Circuit Builder), ETA

(Electronic Design Automation), and QUCS (Quite Universal Circuit Simulator). This study uses CCK which is a simulation which is found in the PhET suite which specifically deals with direct current PhET (Physics Education Technology).

Working with computer simulations to address alternative conceptions is a recent research endeavour. Traditional instruction also includes laboratory work, a lecture approach, textbook emphasis, chalk and talk, less student activity, and less inquiry by learners (Cuban, 1984). Comparing the effect of computer simulations against laboratory experience (Baser & Durmus, 2010; Finkelstein et al., 2005; Jaakola et al.,2011 and Zacharia, 2007) did not agree that computer simulations are better than laboratory in conceptual understanding. Finkelstein et al. (2005) found that computer simulations help in the theoretical mastery of current, voltage and resistance but fall short of making the bold claim that they aid in conceptual understanding. This is alluded to by Jaakola et al. (2011) who concluded that computer simulations alone are not an effective tool in addressing alternative conceptions about electricity. They suggest that they must be used in combination with traditional instruction and laboratory work. In another comparative study (Baser & Durmus, 2010) found that computer simulations had no significant difference to laboratory work and recommend simulations be used to facilitate inquiry learning. In contrast to the above discussion (Finkelstein et al., 2005 & Pace , 2004) found that computer simulations help in understanding electricity concepts by improving confidence, motivation, feedback and the correction of alternative conceptions. This was alluded to by Baser (2006), who asserted that computer simulations help in the modelling of electricity concepts and further criticized the conceptual change approach as failing to address the conceptual understanding of electricity. This is because there are always contradictions between the predicted value and observed data in most traditional laboratories which complicates the learning process. It is worth noting however, that the concepts used to investigate the topic using computer simulations were not uniform across studies and if they were common, they were not extensive. The most investigated alternative conceptions in the studies discussed in this section are confusing current and voltage, confusing current and charge, the inability to connect an ammeter and a voltmeter (Finkelstein et al., 2005; Jaakola et al., 2011; Pace, 2004; Zacharia, 2007). Other investigated alternative conceptions with computer simulations include confusing electron flow and conventional flow, incomplete circuit, conservation of current, Ohm’s law, energy conversions, interpreting series and parallel circuits (Baser, 2006; Baser & Durmus, 2010; Finkelstein et al., 2005; Pace, 2004). Alternative conceptions in the topic of electricity are extensive. They go beyond those listed above and there is need for computer simulations to be used to study a larger number of these alternative conceptions. A study (Ronen & Eliahu, 2000), investigated the understanding of current by learners and other alternative conceptions were left out. Again, literature does not show which alternative conceptions that can be confronted effectively with computer simulations and which cannot. Out of these reviewed studies, one study (Baser & Durmus, 2010) explicitly describes an instrument used to investigate the alternative conceptions. This instrument was DIRECT (Determining and Interpreting Resistance Electric Circuits Concepts Test). Engelhardt (1997) developed the DIRECT test, and it is extensive on the alternative conceptions tested although the investigation did not use computer simulations. DIRECT test is described in more detail in chapter 3. From those researchers that investigated alternative conceptions using computer simulations, very few (Engelhardt, 1997; Engelhardt & Beichner, 2004) described the test instrument in detail. The age groups investigated were also revealing. Most reviewed literature (Baser, 2006; Baser & Durmus, 2010; Finkelstein et al., 2005; Pace, 2004; Weiman et al., 2011; Zacharia, 2007) investigated university students by confronting their alternative conceptions using computer simulations. Very few investigated high school students and this, as indicated in chapter 1, shows that there is a gap in this area of research, especially when using computer simulations to confront alternative conceptions in the topic of electricity.

2.13 Theoretical frameworks

The study of learning and understanding falls within the field of cognitive psychology. Several definitions of learning are given by scholars. Redish (1994), defines learning as a mental, behavioural and social undertaking. Learning is also defined as a permanent change in behaviour that occurs through experience (Halonen & Santrock, 1996). Learning is defined as an intellectual order that makes it possible to transfer general principles discovered in solving one task to a variety of tasks. Learning comes in different types and forms which include the processing of verbal information, the development of intellectual skills, development of cognitive strategies, development of motor skills, and appropriate attitudes (Dunn et al., 2009). Learning takes place in different contexts with external and internal conditions to learning. Dunn et al. (2009) further assert that internal conditions to learning include aspects where the learner can encode information into long term storage, has relevant prior knowledge, has the capacity to retrieve information and can apply information in new situations. External conditions include the context in which the learning is taking place. This includes the way learning material is presented to the learner, an environment which focuses the attention of the learner to the material being delivered, how the concepts are modelled, guided thinking, assessment and feedback (Dunn et al., 2009). As mentioned above, learning falls under cognitive psychology and understanding human behaviour which learning is part of, is a complex endeavour. In an attempt to understand how to teach science effectively, educational researchers and cognitive psychologists have developed several theoretical frameworks in which teaching and learning can be framed on. Major theoretical frameworks that have been used in educational research are briefly discussed below.

2.13.1 Piaget's cognitive development theory

Piaget's theory of cognitive development stands out as one framework used extensively by researchers to inform studies and instruction in science education. The unit of analysis is the individual. He studied cognitive development in children. There are four stages of development in which children have to go through and he called the cognitive structure the schema. The first stage is sensory motor thought. Children during this stage learn by senses such as hearing and basic motor activities. Usually, this stage happens during the child's infancy. The next stage is the pre-operational stage. During this stage, children can symbolically represent the world. However, at this stage, they cannot perform operations such as reversing events. They also cannot perform logical operations. This stage is shown by children from 2 years to 7 years. The next stage is the concrete operational stage. At this stage, learners can perform logical operations such as conservation, reversibility and can understand properties of objects. This according to Piaget is shown by children of 7 to 11 years old. The last stage is the formal operations stage. This is of the age group 11 to 15 years. This means that they can perform abstract, logical and hypothetical-deductive reasoning. At this stage, children are efficient in solving abstract problems that include algebra as well as testing and formulating hypothesis. In the acquisition of new information, Piaget asserts that there are three stages in which the new information is processed into existing schema. This includes assimilation, accommodation and equilibration. Assimilation means new information is incorporated alongside the old information. Accommodation means that the old ways of doing things are changed in the face of new information. Equilibration is where the old information is now structured alongside the new information. Piaget (1954) also emphasized that concept development takes place when a child is able to exhibit object permanence; that is the ability to conserve and apply information in new contexts. In other words, he argues that learning is from the individual to the social. Piaget's theory of cognitive development requires physical maturation as a prerequisite for intellectual development and asserts that until a child reaches a certain point, learning cannot take place. Piaget's theory of cognitive development has received a lot of criticism from other theorists. Other theorists believe that construction of learning cannot be individual only but needs to be social as well. This is referred to as social constructivism and has been used extensively in science education research for the past two decades. Vygotsky (1978) was the main proponent of the social constructivist learning theory.

2.13.2 Vygotsky's social constructivist learning theory

Vygotsky (1978) proposed a theory that went further than individual cognition which was proposed by Piaget. His theory focused on the logical discussion of opinions and ideas relating to the relationship between the individual and society. The assumption of social constructivism is that understanding human thinking cannot be restricted to the individual but needs to be extended to the social aspect of the learning situation. Vygotsky (1978) defines learning as a necessary and universal aspect of the process of developing culturally organized and specifically human cultural functions. He further asserts that learning is a movement from the current intellectual level to a higher intellectual level. Central to his argument is the construct of zonal proximal development (ZPD). In this concept, is the idea that there is the actual developmental level and the potential developmental level of the learner. The actual developmental level is when the child can display competence without assistance and the potential level is where the child is challenged with new material to be learnt or what they are willing to achieve. In order to reach the desired level, there has to be collaboration with an expert or peers. One of the assertions by Vygotsky (1978) is that externalization of learning can lead to internalization of learning, meaning that learning is from the social to the individual and is mediated by tools such as language, culture and symbols. Human learning is constrained by tools. Some of these tools include, diagrams, use of mathematical symbols, mnemonics, diagrams and maps (Palinscar, 1998) . This means mental functions starts with people and are transferred to the individual in contrast to Piaget who assumed that learning starts with the individual and is transferred to the people (society). In other words, external means of thinking can be translated and transformed to control and regulate one's thinking (Palmer, 2005). The advantage of this theory is that collaboration is key to the learning of the individual and there is the need of a more knowledgeable peer or mentor in constructing knowledge. There is a lot of criticism that was levelled against this theory as to what constitutes what is social. This has given rise to alternative theories being developed that could possibly explain teaching and learning of science effectively. This gave rise to the constructivist movement in the 90s.

The emergence of cognitive constructivism and social constructivism was a reaction to behaviourist psychology to explain learning. Behaviourists' gave impetus to traditional instruction. In traditional instruction, the teacher is at the centre classroom discourse, determines the pace, sequence and content of the lesson (Palinscar, 1998). Traditional instruction is known for being effective in transferring factual knowledge but there is no evidence that it results in the development of higher cognitive skills, applied across context and reasoning. It is for this reason, that the constructivist paradigm was initiated. There has been a marked shift from objectivist to subjectivist learning theories. Many objectivists believe that knowledge exists independent of the learner and becomes internalized into the learner through transference which has been criticized. Constructivism is therefore a combination of cognitive constructivism of Piaget and socio-cultural constructivism of Vygotsky which embraces educational subjectivism. According to Applefield, Huber and Moallem (2001), constructivism is generally classified into three categories which are exogenous, endogenous and dialectical. Exogenous means that the mental structure reflects the external reality to the knower. Endogenous refers to the internal mental structure of the learner and dialectical means the construction of knowledge through sharing, debating and comparing (Applefield et al., 2001). Applefield et al. (2001) further assert that central tenets of constructivism are that knowledge is not independent of the knower, knowledge cannot be transferred nor be reproduced to another person and that learning is self-regulated (struggle between old knowledge and new knowledge) and learners are active and always make a tentative interpretation of experience. One of the tenets of constructivism is that learning should be manipulative, active, constructive, collaborative, conversational, reflective, contextualized, complex and interactive (Jonassen, 1992). Applefield et al. (2001) proposed conditions in which constructivist learning should take place. They suggest that in a constructivist learning situation, problems given to learners should be authentic, simple without being oversimplified and collaborative. Major principles of constructivist teaching are where learners construct their own knowledge, new learning is built on prior knowledge, learning should be through social interaction, and meaningful learning takes place through authentic tasks. They further suggest conditions in the classroom which support constructivist teaching such as giving learners an appropriate background before giving new concepts, scaffold learning, and facilitate the acquisition of transferable skills. Constructivism is not without its critics though. Some argue that there is no focus and no clear goal, no thoughtful planning involved, an absence of structure and an assumption that as long as learners are actively involved meaningful teaching and learning is taking place (Applefield et al., 2001). A further criticism levelled against constructivism is that it does not suggest task structure and there is a lack of efficiency as it requires more time to complete instructions using constructivist pedagogy. Applefield et al. (2001), however, dispels these myths by saying that constructivism is not there to espouse its efficiency but to deliver and facilitate quality instruction by ensuring deeper levels of understanding. The controversy surrounding constructivism, especially socio-cultural constructivism, is that Vygotsky died young without having fully developed his theory. Although constructivism talks about tools in general, there is no particular prescription on how technology is used in the classroom. Therefore, other educational theories have been developed in order to enhance curriculum delivery.

2.13.3 Information processing theory

Information processing theory is one found in literature. According to Lindgren and Schwartz (2009), information theory was developed by Shannon in 1948. The theory emphasizes a-modal problem solving and conceptual organization. Information processing philosophy is said to be a-modal in that cognition and learning is independent of the way in which information is passed. In other words cognition can be triggered in the same way by images, words or feelings (Lindgren & Schwartz, 2009). One assumption of the theory is that communication between systems is a manipulation of information and that information is processed in the form of units which are independent of the internal or external media. Spatial learning is one construct used in the information processing discourse. The main idea being that memory is enhanced by visual information with a spatial structure. This visual information makes it possible for conceptual understanding because visual information has qualities such as structural effect, noticing effect tuning effect and picture superiority (Lindgren & Schwartz, 2009). Picture superiority aids in the modelling of conceptual knowledge which in turn enhances learning. Noticing effect means learners come to notice certain information that they could not have noticed if it was only verbal information.

According to Lindgren and Schwartz (2009), structural effect exposes structural information which could have been difficult without the aid of graphical of pictorial presentation. Tuning effect means learning is recalibrated. This means learning is a continuous adjustment of the previous in light of new information. Information processing advocates for dual coding in science education. Dual coding means that verbal information is accompanied with visual images. This makes retrieval of information easy. Dunn et al. (2009) add, by detailing the pathway in information processing where information is registered by the sensory registers and then undergoes selective perception. It then enters into the short term memory where it is stored and still undergoes semantic coding before it enters into long term memory. This information in the long term memory then combines with old information which then gives rise to working memory. Hence, according to Dunn et al. (2009), learning involves the transformation of information to produce a working memory. This theoretical framework is used to inform research in very few studies which show the implications of it in classroom practice. There is a slight implication on technological use when it comes to importance of images in learning, especially the concept of dual coding. One theory that attempts to explain teaching with technology in more detail, is activity theory.

2.13.4 Activity theory

Activity theory was developed to explain how teaching with technological tools can be effective. Activity theory is also known as Cultural Historical Activity Theory (CHAT). According to Kari (1996), activity theory is derived from the Soviet cultural-historical research tradition which includes Vygotsky, Leoutev and Luria. Activity theory is defined as philosophical and a cross-disciplinary framework for studying different forms of human practices, a development process with the individual and how the social relates to the individual (Kari, 1996). The unit of analysis is the activity. This theory is best at explaining the human-computer interaction (Kari, 1996). In addition, activity theory is a system of human subjects, tools, objects, rules, community and a division of labour (Engestrom et al., 2010; Roth, 2007). A subject is the individual or group. An object includes artefacts and motivations for the activity. Tools are the material conditions used to achieve the motivations or objectives of the activity such as mathematical models, computer hardware and software. Roth (2007) further assert that rules are the explicit and implicit norms, conventions and social relations during the activity. Community refers to the human aspect interacting in the execution of the task. Division of labour is the level of organization in the processing of the task Engestrom et al., 2010; Kari, 1996). There is a high level of interactivity between the elements in the activity system. He explains further that human interaction takes place at different levels. These levels underpin the activity theory, the first being the technical level. At this level the human memory is active and motor skills are utilized during interaction with technical objects. At the second level, there is conceptualization which includes the psychological aspect of information processing and the last is a work process level which includes the formulation of theories to explain phenomena (Engestrom et al., 2010). Activity theory is also influenced by the paradigm shift in knowledge production which has seen a gradual shift from product to process, individuals to groups, from laboratory to work place, novice to expert, and from analysis to design. One of the most important elements in the activity system, according to Kari (1996) is technology. As noted in previous sections, technology enables an activity to be processed with speed, enhances visibility and provides graphical presentations. One of the technological devices extensively used in science classrooms is a computer. Technology makes difficult concepts easier to grasp by making impossible activities possible such as simulations. Literature, however, is short of clear explanations as to how activity theory can be used to effectively design instruction when compared to constructivism. Linked to activity theory in terms of using technology in the classroom, is the systems theory. Systems theory is specific on how to use technology such as computers in teaching.

2.13.5 Systems theory

Mandinach and Cline (1992) described systems theory as a philosophy which shows the interconnectedness of complex variables and their interactions. It is another reaction to traditional instruction but it is a philosophy that is based on how to teach using technology such as computers. Classrooms with technology are generally collaborative in nature and are noisy and chaotic. One who does not understand education with technology will easily conclude that there is no learning taking place as teachers do not play a central role as in traditional instruction. So like constructivism, a classroom that is designed around a system theory is learner-centered. Technology in the classroom generally changes the foci from the teacher to the tool and the learner. The systems theory has the following tenets. The tenets has four stages that a classroom practitioners should be aware of. They are the survival stage, mastery stage, impact stage and innovation stage (Mandinach & Cline, 1992). At the survival stage, learners struggle with technology. They are familiarizing themselves with the hardware and software that is involved. At this stage, learners are directed by the teacher and the classroom situation is generally chaotic. During the mastery stage, learners display coping strategies with technology, increased competence and more engagement with the material and other learners. At the mastery stage, learners are slowly showing independence from the teacher. The next stage is the impact stage. At this stage, learners are independent and less threatened by the use of technology. The teacher is now a facilitator and technology at this stage is seen as enhancing the curriculum. The last stage is the innovation stage. Learners are now able to restructure the curriculum using technology, evaluate their actions and possibly form independent explanations of learning with technology (Mandinach & Cline, 1992). This framework is not described by many scholars in literature, which is an indication that it is a theory that still needs a lot of scrutiny and clarity. The same applies to activity theory. Conceptual change theory formed the basis for most conceptual change arguments to date and has been given the label of classical conceptual change theory.

2.13.6 Conceptual change theory

According to Nersessian (1989), conceptual change is defined as a replacement of one linguistic system with another. Nersessian (1989) further asserts that conceptual change involves kinematics and dynamics. Kinematics dwells on the mechanical part of the conceptual system. Dynamics involve the processes in which conceptual change takes place. Posner and Strike (1982) explains conceptual change as being concerned with how learners change their ideas or knowledge. They further classify conceptual change into evolutionary and radical conceptual change. Individual cognitive development theory of Piaget (1950) is classified as evolutionary conceptual change. This form of conceptual change is assumed to be slow and gradual. Posner and Strike (1982) assert that this evolutionary conceptual change is caused by several factors which make it difficult for conceptual change to take place in learners. Firstly is the anomaly of the way the concept is transmitted to learners, secondly, is the existence of metaphors which are used to transmit knowledge, thirdly, is the epistemological beliefs which learners hold, and fourthly, is the metaphysical beliefs. Kuhn (1962) proposed a radical conceptual change which was a paradigm shift. He made the assertion that learners, when learning a new concept, assign knowledge into different ontological categories (Kuhn, 1962). These include mental, process and material ontological states or categories. Explained further, an example of a material category involves learners thinking that electricity takes space and process ontology is whereby learners conceive electricity as the interaction between atoms. The analogy of electricity being like water flowing in a pipe has a material ontological appeal and needs a radical shift to make them conceive that electricity is the rate of flow of charge. Learners hold on to the material ontology and this is explained by some learners that if an electrical wire is cut off, charge will 'leak' out. Conceptual change is also classified into hot and cold categories. Cold conceptual change involves cognitive and structural changes to knowledge whilst hot conceptual change involves motivational and environmental factors which assist in conceptual change (Pintrich, Marx, & Boyle, 1993).They further suggest that environmental conditions that assist in conceptual change. Firstly, learners must have a weak belief, for example, in the current concept. Secondly, they need to receive coherent information. Thirdly, the new information should be plausible. Fourthly, the new concept should be highly engaging. This was alluded to by Hewson (1992), who proposed some conceptual change tenets. The major tenets of the theory are that for conceptual change to take place, the new concept learners should experience dissatisfaction with the current concept that they hold. This means that the current concept should be seen in the light that it cannot offer potential explanations to scientific phenomena under investigation. Another tenet is that the new concept should be intelligible. This means that the new concept should be coherent to avoid rote learning. This is achieved by making sure that the new concept should have propositional linkages. The third tenet is that the new concept should be plausible. Plausibility is made possible by making the new concept believable. When learners experience a new concept and believe in it, they will be willing to exchange their old concept for the new concept. The last tenet is that the new concept should be fruitful. This means that the new concept must have the power to solve problems. Fruitfulness is also shown by the ability of the new concept to predict phenomena more precisely than the preceding concept (Hewson, 1992).

Apart from Hewson (1992) classic conceptual model, Nersessian (1989) proposed a look at the history and philosophy of science as a way of understanding conceptual change. The main assumption is that scientists also learn science and understanding conceptual change in scientific revolutions gives an insight into conceptual change. A leading question is how did scientific revolutions occur? This approach to conceptual change is known as cognitive-historical analysis and the widely studied scientist of this approach is Galileo. In this approach, conceptual change is seen as involving coordinated changes. A concept is considered part of a conceptual network and a change in part of the network would require coordinated changes in the whole conceptual structure. Conceptual change involves describing the current conceptual understanding, exposing the weaknesses of the current concept, explaining the construction of the new concept, creating new data which conflicts with old concepts, and then explaining the new concept using idealized techniques which are coupled with analogous arguments. Strategies used in cognitive-historical analysis as advocated by Nersessian (1989) to bring about conceptual change are when a concept is changed a number of other concepts in the conceptual framework need to be revised at the same time. Secondly, new concepts should be coordinated. Thirdly, abstract ideas need to be introduced by explaining certain ontological assumptions. This means certain words and meanings need to be explained fully to explain the difference in the meaning of certain ideas. Lastly, when introducing a certain concept, one should avoid generalizations. For example, 'current is the flow of electrons'. These kinds of conceptual generalizations can introduce serious alternative conceptions. Nersessian (2001) was however, quick to point out some of the weaknesses of these conceptual change strategies by saying that introducing a new concept does not always lead to a change in conceptual structure and went on to say that not enough is known about conceptual change to provide a definitive solution to effective instructional strategies, and there is still conflict between cognitive theories and scientific practice (Nersessian, 2001). However, conceptual change strategy had a few problems. One of them is the textbook as they are known to be justificatory. This means that they introduce a concept with an assumption that it is already known by learners. Textbooks reinforced a known principle and law than in explaining and bringing about conceptual understanding. Another impediment to conceptual change in science is that conceptual change is an assumption that correct data leads to correct conclusions or changes in the conceptual framework. This is incorrect as data is usually affected by pre-conceptions about a phenomenon. Again, extreme empiricism is seen as a barrier to conceptual change as scientific change is assumed to be generated from empirical data. Most learners and scientists explain the data away. Nersessian (2001) argues further by saying that Galileo played around with thought experiments without really getting into a laboratory and brought about profound scientific revolutions and insights. This involves the mental manipulation of variables beyond what is physically possible and then offer plausible ideas and scientific explanations. Another problem faced in most conceptual change strategies is an over reliance on algorithmic reasoning (deductive or inductive) as reasoning goes beyond logic. One proposal by Nersessian (2001) is that conceptual change should engage imagistic and analogic reasoning as they produce an abstract schema or template which facilitates conceptual change. Imagistic reasoning provides the mental template and analogies provide a primary vehicle to transfer knowledge from one domain to the other. Having exposed these weaknesses of some of the conceptual change strategies, Nersessian (2001) went on to propose that cognitive–historical analysis is a potential conceptual change strategy as it demystifies how scientists think and bring about scientific revolutions and paradigm shifts in the understanding of science.

Having discussed these conceptual strategies, it is important to note for the purposes of this study, the conceptual change theory (Hewson & Hewson, 1984; Kuhn, 1962; and Posner et al.,1982) will be used to inform research questions one and two as they offer a viable lens and strategies in the understanding of conceptual change. Social constructivism will be used to inform research questions three and four. This is done for several reasons.

According to Taber (2011), social constructivism provides a sound theory for explaining teaching and learning at all levels and it is drawn from wide research (Kuhn, 1962; Posner et al., 1982) and broad scholarship. This is alluded to by Palmer (2005) who asserts that constructivism is seen as a dominant paradigm of learning in science. Firstly, social constructivism is a learner-centered approach to teaching and learning. Secondly, it describes with clarity, how human learning occurs, especially the zone of proximal development which clearly juxtaposes the importance of individual schema, the role of prior knowledge and the role of the teacher in the learning environment. Social constructivism is clear on the importance of guided instruction and the critical importance of group and collaborative work. Thirdly, it describes the factors that channel learning and fourthly, it describes how curriculum and instruction should be designed (Taber, 2011).

Constructivism also describes both the individual and social construction of knowledge. Another advantage is that literature also describes what constructivism is not and the outstanding issue so that when one uses this philosophy, there is no doubt one avoids the myths, and plans teaching with the necessary awareness of the weakness of this philosophy. Activity theory and system theory although inclined to use of technology in the classroom which the main idea of this study, they fall short on describing the classroom design to inform instruction and literature does not objectively expose the weakness as well as some loopholes of these theories. Besides, these theories also involve collaboration and learner centeredness as their key tenets. However, social constructivism describes most of the tenets they describe such as collaboration, learner centeredness and interactivity of people. This makes social constructivism an all-embracing theory to use in this study. Constructivism has been widely used in science education research in the last two decades. It is therefore prudent to use a widely utilized framework for some time as there is rich information to refer to and to inform design of this study.

2.14 Conclusion

This chapter gave a historical relevance of science in technological development. This was then linked to the contemporary learning of Physical sciences to debate the importance of passing and understanding Physical sciences. Extensive lists of barriers to learning of Physical sciences were also discussed. This was then linked to efforts that have been made in the science community to confront alternative conceptions in Physical sciences. Advantages of computer simulations were then discussed to justify their use in this study. The chapter gave a detailed review of the alternative conceptions of electricity. This was linked to how computer simulations have been used to address the alternative conceptions of electricity. The last part of the chapter looked at the theoretical frameworks that have been used in science education to inform studies. These included constructivist theory, information processing theory, activity theory, systems theory and conceptual change theory. The next chapter describes in detail the methodology and research design used to collect data.

Chapter 3

Methodology and Research Design

3.1 Introduction

This chapter will look at the research design by looking at the rationale for choosing the mixed methods design. This will be followed by a description of the purposive sampling method. The chapter also gives a detailed description of the experimental method and how confounding variables were controlled for during the study. This is followed by a description of the instruments used to gather data which includes a conceptual test, a semi-structured interview and a video. Finally, the chapter looks at ethical dilemmas and how they were addressed to produce reliable and valid data.

3.2 Rationale for mixed methods methodology

The design of the research was informed by the research questions reported in chapter 1. The first research question asks, "What are Grade 10 learners understanding of electricity concepts prior to the implementation of computer simulations?" The second research question asks, "What are Grade 10 learners understanding of electricity concepts after the implementation of computer simulations?"

These two research questions focus on measuring performance before and after using computer simulations. The independent variable was the simulation treatment and the dependent variable was the performance of the learners after the treatment was administered. An Electricity Conceptual Test (ECT) was then designed to measure the effect of computer simulations on participants. As will be explained in detail below, the pre-test and post-test gathered quantitative data. Quantitative data includes data that is gathered through a questionnaire of multiple choice questions which generate numbers in the form of frequencies such as medians, modes and means to try and makes sense of the data. Quantitative data also allows for statistical analysis to be performed so that probability inferences can be made.

The third research question asks, “How do learners in Grade 10 engage with computer simulation activities on electricity?” This research question looks at the behavioural aspect of how learners responded to the treatment in the project, and in order to gather data of this form, videotaping was used to gather the pictorial and motion picture data to look closely at how learner’s behaved when they were working with computer simulations.

The fourth research question asks, “Why do learners in Grade 10 engage with computer simulations in electricity the way they do?” This research question was used as a follow up to explore in depth the first, second and third research questions, and made use of an open ended interview questions. Interview data create words that were analysed to explore deeply and find themes that would give a better understanding of the effect of computer simulations in aiding understanding of electricity concepts. Quantitative data cannot answer fully all the research questions stated above and the use of video data and interviews were used to triangulate and compensate for the weaknesses of quantitative data when used alone. Therefore, one of the practical ways to provide answers to the research questions was to use both quantitative and qualitative methods for mixed methods research design. Mixed methods design is a procedure of collecting and analysing data which includes both quantitative and qualitative data (Creswell, 2012) In order to adequately address the research questions, it was then appropriate to adopt a design that would generate numerical, pictorial and voice data. The quantitative approach cannot answer the qualitative questions in detail. A qualitative approach cannot answer quantitative questions in detail. Data from the qualitative questions would enhance, elaborate and complement the quantitative data and vice versa (Creswell, 2012).

A mixed method approach naturally brings advantages of the quantitative and qualitative methods. Advantages of the quantitative method are that it is easy to test and validate theories and hypothesis, can test causal relationships, is able to generalize the results, have the ability to eliminate confounding variables and provides numerical data which is easy to analyse. Results from quantitative methods are generally considered independent of the researcher, results appeal to policy makers and are useful for studying a large number of people (Johnson & Christensen, 2014). The quantitative approach however, does not provide personal and deep insights into a problem or phenomenon. This is compensated by using the qualitative method. Advantages of the qualitative approach are that it obtains information from a small number of people, can describe the process and personal experiences in depth, can expose contextual factors relating to the case, exposes how participants interpret information, and answers how and why something occurred (Cohen, Manion, & Morrison, 2007). Mixed methods therefore, falls under the research paradigm of pragmatism which is defined as a research approach which uses methods that practically answers the research questions at hand (Johnson & Christensen, 2014).

3.3 Explanatory mixed method

Mixed methods research comes in many types. This study uses a type called explanatory mixed method. This design involves sequentially collecting quantitative data and then qualitative data (Cameron, 2009). The quantitative approach gives the general picture of the problem and then the qualitative approach seeks to refine, explore, extend and explain the picture that was created by quantitative data. Johnson and Christensen (2014) assert that in an explanatory approach, qualitative data explains quantitative data in such a way that research questions are answered fully. This approach logically follows the research questions in sequence and indicates how data were also analysed. Quantitative data were collected and analysed first. This was then followed by qualitative data collection and analysis.

The quantitative approach used the experimental design to measure performance. The strength of the experimental approach is based on the following assumptions: The experimental approach was used for its strength in gathering data that is independent of the influence of the researcher (Ivankova, Creswell, & Stick, 2006; Christensen, Johnson & Turner, 2014). The other advantage is the ability of an experiment to control variables and create a strong causative relationship. Research instruments such as tests and questionnaires are rigorously designed to increase their internal validity and hence, increase the generalisability of the findings. Data from tests and questionnaires are quick to analyse as computer statistical software can be used compared to extensive interview data (Cohen et al., 2007). Confounding variables are easily controlled in an experimental approach as random sample selection and random assignment techniques are used to cancel the effect of variables that the sample naturally brings (Creswell, 2012).

3.4 Sampling

Important aspects in a sample selection strategy include time orientation and the relationship of the sample and sampling scheme (Jiao, Onwuegbuzie, & Collins, 2007). Time orientation includes the general research approach. The study used a quantitative method which then informs the qualitative method. More data would come from the quantitative concept test. The qualitative results were triangulated with video and interview data. The study also gives more weight to the quantitative aspect more than the qualitative aspect. All participants were involved in the quantitative phase of the study where they participated in the pre-test and post-test. For the qualitative phase, half of the sample from the quantitative phase participated in the qualitative phase of video observations and focus group interviews. Video observations and interviews were done as a follow up to quantitative test results. The next level is the relationships of the sample. Participants were all from the same grade and were taught the same content at the same pace by the same teacher. Participants were all from the same socio-economic background. The relationship of the sample was therefore identical. Since the setting, groups and individuals were based on similar characteristics, the sampling scheme was homogenous (Jiao et al., 2007; Onwuegbuzie & Collins, 2007). The schematic diagram in Figure 1 illustrates this strategy.

The study was undertaken to investigate a problem in performance by Physical sciences learners in the school that the researcher was teaching at the time. This means data were collected in situ, where the choice of participants was specific to grade 10 Physical sciences learners in a particular school. Therefore, the strategy used in sampling was purposive sampling. The school was underperforming in Physical sciences and this made it appropriate to investigate the causes. The Grade 10 class has a large number of learners which made it appropriate for quantitative data gathering and statistical analysis. Choosing only Grade 10's helped to control other variables such as age as most of the participants at this level are entering the FET phase. Intervention strategies at this level will have an impact as the participants' progress through the grades. At this level conceptual understanding is controlled because in Grade 11 and 12, conceptual understanding in the topic of electricity is varied. Again, the school did not have computers and therefore, it became imperative to reduce the number of learners only to grade 10 to match the number of computers the researcher brought to the site. Therefore, purposive sampling was appropriate to make the study feasible.

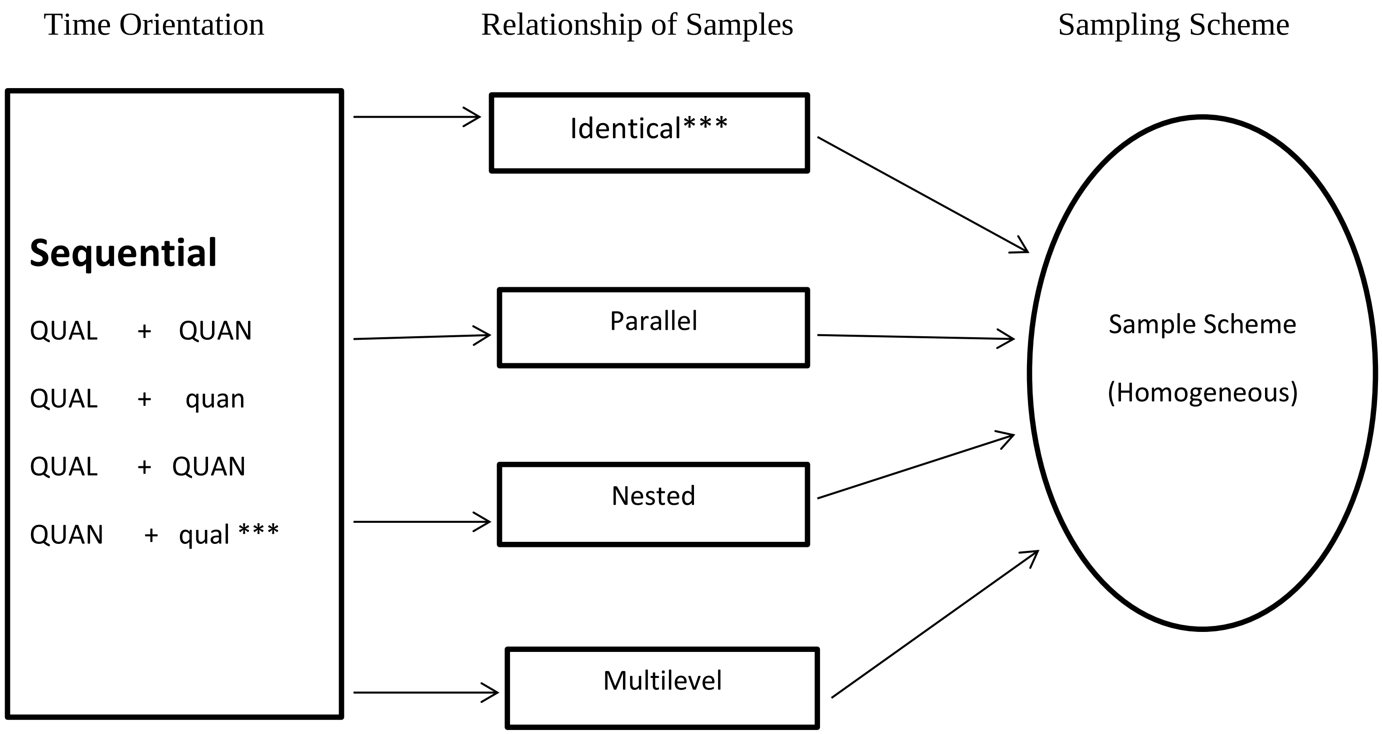


Figure 1. Diagrammatic representation of sampling strategy in mixed methodology

Adapted from Collins et al. (2007)

As indicated above, the study used a mixed method design which included the quantitative as well as the qualitative data collection. To be consistent with this research design, an experimental method was used to gather quantitative data by use of a conceptual test. This quantitative aspect was then triangulated by observational and interview data which was qualitative in nature. Therefore, the sampling was specific to the site as well as the participants.

Purposive sampling is when researchers intentionally select individuals and sites to learn and understand the central phenomenon (Cohen et al., 2007; Tashakkori & Teddlie, 1998). Additional reasons leading to purposive sampling was that the researcher was the Physical sciences teacher at the study site. As indicated above, the school had poor results in Physical sciences before and during the tenure of the researcher. It became convenient to conduct the study as the researcher had more control of the site and the participants and had no need to travel to other sites to collect data. Therefore, the sampling strategy reduced material and logistical costs. The school was surrounded by urban schools which were performing well in the subject. This made finding a larger sample from other schools in the area very difficult. Another factor that was considered by the researcher was to control confounding variables such as a different teacher, different attitude, different subject motivation, discipline, syllabus and content coverage. Choosing one school with only Grade 10 Physical sciences Physical sciences learners taught by one teacher equated the participants and controlled many of these confounding variables. This kind of sampling is referred as a homogenous sampling scheme. According to Collins, Onwuegbuzie and Jiao (2007), a homogenous sampling scheme is one in which settings, groups and individuals are chosen on the basis of similar or specific characteristics. As explained above, the research design is an explanatory mixed methods design. The quantitative data collection is followed by qualitative data collection. For the quantitative part, all 68 students participated in the pre-test. After the administration of the pre-test, participants were randomly split into two groups; one treatment group and the other a control group. This was done by the use of a class register of those who agreed to participate. The register has an advantage that students are placed in alphabetical order only and not on ability or any other attributes. Only the treatment group (25 participants) was exposed to the computer simulation activities for a week and were videotaped during the treatment. A post-test was then administered to both groups. After collection of the pre-test and post-test results, simulation activities were then administered to the control group so that they would have the same experience as the treatment group in case the simulation activities were beneficial at the same time without affecting the results of the experiment. Participants were then interviewed after the post-test. Focus group interviews were then conducted to gather qualitative data. These focus groups were made of six participants each. Data were then analysed.

3.5 Pre-Test Post-Test control group design

In an experimental design, the confounding variables are the ones that are hard to control. These include age, motivation, stress and intelligence. How to control them was described below. The specific experimental design used was pre-test post-test control group design. This is illustrated in Figure 2 below. As mentioned above, the sample had 68 grade 10 participants. These participants were given a pre-test and later randomly assigned to two groups. The random assignment used the number generator technique (Christensen & Johnson, 2016). Other random assignment techniques used included matching. This included putting learners of the same age together and then put them in different groups. Those of the same academic performance were grouped together and then randomly assigned to different groups. Gender was controlled for by putting girls together then randomly assigning to different groups. Boys were put together and also randomly assigned to different groups. The treatment group (25 students) was exposed to direct current simulation activities. This group worked on simulation activities on their own without the intervention of the teacher as it was important to measure the effect of computer simulations without the intervention of the teacher. The control group (27 students) was not exposed to simulation activities. The number of participants for experimental and control decreased as some participants declined to continue with the research.

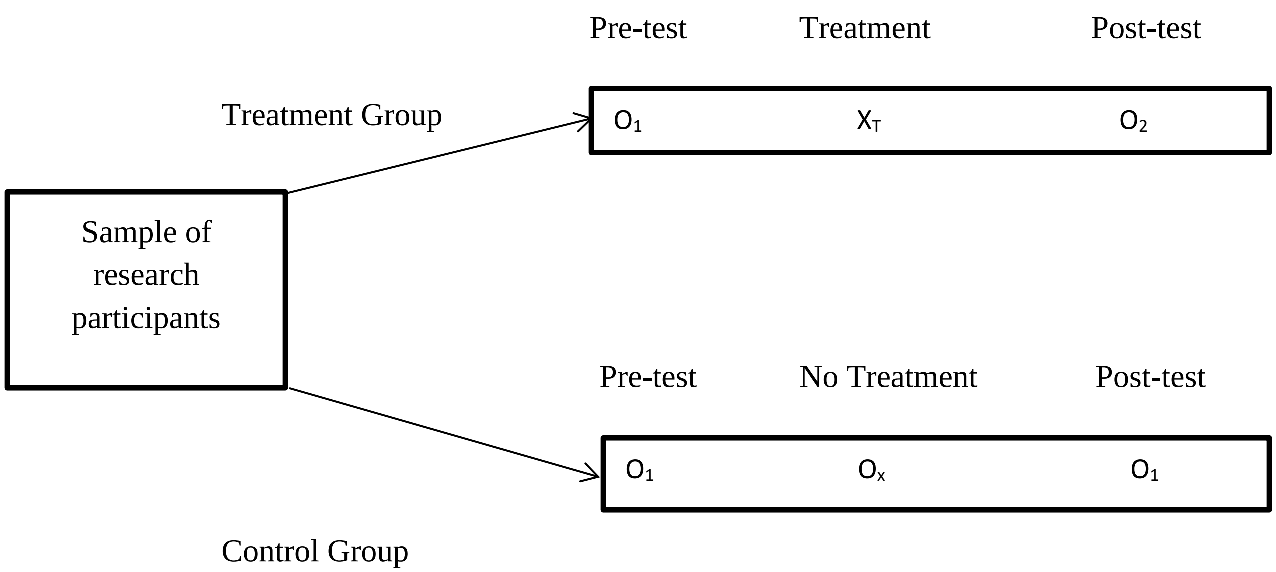


Figure 2. Diagrammatic representation of pre-test, post-test experimental and control group design. [Adapted from Johnson and Christensen (2016)]

After the treatment group was exposed to simulation activities, both groups were given a post-test with the same test items. The control group continued practising on the circuit diagrams worksheets without exposure to computer simulations. They were also given time to practice as the experimental group before a post test was administered. The control group was then exposed to the simulation activities after the post- test.

There are experimental factors that need to be controlled during the period between the pre-test and post-test that may affect results which are: differential attrition, history, testing, instrumentation and maturation (Cohen et al., 2007; Creswell, 2012; Johnson & Christensen, 2016). The pre-test post-test control group design was able to control the above variables, except differential attrition which the researcher could not control: Differential attrition is when participants drop out of the research and the number decreases (Creswell, 2012). This can affect statistical analysis and the researcher had little control over it. History means events that take place between the pre-test and post-test that influence results including familiarization with the simulation software of the other group. This was controlled for by making sure that each student stayed in their control group or treatment group and there was no sharing of the software between groups. Testing is when the post-test scores are influenced by students having familiarized themselves with the initial test. In this case, participants were told they would have another test with different items although the structure and content of the test did not change. Instrumentation is the change in scores due to the way the dependent variable is measured. The same test was administered for the pre-test and post-test to minimize the problem. Maturation refers to the physical and mental change that takes place due to the experimental treatment. This was controlled for by having the period between the pre-test and post-test minimized. There was a week gap between the pre-test and post-test. It took one week between pre-test and post-test. Participants undertook simulation activities on their own and the teacher only facilitated. Differential selection, a situation where equivalent groups are created was controlled by random assignment. Any difference in comparison was due to chance. Sequencing, in which a participant participates in both treatments, was controlled for by the teacher who was familiar with the participants and their groups since the researcher was the teacher of the learners. Hence, it was not possible for the participants to change groups.

3.6 Research Instruments

In order to measure the performance of participants and determine the kind of alternative conceptions they were having before and after intervention with computer simulations, an electricity conceptual test (ECT) test was developed (Appendix A). This conceptual test was then used to answer research question 1 and research question 2. In order to observe the behaviour of participants when engaging with computer simulations, a video was recorded, and in order to triangulate the test data and videos, interviews of participants was undertaken. These instruments are described in detail below starting with conceptual test, video and lastly, the interview.

3.6.1 The Electricity Conceptual Test (ECT)

A conceptual test was developed to gather quantitative data. A test measures skill, depth of understanding and an individual's knowledge in a given subject domain (Gall, Gall & Borg, 2005). This section describes how the test was developed, the way content was incorporated, the building of reliability and validity of the test as well as the discussion of the merits and demerits of the test. As indicated in chapter 1 and chapter 2, the purpose of the conceptual test (ECT) is to measure the level of alternative conceptions that grade 10 learners have about electricity. To this end, the researcher used comments from textbooks used in grade 10, national examination reports as well as research articles on alternative conceptions of electricity. The ECT will therefore try to find if the alternative conceptions found in literature are similar to the participants. The test will also try and find if there are any new alternative conceptions arising that have not been described in literature. This instrument was developed by looking at the grade 10 CAPS document and by examining the learning outcomes for electricity. The document emphasized one major misconception, that a battery is considered a constant current source. This misconception was then incorporated in the ECT design. Examination of the Grade 10 textbooks (Bronster, James, Carter, & Horn, 2013; Kelder et al., 2008) also indicated the same misconception as the CAPS document where learners always think the battery is a constant current source. Most Department of Basic Education grade 10 examination papers tested quantitative aspects of electricity but not qualitative aspects that solicited conceptual understanding. Early research on alternative conceptions in the topic of electricity (Osborne, 1983; Riley et al., 1981; Shipstone, 1984) articles on the topic of alternative conceptions of electricity provided greater insights. Shipstone (1988) provided one of the initial insights on the topic and provided common alternative conceptions in the topic of direct current. A DIRECT test (Engelhardt, 1997) described alternative conceptions in detail. The test provided more questions with enriched insights into alternative conceptions held by most learners from high school to university in the topic of electricity. Some of the ECT items used in this study are adopted from this research because the test has already been validated and its reliability was confirmed by experts in the field. However, as described in paragraphs below, ECT had to be piloted since not all questions came from DIRECT. The following are themes of alternative conceptions that were used to design the conceptual test. These themes have been described in more detail in chapter 2 above and are summarized below.

The first theme is battery superposition. This theme is a conception in which participants think that regardless of arrangement, the bulb shines two times brighter if another battery cell is added. Learners fail to understand that a battery is part of the external circuit (Engelhardt, 1997). The second theme is that participants believe that the battery is a constant current source. This means that regardless of the components of the circuit and their arrangement, a battery cell will supply the same amount of current (Cohen et al., 1983). The amount of current produced by a battery is affected by total external resistance. The third theme which is incorporated in the test is the concept of complete circuit where participants fail to recognize a complete and incomplete circuit and how it affects energy transfer in the circuit. The fourth theme is where participants conceive that current is consumed in the circuit. The incorrect conception is that current is used up as it moves from the source through circuit components. Learners have a conception that current is affected by what happens before a component and not after it (Shipstone, 1988). This misconception is also referred to as time dependent (Riley et al., 1981). The fifth theme incorporated into the test is the alternative conception that when current reaches a junction, it is split up into two equal halves irrespective of total resistance in each branch. This was also tested. Properties of resistance in a direct current circuit is also least understood. In this sixth theme, participants perceive resistance as a function of current. This means that if there is no current, participants would incorrectly think that resistance of the resistor becomes zero. The seventh theme is the term confusion. Participants do confuse terms such as current, potential difference, power and energy as having the same properties (Engelhardt, 1997; Education, 2014, 2016; Rankumise, 2012). Interpreting a short circuit is another eighth conceptual challenge in the topic of electricity. This is where participants are unable to describe what will happen when a wire of low resistance is put between two resistors. Current would flow into the wire and cut off flow to resistors. The ninth theme incorporated in the test was where participants displayed what is termed local reasoning. This is where participants incorrectly reason that a change on one part of the circuit does not affect other parts of the circuit. The tenth alternative conception is where participants confuse electron flow and conventional flow current. In this case, participants incorrectly reasoned that protons, instead of electrons, move from the negative terminal to the positive terminal. The eleventh and last theme is misunderstanding the microscopic nature of the circuit. This is where participants have a flawed model of what constitutes current in a conductor. A minimum of two questions were designed around each alternative conception. A pilot test was conducted on three schools (Appendix G). One university professor of physics education and four experienced teachers of Physical sciences in high school gave feedback on the quality of the questions and made comments on the quality and level of questioning. Test items were taken from DIRECT version 1.1 and was modified to suit grade 10's and was termed ECT. Aspects that were adjusted included the removal of grade 11, grade 12 and university content. Modification also included removing questions on magnetism and reducing items from 29 to 25. Test items were then developed to suit grade 10 participants using the alternative conception themes described above as well as items suggested by an expert university professor and experienced high school teachers.

The format of questioning used in ECT was multiple choice questions. A multiple choice test with 25 items was then developed. Multiple choice questions have many advantages in quantitative data collection over other test types (Zimmaro, 2016). Firstly, MCQs have the ability to allow the diagnosis of difficult questions easier as they can easily be revealed by item analysis. Secondly, they make analysis to large participants easy. Thirdly, MCQ scores are easily compared within the group and across groups. Fourthly, it easily discriminates weak students from strong students and fifth, they cover a lot material in a short time. Lastly, multiple choice avoids making errors, marker subjectivity, marking inconsistency and decreased motivation (Cohen et al., 2007; Zimmaro, 2016).

3.7 Quality of the multiple choice questions

The ECT also removed calculations and therefore it was mainly a qualitative test with descriptive concepts which solicited deep understanding. This is because as described above in the review of literature, problem solving and calculations mask alternative conceptions. In addition to this, several steps were taken to increase the quality of the multiple choice questions. A considerable number of items were incorporated into the test. This was to make sure that there were at least two questions per theme in order to triangulate alternative conceptions if there were inconsistencies. The stem of a multiple choice item was checked for simple understandable language with clear expression. One question was simply phrased: A battery is a source of______. This means that in most questions, spelling mistakes, grammatical errors and ambiguous statements were largely eliminated. Ambiguous statements were also avoided by removing double negative wording which confuses participants. An example of double negative questioning that was avoided include: Which ammeter above has the potential not to record no current? _______. Another important area of the test is the distractors. These are the answer choices that participants need to choose. Good distractors are effective diagnostic tools and in this study, they would point out alternative conceptions that participants have. Distractors for each question item were designed in such a way that they were all plausible and the same length. Plausible means that it must be challenging to find the correct answer (Zimmaro, 2016). If the distractors are of the same length it would be challenging for them to pick up the wrong and correct answer. If the distractors are of varying length, some students would infer that the longest or shortest answer is the correct choice. This is a form of intelligent guessing which can be discouraged by changing the position of the correct answer. As mentioned earlier, the test was then given to an expert physics education professor at university and four experienced high school teachers (Appendix H)**.** After taking their advice and making the necessary corrections, the test was then piloted to three high school grade 10 classes with an average of thirty participants per school per class. There was consistency in the average performance. After piloting the test, very difficult and very simple items were adjusted. The Spearman Brown reliability coefficient was 0.71 and this means the test fell within an acceptable range of reliability. Simple questions on complete circuits were removed and difficult questions such as one on combined circuits were removed as well.

The MCQs have inherent weaknesses. Besides the participants guessing the correct answer, which was minimized by good distractors (verified through analysing pilot test), it could not test the expression of ideas and hence, there is no feedback on the thought process of the participants. Information on how participants understood and misunderstood the concepts was not measured. MCQs also could not measure why participants behaved the way they did during treatment with computer simulations. Open ended interview questions were then designed to triangulate the test scores as well observational data to get a deeper understanding of the experiences of participants with the conceptual test and the computer simulation activities. Video data recorded the behaviour of participants as they dealt with computer simulations and below is a brief description of the video instrument.

3.8 The video

A video is an instrument used to gather qualitative data. A video allows to collect data whilst the event is unfolding (Caldwell & Atwell, 2005). Videos gather observational data and hence, data is stored in the form of motion pictures and is a function of time. Not only does a video record a motion picture but it also records words of the observational situation and non-verbal cues (Cohen et al, 2007). The video observation took place in the grade 10 classroom where participants were using computer simulations and were placed in groups of four. The teacher who was the researcher did not intervene with the way participants interacted with computers simulation activities and only assisted when the computer froze and needed refreshing. The teacher did not give directions on content and behaviour. An observation comes in different forms. It can be highly structured, semi structured or unstructured. A structured observation is where the observer is clear about data they want to gather. This means they enter into a context with a check list of items which they are going to observe. A structured observation is therefore a hypothesis confirmation exercise and on the other hand, the unstructured observation is where the observer gathers data first in order to generate hypotheses and theories (Cohen et al, 2007). This study adopted the unstructured approach. This approach allowed the observer to collect all forms of data without selecting which one is important and which one is not. A video camera permanently stored data. Hence, there was no need to have an observational schedule since the occasion can be replayed several times to analyse a particular participant. Since the researcher gave instructions and assisted participants where they had difficulty using a computer the appropriate term to use is observer as participant (Johnson & Turner, 2003). Codes and themes were developed after all the video data has been recorded.

Participants were randomly selected and put into groups with an equal number of boys and girls in each group. Random selection was a way of mixing intellectual ability and at least one group had one person who had good computer literacy. Those who had computer literacy were chosen after a short computer familiarization exercise was done with six laptops for a week before using computer simulations. Observational video data comes with many advantages such as triangulation, valid authentic data, recording of subtle classroom behaviour, clearly focuses on participant behaviour, offers an opportunity to record non-verbal behaviour and avoids the weaknesses of interviews where data is perception based (Gall et al., 2005). Observation with a video is advantageous compared to an observational schedule without a video recording and yield more accurate data (Cohen et al., 2007, Tashakkori & Teddlie, 1998). This is because a video recording compensates for selective attention, selective data entry and selective memory which is a weakness of interview data and an observation protocol that has a check list of items to be ticked. However, video data can be problematic when it comes to interpretation. Selective data interpretation when coding and forming themes is a real problem from videos as what counts as real and valid data will always be challenging. There is also the disadvantage of participants adjusting their behaviour when they know they are being recorded. This phenomenon is known as Hawthorne's effect and affects the accuracy of the data collected. This is termed reactivity or expectancy effect by Cohen et al. (2007). Data from the video was then stored for analysis and the details of analysis are in chapter 4. Another limitation of video data is that one cannot infer intention from observation (Cohen et al 2007).

Observational video brings some ethical dilemmas. Covert observations where the researcher hides their real intention in the research violates the right to consent of participants. At the same time, overtly stating your intention would result in gathering artificial data from participants as they adjust their behaviour. Data generated becomes unreliable.

3.9 The interview

An interview makes it possible to collect data by direct interaction between the researcher and participants (Gall et al., 2005). As described above, a pre-test and post-test were able to gather quantitative data. An observational video was able to collect qualitative data focusing on behavioural data. These two instruments have the merit of collecting data to a large number of participants and if it is a parametric test as the one used in this study, data can be analysed using statistical instruments. However, quantitative data is limited to exposing the thought process of participants and cannot measure processes and attitudes (Creswell, 2012). Although video data has the strength of showing the process in which participants engaged in computer simulations, it is not easy to infer a participant's intention from observation (Cohen et al, 2007). Interview data has the capacity to compensate for the limits of test data and video data. While test and video data tend to put distance between the participant and the researcher or observer, an interview tends to decrease that distance and encourages rapport. There is a direct exchange of information between the researcher and the participants (Lauer, 2006; Suter, 2012). It is a tool that increases human contact of the research and comes with several advantages. Whist tests and questionnaires can easily give quantitative surface information on performance measures, they cannot measure attitude, motivation, opinions and thought process used in answering questions (Cohen et al., 2007). For example, in this study, the test offered to participants was able to measure performance and diagnose alternative conceptions but could not give information as to why they did poorly in some questions. Again, in an observation, some participants were not actively manipulating the computer during simulation activities. Instead of making assumptions about performance results and behaviour in the video, an interview of the participants would give deep insights as to how and why certain things happened. In other words the interview triangulates the conceptual test and video data. The act of using different research instruments on the participants is termed methodological triangulation and helps to validate research data (Cohen et al., 2007). An interview also allowed a follow up to unexpected results possible and in that act, completes the data collection exercise.

Interviews come in different types and forms depending on the purpose and research questions. There is the informal conversational interview, open interview approach, standardized open-ended interview and closed quantitative interview (Cohen et al., 2007). Other authors such as Rowley (2012), classifies them as structured, semi-structured and unstructured interviews. Depending on the purpose, structured close-ended interviews gather quantitative data. Semi-structured interviews gather a continuum of data from quantitative to qualitative (Creswell, 2012). Unstructured interviews are engineered to gather qualitative data. Each type and form comes with its merits and demerits. This study however, adopted the semi-structured interview in line with the mixed methods design. Mixed methods design gathers both quantitative and qualitative data and semi-structured interview in this case would be fit for this purpose.

Details of the interview questions are found in Appendix F. The first three questions sought to gather data around the conceptual test. Hence, they solicit brief responses from participants. In this effort, these data would help to confirm and correlate quantitative results. Brief and specific responses would also be easier to analyse and are a good follow up to performance variable that is measured by research question one and two. Probing was undertaken to seek why participants thought the way they did, especially why some questions were difficult. Open-ended interview questions were designed from question 3 to question 4 (Appendix F). These questions sought answers to research questions 3 and research questions 4. These research questions interrogated the behaviour of participants when they were working with computer simulations. The purpose was to confirm and extend the theoretical implications of working with computer simulations and how best they can be used to enhance conceptual understanding. Understanding, attitudes and opinions cannot be measured using a test or questionnaire. The last three questions of the interview would measure and record the thought processes participants used when answering the conceptual test and substantiate their behaviour when engaging with computer simulations. In the design of the interview questions, care was taken to make them simple, clear, unambiguous, unassuming, and less speculative and where they don't lead to an answer (Cohen, et al, 2007). Additionally, to allow participants to feel at ease during the interview, questions should progressively move from more simple, short and specific questions to those that are more complex and more open-ended in style. Open-ended interview questions solicit deeper explanations, give insights into the research problem, increases rapport during the interview process and increases the potential to produce unexpected answers. Unexpected answers could add value to the research problem. An interview as an instrument is not without its problems; the main problem being an interpretive problem. The interviewee might not interpret the question correctly and may give data that is not relevant to the research questions. Another problem is interpretive bias. The researcher has a dilemma in selecting information that would be appropriate for analysis and hence, there is an element of bias which may affect the quality of the findings. The interviewee might also add to the problem by giving answers that are socially desirable as they are aware that they are being researched. Another issue is that an interview is best at a small number of learners and therefore, results from this sample cannot be generalized to other populations. In this study, the interview was administered to twenty one students who were in groups of three.

3.10 Ethical Consideration

In order to gather data from the school, permission to conduct the research was sought from the Department of Education Head Office as well as from the principal of the school (Appendix B) where I was doing the research. Consent was requested from the guardians of learners I was doing research with so a letter of consent was drafted seeking permission from parents of participants (Appendix C). The consent letter explains the objectives of the research and its purpose. The letter also explained to guardians that their child's name will be anonymous and that they will not be harmed by the research. The letter to the department of education, principal and parents stated clearly my contact details, the institution the research study will be submitted to and my supervisor for my research. It was also clearly stated that, participants were allowed to decline participation at any stage and contribution to the study was strictly voluntary (Appendix D). A commitment was also made to keep the school and the participants anonymous when reporting and publishing results of the research. The researcher received ethical clearance from the university to go on carry out the study after careful consideration (Appendix E). The topic of electricity challenges learners and this has been discussed extensively in Chapter 1 and Chapter 2. It is anticipated, results of this research will immensely contribute to how to teach the topic effectively. Hence, results and findings of the research were to be shared with the school and the participants.

Computer simulations were a new pedagogical tool used for the first time in the school. Its advantages have been discussed in chapter 2. According to the experimental design, only participants who were in the experimental group were to receive a treatment with computer simulations. The control group would continue with traditional instruction. This is not in line with the promise to parents that all participants will benefit from the intervention. To keep this promise, the control group was exposed to computer simulation activities after the post-test so that they would also benefit. Therefore, the experiment was designed in such a way that all participants would experience the computer simulations. Assignment into experimental groups and control groups was random. Besides the obvious reason of making the data statistically valid, random group assignments were undertaken to avoid stereotyping and discriminating learners intentionally. Participants who had average poor performance in pre-test and post-test as well as those that showed a great improvement in pre-test and post-test were invited for an interview. Another criterion was that they should have worked with the computer simulations. Care was taken in the interview that they were free to express themselves and confidentiality of what they say was to be kept. During observations with computer simulations, the role of the researcher was explicitly explained to participants to avoid misrepresenting their intention.

3. 11 Conclusion

This chapter looked at the research design by looking at the rationale for choosing the mixed methods design. This was followed by a description of the sampling method which was purposive in order to answer the research questions and to for the research design. The chapter also gave a detailed description of the experimental method and how confounding variables were controlled. Instruments used to gather data were described and these include a conceptual test, a semi-structured interview and a video. Finally, the chapter described ethical dilemmas and how they were addressed to produce reliable and valid data. The next chapter analyses data and reports on the findings of the research.

Chapter 4

Data Analysis

4.1 Introduction

This chapter reports on the analysis of data collected in the study. Data were collected using a conceptual test, video observations and interviews. These research instruments were described in more detail in chapter 3. This chapter will first describe and report on results gathered through the pre-test administered to all participants before they were divided into the control group and experimental group. This is done through a categorization of questions by looking at the alternative conceptions they were testing and how these misconceptions fared in scores. The analysis of pre-test results is then followed by an analysis of the post-test experimental results. This section analyses and reports on the test results of participants who were exposed to computer simulations. This is then followed by an analysis of post-test results of the control group. This group received traditional instruction and were not exposed to computer simulations. This group was the control group and was there to provide comparison to the experimental group. A combined analysis of all the pre-test, post-test experimental and post-test control group was reported. This section is then followed by statistical testing for significance between the groups. This section uses descriptive statistics and independent t-tests are performed to see if there is any significance difference between the groups. Effect size tests such as Cohen's d are also performed to see if there are any practical differences between these groups. These quantitative results are then triangulated with video and interview results. This chapter ends with an analysis of observation and interview data.

4.2 Pre-Test Results

As described in chapter 3, alternative conceptions tested fell in different categories and table 2 shows the different general categories alternative conceptions fell into. The table also shows each question and the concept that it tested. A total of 16 categories and a number of questions emerged. The theme of interpreting series circuits, short circuits and parallel circuits had more than two questions each. Other categories of alternative conceptions had a maximum of two questions set. After the administration of the test, a performance analysis of the questions was completed and table 2 summarized the performance categories in which each question and the alternative conceptions which they fell into. This made it easy to see which questions and alternative conceptions were difficult for participants and which ones were easy.

Table 2: Summary of Categories, Alternative Conceptions and Questions

Concept	**Question**
Ohm’s law	4, 20
Current in parallel always split into half	10
Resistance in series and parallel	9, 21
Interpreting short circuits	8, 11, and 25
Current Definition	1
Direction of current in D.C circuit	18, 24
Conservation of current	2, 7
Current voltage confusion	14
Current resistance confusion	13
Global interpretation of circuits	12, 19
Interpreting parallel and series circuits	5, 12, 19, 22, 23
Complete circuit	3
Energy Conversions in a circuit	6
Purpose of battery	15, 16
Nature of charge in conductor	17

These scores were then used to group alternative conceptions according to the level of difficulty, item discrimination and scores on each item distractor. Alternative conceptions that recorded high item discrimination, high scores, low scores and high difficulty are indicated in bold in Table 3 below. A Statistical Package for Social Sciences Software (SPSS) was used to generate the frequencies of scores in table 3 below.

Table 3: Summary of Pre-Test Results Showing Item Analysis:

N = 68

Question	Option	Difficulty	Discrimination	Learners Choices %				
				A	B	C	D	NR
1	C	**0.59**	**0.50**	14	20	**59**	6	0
2	D	**0.70**	0.33	3	3	23	**70**	2
3	C	**0.76**	0.42	5	11	**76**	3	3
4	D	**0.82**	0.42	8	5	5	**82**	2
5	A	**0.27**	**0.67**	**29**	11	20	24	**18**
6	D	**0.38**	**0.67**	15	15	30	**38**	2
7	C	**0.70**	0.33	3	6	**70**	21	0
8	C	**0.26**	**0.50**	**26**	32	52	27	0
9	C	**0.52**	0.25	15	6	**52**	27	0
10	B	**0.46**	**0.75**	17	**46**	18	18	2
11	D	**0.15**	**0.08**	21	14	50	**15**	0
12	A	**0.33**	0.25	**33**	21	24	21	0
13	C	**0.30**	0.50	23	17	**30**	30	0
14	D	**0.27**	0.25	44	6	21	**27**	2
15	C	**0.21**	**0.17**	21	42	**21**	4	0
16	B	**0.46**	0.58	21	**46**	36	0	0
17	A	**0.21**	0.33	**21**	17	44	18	0
18	B	**0.46**	**0.75**	20	**46**	15	20	0
19	A	**0.29**	**0.58**	**29**	15	24	29	3
20	A	**0.42**	**0.50**	**42**	9	14	33	2

21	A	**0.39**	**0.17**	**39**	24	12	23	2
22	D	**0.26**	0.42	20	27	26	**26**	2
23	C	**0.71**	**0.17**	18	6	**71**	5	0
24	D	**0.38**	0.33	8	41	14	**38**	0
25	C	**0.17**	0.33	24	41	**17**	17	2

Difficulty measures how well participants did in a particular question and item discrimination measures how well a question separates high score participants from low score participants. Questions above 70% were considered less difficult and those below 30% were considered very difficult for participants. Distractors are options on the question where the participants would choose the right response. They are shown above (Table 3) to help uncover the level of alternative conceptions held by participants. They showed the alternative views participants held compared to the scientifically correct view.

Results from the pre-test were used to group alternative conceptions and corresponding scores into categories. Questions which scored less than 30% were categorized as highly misconceived and these questions were generally more challenging for participants. These are questions where participants had problems with distractors. Those above 30% but less than 50% were also categorized as misconceived. These questions were not answered well by participants. Another category is where participants scored between 50% and 70% on questions. This category was termed moderately conceived. Concepts that were well-conceived were between 70% and 90% and those above 90% was considered to have no misconceptions. Table 4 below shows summarizes this information.

Table 4: Summary of Performance Categories

Range	Category	Questions	%
$x < 30$	highly misconceived	5,8,11,14,15,17,19,22,25	36
$30< x<50$	misconceived	6, 10, 12,13,16,18,20,21,24	36
$50<x < 70$	moderately conceived	1,2,7,9	16

70 < x< 90	well-conceived	3,4,23	12
90 < x < 100	no misconception	none	0

A high number of participants fell into the highly misconceived and misconceived categories, and when they were combined, show a performance which is less than 50 percent. When these categories with less than 50% in scores are put together, they give an aggregate of 72% of the questions were viewed as alternative conceptions from the participants. This shows in general that participants held a lot alternative conceptions in the topic of electricity. This grouping (categorization of concepts) as shown in table 4 was an approach made by Engelhardt (1997) in her study on alternative concepts. A summary of percentage per category are given in Table 4 above.

Although there are questions that participants did well on, pre-test results also showed that participants had alternative conceptions in almost every question as there was no question that scored above 90 percent in the ‘no misconception’ category. This information is summarized in Figure 3 above. The questions in which participants did well in are introductory concepts. They concern complete circuit and basic circuit configuration which are learnt in earlier grades such as Grade 8 and 9. Some questions also had participants not responding to options. This is explored in the interviews to find out reasons why they never gave a response. Question 5 had the highest non-response rate at 18 percent. Interview data uncovered the reasons and this is reported below in the interview data section. In the highly misconceived a category, question 11 and question 25 had the worst performance. Scores were very low on the questions meaning participants could not identify a short circuit and how it behaves. In the well-conceived section, question 3, 4 and 23 showed very high scores. Detailed analyses of questions from the pre-test follow below. The criteria included the level of difficulty, ability of the question to discriminate, ability of the question to bring out alternative conceptions, and questions which had a high no response rate.

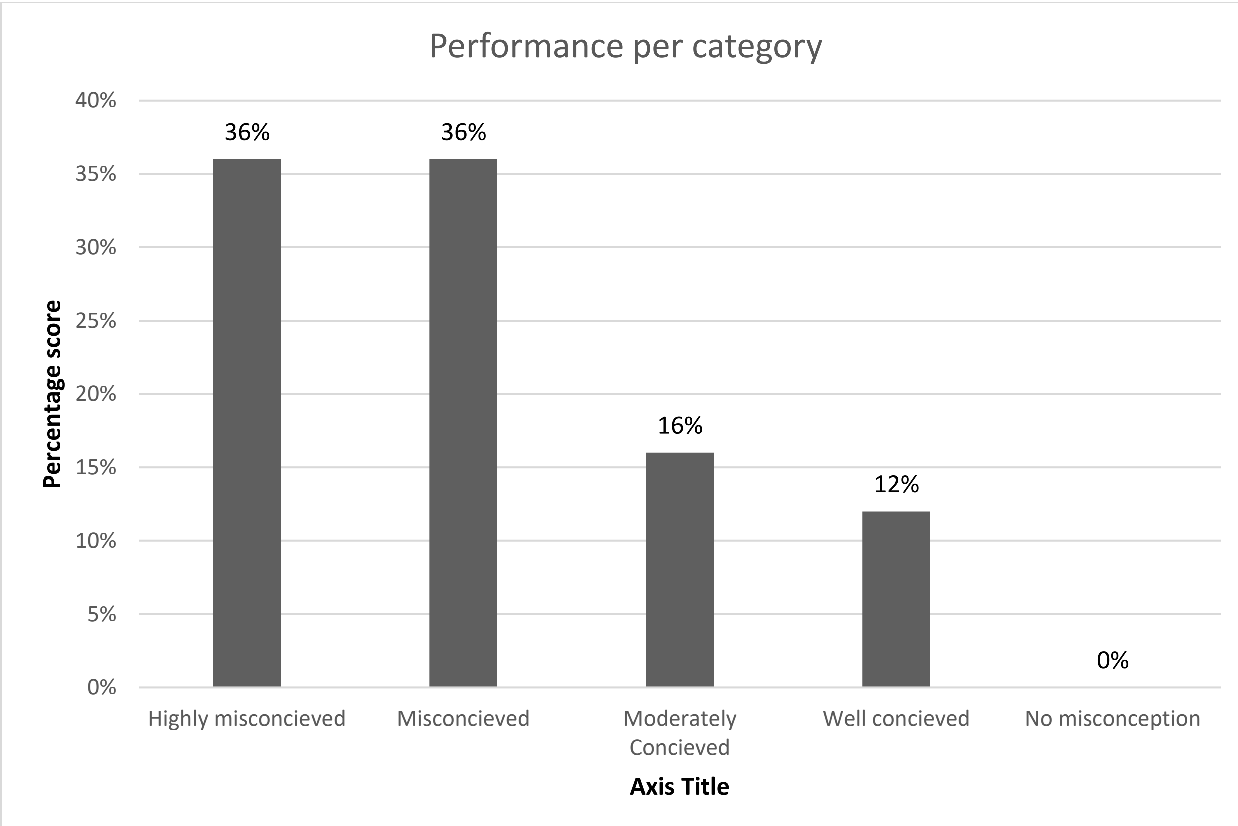
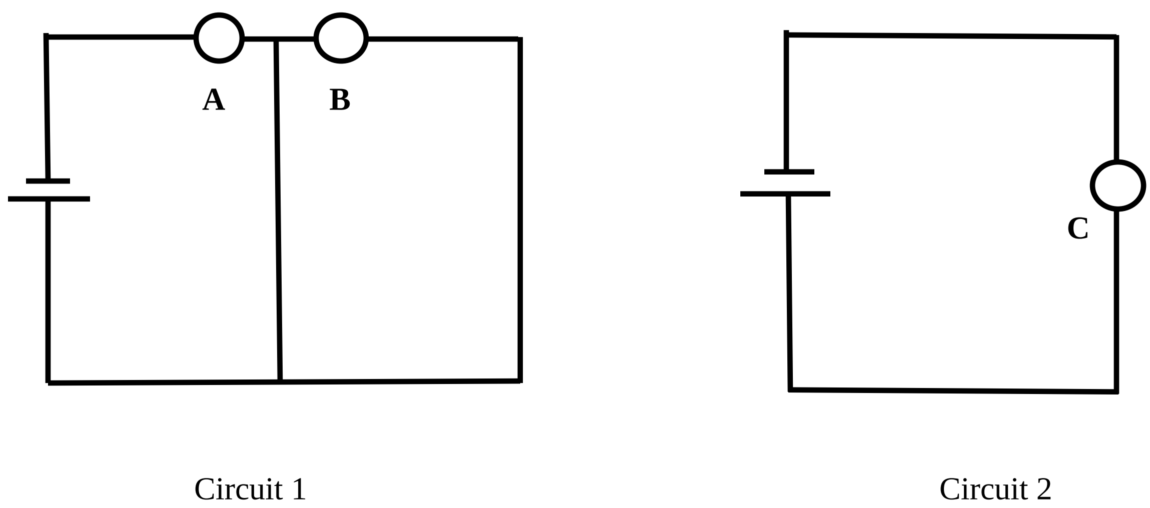


Figure 3. Graphical representation of performance in categories

Figure 4 below shows question 11 which is a question on short circuits. Most participants did not notice the presence of a short circuit in circuit 1 and thought that the bulbs will have equal brightness. This shows that participants were not aware of a short circuit and therefore, performed poorly in the question. Question 11 is shown below.

The correct response is the brightness of A is equal to brightness of C. However, most participants did not see the effect of the short circuit on circuit 1 and thought all bulbs will have equal brightness with (50% of participants). Assuming there is no short circuit, bulbs would still not have equal brightness as current is divided in circuit 1. However, a short circuit cuts off current to bulb B. Hence the brightness of bulb A becomes equal to the brightness of bulb C. Only 15 % of participants got it right making the question one of the most difficult.

Compare the bulb A in circuit 1 and bulb C in circuit 2. Which bulb is brightest?



- *A.* *A = B*
- *B.* *B = C*
- *C.* *A = B= C*
- *D.* *A = C*

Figure 4. Question 11 showing the presence of a short circuit

A similar pattern was shown in question 25. Most participants had problems interpreting short circuits. Again question 25(Appendix A) was difficult for participants. All bulbs are shorted out by the wire connected between the two points. The correct answer was no bulb lights up. Only 17 % of the participants got the correct answer. This means 83% did not understand the concept well. As shown in Fig 6 below, many participants thought that the brightness would decrease and about 5 % left the question unanswered. About 40% reasoned that brightness of the bulb would decrease with an incorrect reasoning that a wire that branches in a parallel circuit always divides current equally irrespective of the circuit configuration. This was incorrect thinking as they did not notice the presence of a short circuit. This is in line with the reasoning that most participants thought that current is divided if the number of junctions' increases and therefore, brightness would decrease. More will be revealed in the following sections as interviews uncovered the reasons behind such thinking. There is however, a pattern between question 8, 11 and 25 in that most participants found these questions equally challenging and the implications are discussed in chapter 5.

Question 14 and question 15(Appendix A) were also among the highly misconceived. Question 14 tested the relationship between current as a function of potential difference. Question 14 was directly adopted from the DIRECT version 1.1 by Engelhardt (1997). Most participants incorrectly reasoned that when the switch is opened there is no potential difference. Most conceived potential difference as a function of current and that current causes the potential difference. If there is no current, there is no potential difference (44% of participants). This who got the answer correct, reasoned that if the switch is open, only electromotive force of the battery remains and 27% of the participants got it right

Question 15(Appendix A) was also challenging to participants. This question tested if participants understood the main purpose of a battery. A battery is known as the energy source and contains chemicals which react and supply electrical energy. This question showed that participants are not aware of the chemical composition as well as the energy conversions taking place. In everyday life participants are aware that a battery goes flat. However, this question revealed that they are not aware that there are chemical reactions taking place in order to produce electrical energy in the form of current. As a result of the challenges participants were facing, 42% did not know what happens when the battery goes flat with only 21% stating the correct answer that all chemical are used up. This challenge is further discussed in chapter 5.

This brings us to an interesting observation that participants seem to confuse electrical energy, electrical power and electrical charge. Power is the everyday use of the word used in everyday life to mean almost the same as energy. This understanding is brought to the classroom and interferes with learning of concepts in the topic of electricity. These concepts of charge, energy and power are used interchangeably. As a teacher of Physical sciences and a researcher I also attest to this experience in the classroom. These terms are confused by learners. Another deduction, which would be discussed in detail later, is the inability of participants to see a circuit in terms of energy conversions. A battery contains chemicals whose energy is converted to electrical energy when the circuit is complete. When electrical energy faces resistance, it is converted to light and heat. The correct response is that when a battery goes flat, all chemical energy has been used up and only 46 % of the participants got the question right. This response is related to the poor response of question 16 in which participants erroneously thought that since the charge is used up, a battery is therefore a source of charge. A good number incorrectly thought that a battery is a source of power.

Question 5 and question 22 (See Appendix A), had poor scores and were classified in the highly misconceived category. Both questions were testing whether students understand the basic interpretation of circuits. The author viewed it as a simple question and anticipated that participants would easily score well on this question since the concept is taught in earlier grades in high school. However, these questions revealed that series and a parallel concept is not well understood by participants. Question 5 and question 22 had batteries connected in parallel to the batteries. These two questions revealed that few participants can understand and interpret a circuit where battery cells are connected parallel to the bulb (29 % in question 5 and 26 % in question 22) chose the correct response. This means on both questions about 70 % hold alternative conceptions in interpreting batteries connected in parallel to bulbs. A further examination of results also showed that question five had the highest percentage of no response compared to all other questions meaning the question presented a challenge to participants. This is further discussed in chapter 5.

Participants were challenged with questions dealing with the microscopic aspect of the circuit. This aspect was tested by question 17 and question 24 tested the concept. See Appendix A for detailed schematic diagrams of the questions. Looking at question 17, participants had problems identifying why lights come up immediately when a switch is closed. The correct response is that charge is already in the wire and only 21% got it correct. However, the popular response was that charge travels fast in the conductor (44% of participants). Competing incorrect mental models of thinking that energy is released same time and current is already flowing are some of the responses given by participants. This question reveals that the microscopic nature of circuits are not well understood by participants or are not emphasised during teaching and learning.

This kind of thinking was also exhibited in question 24. Asked about the nature of charge in a circuit, participants were not sure if it was protons or electrons that move. Surprisingly, some even chose the option that it is water like fluid. This confirms the lack of understanding of the microscopic nature of the circuit.

Participants had problems interpreting combined circuits which were examined in question 12 and question 19. See Appendix A for the schematic diagrams of these questions. The same concept was asked differently and the scores showed that the closing of the switch changed a circuit from a series to a parallel which affected the overall resistance of the circuit. The ammeter reading was asking for the amount of current flowing which was a way of testing the relationships between current and resistance. Question 19 (Appendix A) asked: *Switch 1 is now closed, what will happen to the reading on the ammeter?* An examination of the responses showed that the question had good distractors as participants could not find the appropriate answer. Question 19 also revealed that participants could not conserve current which was an important concept in answering this question. There is confusion where participants think that what happens after current has passed a particular element will not affect the element in question. Hence, the option ammeter reading will remain the same was also chosen by participants. Question 19, therefore, was able to offer several alternative conceptions at once and a further review of the concept is undertaken below in this chapter when examining interview data.

Question 18 tested knowledge of direction in DC circuits. Over half of the participants thought that direction changes or the pointer of the ammeter remains the same (Appendix A). This was erroneous thinking. This revealed that participants had a poor appreciation of what it means to say direct current. Results from question 24 confirm that participants have a poor understanding of direction in DC circuits. Implications are further discussed in the study. This question, together with question 5, showed good discrimination as it was hard for participants to choose the correct answer. In this question, participants incorrectly reasoned that when current passes a circuit element, direction changes and others surprisingly reasoned that the ammeters will not show any direction.

There was confusion concerning the effect of current on resistance as revealed by question 13. Most participants (70 %), incorrectly responded to the question and showed the wrong mental model to answer the question. Of the 70% who got the question wrong, 30 % thought that when there is no current, there is no resistance. They did not conceive that resistance is the property of the object and independent of current.

There were questions in which participants did well. However, they still displayed incorrect reasoning in these questions. The definition of current was scored relatively high by participants. This concept was examined by question 1 and question 24. Well over 60% could define current but there was an emerging pattern between these two questions where some participants still thought that current is some form of fluid flowing in the conductor. This alternative conception could be due to analogies that teachers use to explain and define current which are then misconceived by participants.

Conservation of current was tested by question 2 and question 7. There is consistency in the scores of the two questions. They both scored 70% with correct responses and they effectively brought out the misconception that participants think current gets less as it moves away from the battery or source. The assumption being that it is used up in the bulb. This is shown below where participants thought there is more current closer to the source and less further away from the source. In both cases, the alternative incorrect answer was $A_1 > A_2$. This is an indication that some participants did not understand conservation of current. This is illustrated by Figure 13 below.

Question 4 and question 20 tested the concept of Ohm's law. However, these questions recorded different scores and did not fall in the same category in terms of performance. Question 4 was well answered recording the highest score compared to other questions. This could be attributed to a moderate discrimination index where even low performers managed to answer the questions. Another reason could be that participants could easily interpret series circuits. This question however, did not directly ask the relationship between current and potential difference but surprisingly participants were able to figure it out. What is interesting to note was that question 20 directly asked about the relationship between current and potential difference without a schematic diagram which challenged participants. As will be discussed further in chapter 5, this question revealed participants need schematic to aid them in reasoning about electricity. The popular alternative conception was that the battery would become hot even though the question clearly stated that the battery had no internal resistance. This result was explored in the interviews to see what made them think this. Furthermore, participants disregarded the assumption that there is no internal resistance. Implications of this are discussed in the preceding sections.

Besides question 4, other questions that recorded high scores were question 3 and question 23. Table 5 below shows this. Question 3 tested the students' knowledge of a complete circuit. Surprisingly, a high number of 26% still could not recognize the difference between a complete circuit and an incomplete circuit. Question 23 tested interpretation of a parallel and series circuit with bulbs and not cells like in question 5. They were able to tackle the question but 30% still were unable to interpret a series and parallel connection. This will be discussed further in chapter in chapter to check on why some participants still had alternative conceptions even on presamably simple questions.

As described in chapter 3, after a pre-test was administered, participants were split into two groups. One was experimental and the other control. The experimental group was then exposed to PhET simulations, a computer program which helps participants to construct circuits. PhET simulations are described in detail in chapter 2. The post-test experimental results and post-test control results

Table 5: Summary of Performance Analysis on Pre-Test, Post-Test Experimental and Post-Test Control

Question	Pre-test	Experimental	Change	Control	Change	M
1	70	44	-17	33	-26	**45**
2	70	65	-5	60	-10	**65**
3	76	88	8	93	17	**86**
4	82	96	14	97	17	**86**
5	29	56	25	67	38	**51**
6	38	69	31	27	-11	**58**
7	70	73	3	20	-50	**54**
8	26	58	32	-27	1	**37**
9	52	46	-6	47	-5	**48**

10	46	58	12	30	-16	**45**
11	15	50	35	37	22	**34**
12	33	42	9	-40	7	**38**
13	30	30	0	7	-23	**22**
14	27	23	-4	37	10	**29**
15	21	35	14	33	12	**30**
16	42	35	-7	83	41	**53**
17	21	39	18	10	-11	**23**
18	46	62	16	33	-13	**47**
19	29	54	25	50	21	**44**
20	42	50	8	67	25	**53**
21	39	31	-8	10	-29	**27**
22	26	39	13	13	-13	**26**
23	71	77	6	63	-13	**26**
24	38	35	-3	7	-31	**27**
25	17	65	48	17	0	**33**
M	**41.8**	**52.8**	**11**	**40.32**	**-1.43**	**-**

are then compared with the pre-test results. These comparisons would help to see if computer simulations would have an effect on conceptual understanding. The other group was not exposed to computer simulations and continued with traditional teaching. An independent t-test is then run to see if the difference in mean was significant. Another test statistic called effect size was computed to see if the differences in the mean of the groups were practically significant. The following table shows face value performance per group and the change each question had from the pre-test scores.

4.3 Post-test experimental results

Post-test experimental results showed an average increase of 11% compared to the pre-test. This was an indication that that computer simulations have had an impact on learners. Some questions indicated a very high positive increase, others moderate increase and others showed a decrease in scores. Table 5 above shows the classification of these concepts in terms of their relative increase from the pre-test. Concepts that showed a huge increase after exposure to computer simulations were interpreting short circuits, interpreting series and parallel circuits, energy conversions and combined circuits. Question 5 as noted in earlier sections, tested the concept of parallel and series circuit and after simulations, there was a very high change in scores compared to the pre-test. Participants later realised that cells in parallel have the same potential difference and those in series have more potential difference. Hence, they deliver more energy which causes the bulbs to glow brighter. This question also showed that a significant number had a problem understanding battery superposition with 30% of participants still thinking the number of cells affects the total potential difference irrespective of the arrangement of the cells.

Question 6 also received a very big positive change in scores from the pre-test to the post-test. This question tested the concept of energy conversions. Participants at first had problems with the energy dynamics of an electrical circuit. Since there is no current flowing in the circuit, electrical, heat and light energy cannot be realised but the presence of charge in the conductor makes electrostatic energy the correct option if the switch is open. All questions testing the concept of short circuits recorded a significant change in scores. In these questions (8, 11 and 25) most participants chose the correct option that when there is a short circuit, bulbs do not light up. Question 19 also received a significant positive change in scores from the pre-test. This question tested whether participants could interpret combined circuits. Combined circuits tested participants to see if they can observe the change from a series circuit to a parallel circuit and vice-versa. Change from a series to a parallel circuit comes with the overall change in circuit resistance which then affects total current of the circuit. As will be discussed in detail in chapter 5, participants managed to construct combined circuits and this could suggest the increased score on the questions.

The concepts which did not show a significant change after exposure to computer simulations, were conservation of current (question 7) and current resistance confusion (question 13). This means the average score for these questions did not change. As discussed earlier, this question tested the thinking that resistance is a function of current. Participants could not figure out the correct answer even after exposure to simulations. This showed some confusion. This question also showed that question 13 had good distractors as participants could not easily figure out the correct answer. Table 6 below shows further details of the concepts which recorded significantly negative scores after exposure to computer simulations. This pattern of results was further explored in the interviews as well as in the observational results below. An analysis of question 1 produced surprising results.

The definition of current is considered one of the simplest concepts of electricity. This question produced the greatest negative score in the post-test experimental group. Surprisingly, even after simulations, participants could not define current and the negative score. Participants chose the correct response of the rate of flow current in pre-test.

Table 6: Summary of Questions and how They Changed from Pre-Test to Post-Test

Experimental

Change	*Concept*	*Question*
High Positive Change	Interpreting parallel and series circuits	5
	Energy conversions	6
	Interpreting short circuits	8,11,25
	Interpreting combined circuits	19
Positive change Moderate	Ohm's law	4
	Current in parallel circuits	10
	Purpose of a battery	15
	Direction of current	18
	Interpreting series and parallel circuits	22
No change	Current resistance confusion	13
	Conservation of current	7
Negative change	Current definition	1
	Conservation of current	2
	Interpreting series and parallel Circuits	9
	Current voltage confusion	14
	Purpose of battery	16

During the post-test, participants had conflicting answers between the rate of flow of current and just the flow of current with both options receiving equal responses in the post-test experiment. This shows a tendency among learners to be engaged in rote learning without a deep understanding of concepts. In the later sections, this idea is further explored during interviews and video data. Question 2 also received a negative score. Question 2 tested conservation of current. Even after exposure to computer simulations, a significant number of participants still thought that more current is closer to the source than further away. This is referred to as the attenuation model in literature (Engelhardt, 1997) . Implication of this kind of reasoning is further discussed in chapter 5. Question 14 was an easy circuit to construct using simulations. However, participants had a negative score on performance on the question compared to the pre-test. It remains to be seen with the interviews and video results if they managed to experiment with this question. Participants shifted from the correct answer of twelve volts to reasoning that when there is no current flowing, there is no potential difference across the circuit component. This shows that this misconception persists with participants. There was also a notable number of participants, even after exposure to computer simulations, who thought that current is a flow of 'fluid like substance' in their responses (Beaty, 1995). Another question that showed conflicting responses was question 16. In the pre-test, more participants chose the correct response of the battery as a source of energy but in the post-test they changed their responses to charge. This is illustrated in the table below. Question 16 was phrased this way:

In an electrical circuit, a battery is a source of...

Power

Energy

Charge

Field

Table 7: Analysis of Options in Question 16 on Pre-Test and Post-Test Experimental

Test	*Power*	*Energy*	*Charge*	*Field*	*No responds*
Pre-test	22	39	35	2	1
Experimental	14	33	48	5	0

As can be seen from the table 7, participants were split between choosing a battery as a source of energy or the charge and in the post-test experiment, more participants chose charge instead of energy. There was a shift from the correct answer to an incorrect one. Computer simulations model charge moving and this might have reinforced the idea that a battery cell is a source of charge and not energy as they see charge and not energy. This could tell more about the possible limitations of computer simulations in addressing misconceptions. Question 21 also resulted in a negative score in comparison to pre-test results. It again tested the relationship between increased resistances of current. About 70% of participants had difficulty with the question.

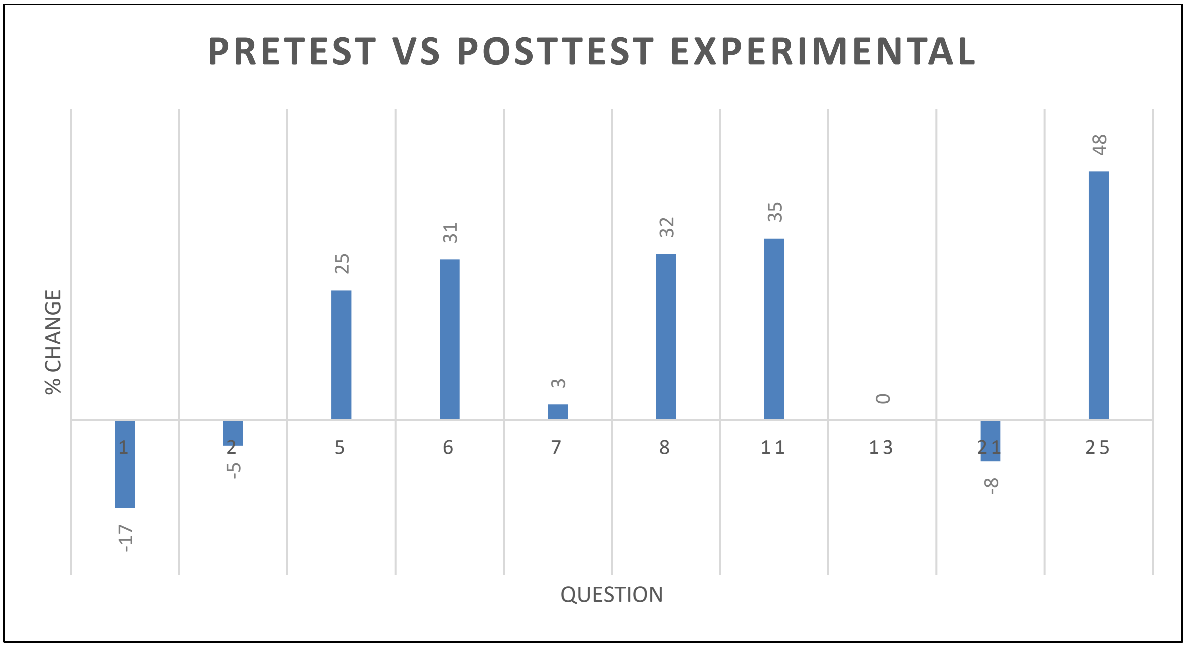


Figure 5. Performance change of questions from pre-test to post-test experimental

4.4 Post-test control results

Referring to Table 5, it can be seen that the post-test control average performance is 40.32 % which is slightly lower than the average score of 41.80 % of the pre-test group and recorded a decrease of -1.43%. The control group continued to receive traditional instruction and were not exposed to computer simulations. The post-test control group had lower performance scores compared to the both the pre-test and post-test experimental group. Most questions recorded a comparatively negative change in performance. A new set of results emerged as to which questions were highly misconceived and those that scored well. Question 3 and 4 consistently scored high in the pre-test as well as the post-test experimental results. As explained above question 3 tested the concept of a complete circuit and question 4 tested Ohm's law, an indication that concepts can be well understood even without computer simulations. This is a significant finding that some conceptions may not require computer simulations to understand and could be an indicator that traditional instruction can be enough to address them. Although many questions showed a comparatively negative score in the pre-test results, participants performed poorly in questions 13, 21 and 24 in this group. See table 8 below for the concepts these question tested. Question 13 tested the concept of current resistance confusion, question 21 tested understanding resistance in series and parallel circuits, and question 24 tested direction and the microscopic nature of the circuit. Table 9 below shows the comparative performance between the pre-test group and the post-test control group. Some participants' scores improved in both the experimental and the control group. These are questions 3, 5, 11 and 19. Question 25 which tested the alternative conception of short circuits did not change in performance recording a 0% change. This pattern is discussed further in chapter 5. The post-test control group however, showed a negative decline in performance of certain concepts. The experimental group had five alternative conceptions that showed a negative change in scores from the pre-test scores. The control group had twelve alternative conceptions showing a decline in performance. This is a difference of almost 50% less than the pre-test results of alternative conceptions. Interviews and video data will be used to explore these results. There is a pattern however. There are questions and alternative conceptions showing negative change on both the experimental group as well as the control group. Table 8 below gives a summary.

Table 8: Alternative Conceptions with Negative Change in Performance in Experimental Group and Control Group

Alternative conception	*Question*
Definition of current	1
Conservation of current	2
Interpreting series and parallel circuits	9
Current voltage confusion	14
Purpose of the battery	16

The concepts in Table 8 confirms the difficulty of the concepts even with the intervention of computer simulations which is a confirmation that some alternative conceptions are persistent and stable (Gunstone & Tao, 1999). These concepts include definition of current, conservation of current, interpreting series and parallel circuits, current voltage confusion, and the purpose of the battery. A further discussion on this trend is done in chapter 5.

Questions 7 and 24 received the greatest negative change in scores from the pre-test and post-test control group and looking into them further might give some insights. Question 7 investigates participant understanding of conservation of current in a series circuit. Figure 6 below shows question 7. This question had a slight increase of 3% from the pre-test to post-test experimental group. This question then had a huge decrease in score of 50% form pre-test to post-test control. This is an indication the concept of conservation of current is challenging on learners. This has been revealed by earlier researcher (Shipstone, 1984). Question 24 tested the alternative concept of direction of current on a DC circuit. Participants showed they had challenge interpreting electron flow and conventional flow of current. This concept received a negative score post-test control group

A further analysis of the post-test results shows that question (definition of current) received a high negative change in score at 26%. This was followed by question 21 which tested understanding of series and parallel circuits at 29% negative change in score. Question 13 which tested current resistance confusion also received a negative change in score at 23%. This question had a challenge even with the experimental group. Question 2 and question 10 also recorded high negative scores.

Study the circuit below. Which statement below is true of the reading on ammeter A_1 and ammeter A_2?

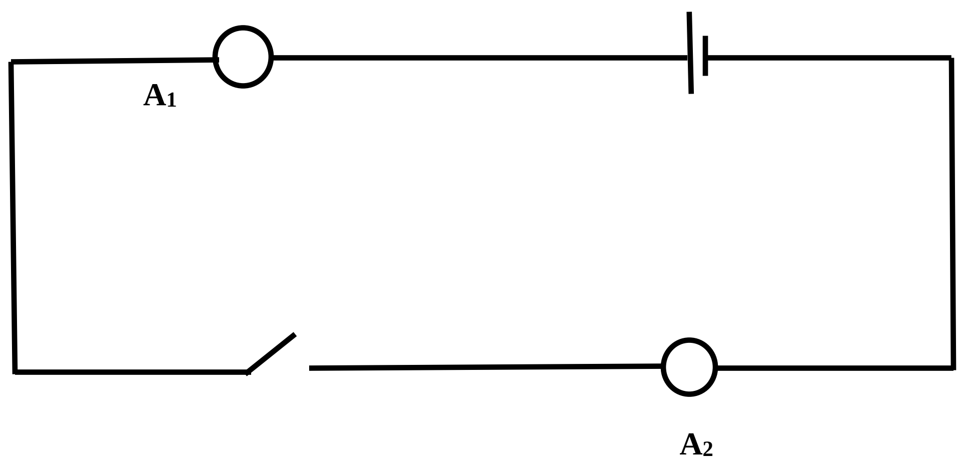


Figure 6. Diagrammatic representation of question 7

A. $A_1 > 0$

B. $A_1 < 0$

C. $A_1 = A_2 = 0$

D. $A_1 > A_2$

Table 9: Summary of Performance Change of Questions from Pre-Test to Post-Test Control

Change	*Concept*	*Question*
Positive	Complete circuits	3
	Interpreting Parallel and Series Circuits	5
	Purpose of battery	16
	Interpreting short circuits	11
	Interpreting combined circuits	19
	Ohm's Law	4, 20
No change	Interpreting short circuits	8
	Interpreting short circuits	25
Negative	Current definition	1
	Conservation of current	2,7
	Energy Conversions	6
	Current splits into half at junction	10
	Current resistance confusion	13
	Interpreting series and parallel Circuits	9
	Current voltage confusion	14
	Purpose of battery	16
	Microscopic nature of the circuit	17
	Direction of current	18
	Interpreting resistance in series and parallel circuits	21
	Direction of current	24

4.5 Trends in category performance

A closer examination of how certain questions fared from pre-test, post-test experimental and post-test control are shown in Table 10 below. Performance of pre-test and control group are closer to each other with the control group showing an overall lower performance on all questions except question 2. The experimental group showed a higher average performance on all questions except question 2. Question 2 talks about conservation of current. There is however an interesting consistency in the categories. Irrespective of group, Ohm's law concept was well understood by all groups. It is a well-conceived concept with an average of 86 %. This is an indication that Ohm's law is well emphasized in traditional instruction as the pre-test and control group did not work with computer simulations. Question 2 which tested the conservation of current was also consistent with the categorization of a moderately conceived concept at an average of 64 %. With an average of 27 %, the concept testing the relationship of resistance and current also fell within the misconceived category and finally, the short circuit concept had an average of 33%. Generally, questions testing short circuits recorded the poorest scores of 10.5 % without factoring in the experimental result of 80 % which skewed the mean performance to 33%. This high score was due to the intervention of computer simulations. This is discussed below in the interview results section.

Table 10: Analysis of Well-Conceived, Moderately Conceived, Misconceived and Highly Misconceived Questions

Category	Question	Concept	Pre-test %	Control %	Experiment %	**M**
Well-conceived	4	Ohm's law	82	80	96	**86**
Moderately conceived	2	Conservation of current	70	53	68	**64**
Misconceived	13	Resistance current relationship	30	23	28	**27**
Highly misconceived	25	Short Circuits	11	10	**80**	**33**
M			**48**	**41**	**68**	**53**

Notes: M stands for mean value in each column and row.

Questions are tabulated above and their frequencies indicate that the post-test control group consistently had the lowest scores followed by the pre-test group and finally the post-test experimental produced better scores. So far, results have shown that computer simulations have had effect on understanding most concepts by looking at the comparisons made above. However, it remains to be seen if the mean differences between groups are significant and the next section looks at independent t tests. Independent t-tests helps to determine if there was significant difference in performance between groups.

4.6 Testing for difference in performance between groups.

In order to test for difference in performance between groups, a test t-statistic is performed to find out if the differences between their mean or average performance are significant. In order for the test to be performed, there has to be a test for normality. Using SPSS, outputs from a test for normality were obtained. All three groups were tested for skewness and Kurtosis. Z value for the groups should be between -1, 96 and 1, 96 for the data to show normality for parametric data. Skewness for pre-test group was -2.96 (SE = 0,291) and Kurtosis result was 1, 43 (SE = 0,574). Skewness for the experimental group result was 0,273 (SE = 0,464) and Kurtosis (SE = 0,902). Except the Skewness value for the pre-test group, all other z values were between -1, 96 and 1, 96 which is a positive test for normality of data which can be used to run t-tests. This is confirmed by histograms which showed a normal distribution for all groups. The following section shows the tests for difference in performance between groups and the use of a t-test to produce such information.

Research question two was used to formulate a hypothesis to test if computer simulations were effective in changing concepts of electricity. A null hypothesis and an alternative hypothesis were formulated.

Null Hypothesis: Use of computer simulations does not change the understanding of concepts in grade 10 on the topic of electricity.

Alternative hypothesis: Use of computer simulations does change the understanding of concepts in grade 10 on the topic of electricity.

One way to test difference in performance is to compare the means of the groups and a t test is one such test statistic that was used. Data of the two groups is assumed to be of equal variance. To reject the null hypothesis, the significant value must be less than 0, 05 ($p < 0, 05$). Statistical outputs are then accompanied by effect size results to see if the results have a practical difference or not. In this regard, a Cohen's d effect size will be run and then compared to zero. The following standards are applied. A $d < 0, 2$ has small effect. A result $d = 0.5$ has moderate effect and a $d > 0, 8$ has a large effect.

4.6.1 Pre-test group versus post-test experimental group

There is no significant difference in scores between the pre-test group and the post-test experimental group.

A t-test was run with equal variance assumed between the pre-test group N = 68 (M = 10.68, SD = 3.024) and post-test experimental group N = 25 (M = 13.64, SD = 3.303) with $t(91) = 0.442$, the significant value $p = 4.61 \times 10^{-4}$. In this case $p < 0.05$ therefore, we reject the null hypothesis which states that there is no difference in performance between the performance of the pre-test group and the post-test experimental group. This means there was a significant difference in performance between the groups. A calculated effect size of $d = 1.66$ was found. Since $d > 0.8$, it shows that there is a significantly practical difference between the group means. The table below shows the summary of the two groups.

4.6.2 Pre-test group versus post-test control group

There is no significant difference in scores between the pre-test group and the post-test control group.

A t-test was run with equal variance assumed between pre-test group N = 68 (M = 10.68, SD = 3.024) and post-test control group N = 27(M = 10.04, SD = 3.611) with $t(93) = 0.879$, the significant value $p = 0.382$. In this case $p > 0.05$ therefore, we accept the null hypothesis which states that there no difference in the performance of the two groups. A calculated Cohen's d (0.35) indicates there is practically no significant difference in the means of the two groups which reinforces the conclusion of the t-test.

4.6.3 Post-test experimental group versus post-test control group

There is no significant difference in scores between the post-test experimental group and the post-test control group.

Another t-test with equal variance assumed was run between a post-test experimental group N = 68(M = 10.68, SD = 3.024) and post-test control group N = 27(M = 10.04, SD = 3.611) with t (50) = 3,745 and p = 9, 4 x $10^{-5.}$ Since $p < 0.05$ we reject the null hypothesis which implies that there is a significant difference in the performance of the two groups. A calculated Cohen's d (1.94) shows the effect size is greater than 0.8 meaning that there is a significant practical difference in performance between the two groups. The following is a summary of the t-test statistic output results run from SPSS software.

Table 11: Summary of t-Test Statistic Results

Pre-test group	Control group	Experimental group	Pre-test group
68	27	25	68
10.68	10.04	13.64	10.68
3.024	3.611	3.303	3.024

t = 0.879	**t = 3.745**	**t =0.442**
p = 0.382	**p = 9.4 x 10^{-5}**	**p = 4.61 x 10^{-4}**
d = 0.35	**d = 1.94**	**d = 1.66**

The test statistics results are then explored further and triangulated with the video observations and interviews. Previous sections described the quantitative results and the following section explores the qualitative results. During use of computer simulation a video record was taken to get the real behaviour of participants when they were using PhET simulations to understand the topic of electricity. Participants were then interviewed after undergoing the experience with computer simulations and these results are discussed below.

4.7 Video Results

A video recording split into four sessions of 40 minutes each was analysed. This was done to monitor the activities of participants and to triangulate the test and the interviews. Themes arose and these are analysed below. In order to explain the behaviour of participants in the project, nine themes were developed and described below. The first of these is teacher activity. An observational protocol was used to analyse the observational data. In line with the research design, the project is designed to see the effect of computer simulations in the understanding of electricity concepts and in this case the teacher had to facilitate only and not play an active role. Under the theme teacher activity, the following codes were summarized and their frequency recorded in time intervals of five minutes throughout the recording. This means each code was monitored twenty four times and the frequency recorded.

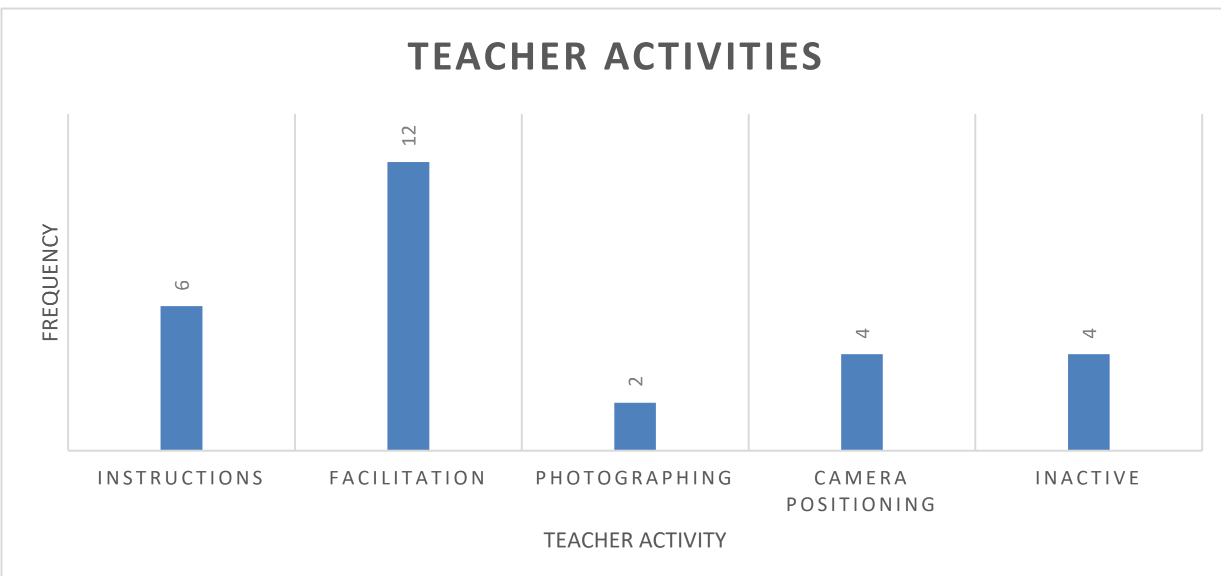


Figure 7. Summary of teacher activities during simulations

As the bar graph shows, the researcher spent much time facilitating the use of computers during the intervention. There were moments when the researcher gave instructions to all groups. There is no incident in the video analysis in which the researcher actively helped participants to construct a circuit during a simulation which is an indication that participants managed to construct and interpret as a group activity. There is no incident in which a participant asked for help to construct a circuit. Considerable time was spent by the researcher bring inactive and making participant observations.

The level of engagement of participants with computer simulations was also analysed. An element which was carefully observed over the whole period was the intensity of engagement. Data were analysed between three categories which are intense engagement, high engagement and low engagement. Intense engagement was when participants were highly focused, making less noise and helping each other in the construction of the circuit diagrams. Highly engaged was when participants were incidentally moving away from the task with activities that were not directly related to the task but working to accomplish the task. Less engaged were periods in which groups were making noise and not focused on the task at hand. Throughout the simulation activity, observational data shows that participants were intensely engaged with the activity at the beginning and less engaged towards the end of the activity. The chart below shows the time series of the level of group engagement. Figure 8 below illustrates this.

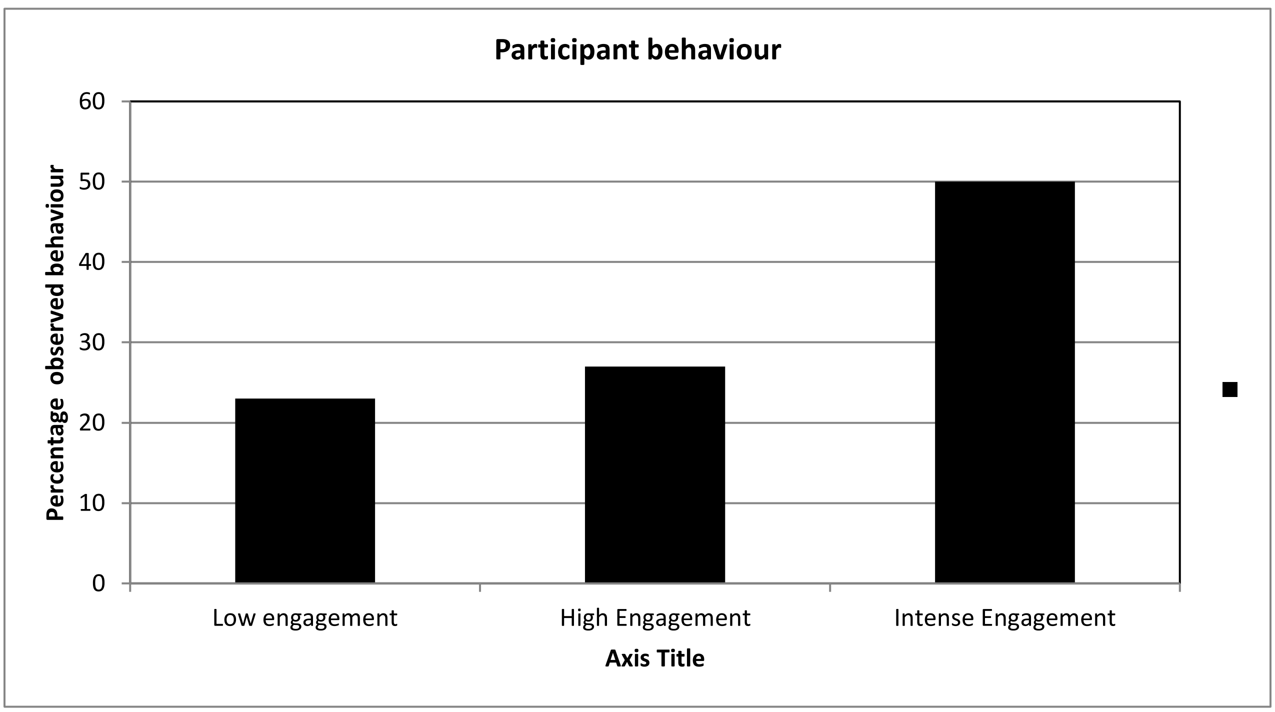


Figure 8. Summary of participant behaviour during video observation

Another category that developed when analysing video data were gestures participants made towards each other, the video camera and to the circuit diagrams that they were constructing. Elements under this category included calmness, smiling, laughter, excitement, gazing at other groups as well as pointing at the circuit diagrams they are constructing on the computer. Many gestures came out of the simulation activity. These were then reduced to the following categories; calmness, enjoyment, gazing away, pointing at the computer, and note taking. There is a pattern with which gestures are more at the beginning of the observational period, those in the middle of the activity and those at the end of the activity. There is a lot of enjoyment (smiling, excitement and laughter) at the beginning of the activity. There is calmness and a lot of pointing at the diagrams drawn in the middle of the activity and a lot of note taking towards the end of the simulation activity. The chart below summarizes the gestures in the observational period and their implications are then discussed in the next chapter.

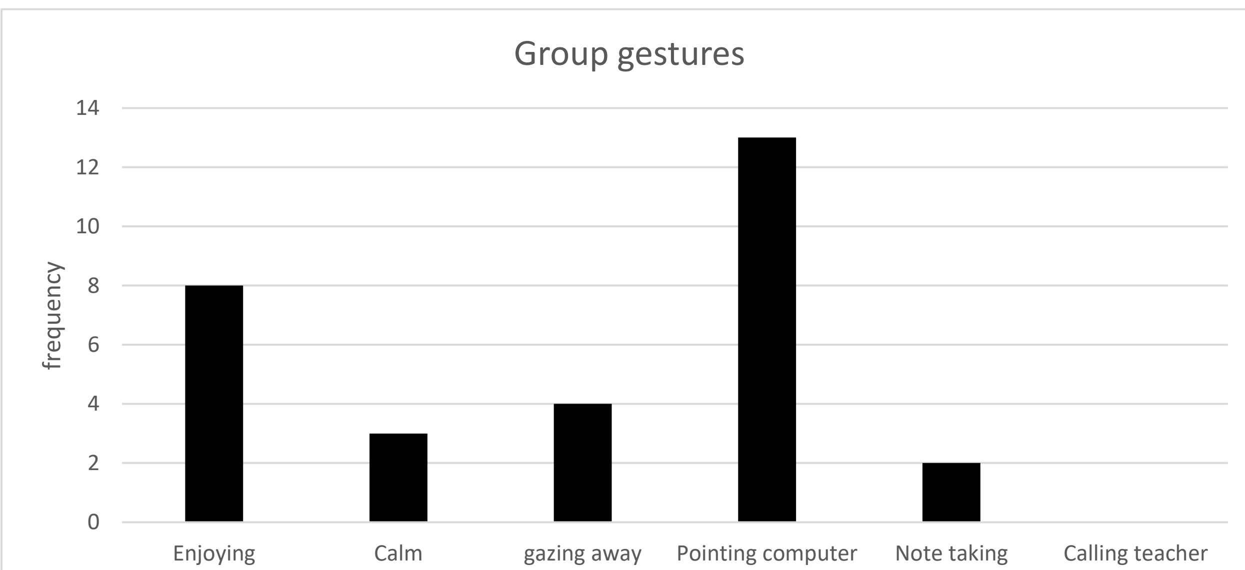


Figure 9. Summary of participant gestures during video observation

Notable was that there is simulation group called a teacher to help them with constructing circuits as shown by the results above. Participants got help from each other during the construction of the circuit diagrams and their interpretation.

Another interesting observation was the level of intergroup and intragroup interaction. Intergroup interaction was found to be minimal. Only in one incident did a participant shift from one group to the other. The majority of groups remained with their composition and numbers and the intragroup interactions were very high. There was a high incidence of participants who instructed how to connect circuit components. Most distractions came from noise outside or laughter from the group itself. Group members were disrupted and experienced discomfort when the video camera was shifted and focused towards them.

Each group had at most two people who were good with computer manipulation. The majority of group members were uncomfortable with using the computer however, they were able to make observations and give instructions to those that could operate the computer simulations. During the observational period, only two groups exchanged the person operating the computer with the rest of the groups having one person operating and manipulating the computer simulations. This is discussed in the next chapter.

The quality of conversations were also observed. These were grouped into agreements, disagreements and casual discussions not related to tasks at hand. Data shows that most of the time, participants agreed with what to do in order to construct a good circuit diagram. On some occasions, there were instructions from group members such as:

> *"Why are you removing the battery Xolo? Connect the battery Xolo. Now connect...connect the wire".*

After successfully connecting the circuit, the whole group was excited at the flaming battery due to a short circuit. In some groups, there were conversations of confusion in what the components as well as how to connect the components.

> *What do we do now? Do we multiply? Do we add? Do we divide? Do we use a calculator to find the answer for the ammeter? Let us see if the simulation values give us the same values as our calculation.*

In the conversation above, participants were validating Ohm's law calculations with the values that are displayed by computer simulations. Besides the agreements and confusions, there were group discussions with disagreements.

> *"Why are you removing the battery Siyanda? Remove the battery…Remove the battery and add voltmeter".*

After a disagreement some group members left. This is evidence that not all groups worked well together.

A further analysis of data showed that question 19 and question 25 were the most constructed by participants during the intervention with computer simulations. This could be a follow up to the difficulty that they faced with the questions during the pre-test, and participants were curious to find answers to these questions.

4.8 Interview Results

As described in chapter 3, this study used a mixed methods research design. This means quantitative data is triangulated with qualitative data. Qualitative data were gathered through video data were described in the previous section. This section analyses video data and interview questions are found in the Appendix F. Data were first coded to find the general trend in responses from participants. Upon examining data, participants repeated certain words and numbers. These were then grouped into codes. Codes included easy questions, difficult questions, confusing questions, improved questions after exposure to simulations, where simulations were helpful, advantages of simulations in conceptual understanding, reasons for improvement in conceptual understanding, and effectiveness of group work when working with simulations.

Interviews were conducted to gain an insight into how participants went about answering questions and to find out the pattern of thought when engaging with electricity concepts. In this regard, participants found certain questions much easier to answer than others.

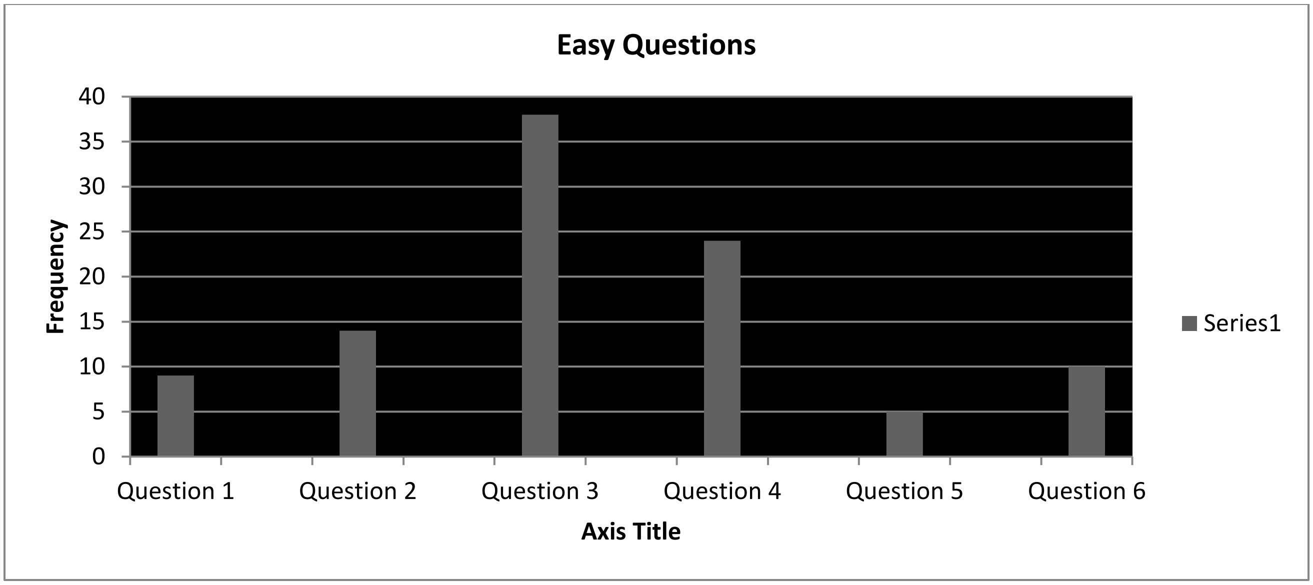


Figure 10. Summary frequency of participant responses on questions they thought were easy during the interview

Questions 2, 3 and 4 were cited as the easiest. These questions tested the concepts of conservation of current, a complete circuit and Ohm's law respectively. One participant had to made the following comments

Sir, question 3 and 4 were the easiest for me. Sir, we covered complete circuits in grade 8 and 9. We were told no current flows in an open circuit so I got this one right. As for question 4 Sir, cells which are in series have more potential difference therefore the bulbs glows brighter.

This is explained more in chapter 5. Another category that came out in the interview was questions that were difficult. Figure 11 gives the frequencies in percentages in the mention of difficult questions as interviewed from participants.

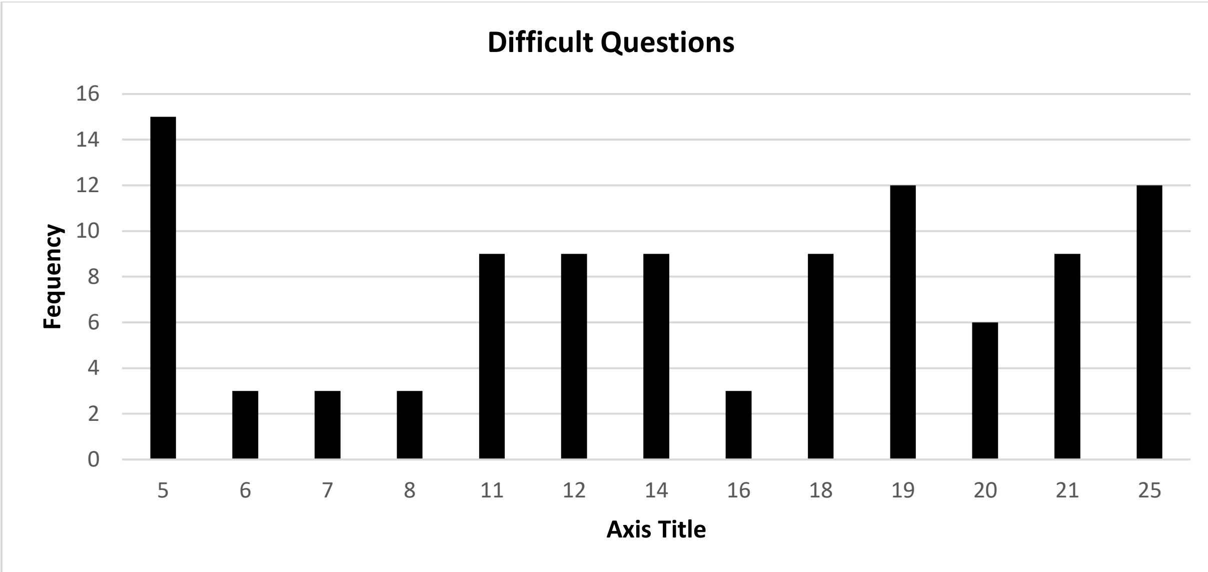


Figure 11. Summary of frequency of questions participants thought were difficult during the Interview

Interview results indicate question 5 as the most difficult. This was followed by question 19 and 25 as the most difficult and then question 11, 12, 14 and 18 had the same frequency as well. These difficult questions were then analysed for the most confusing and most guessed questions. The question tested interpreting parallel and series circuits. One participant had to say this about question 5.

> *As for question 5, I could not formulate in my mind which bulb would glow brightest. It was my first time to come across battery cells in a parallel connection. We are used from earlier grades to see cells usually in series. Sir, it became difficult to choose the correct answer between more cells in series and more cells in parallel. Question 5 was hard for me as I would not know which circuit would produce a brighter bulb because they were so different. Sir, if I add more cells will the brightness of the bulbs decrease? What happens when you add more cells in series?*

Question 18 came out in the data as challenging many students. Question 18 tested the concept of the direction of current. This question tested an understanding of the microscopic nature of the circuit as well as their understanding of what is meant by DC. Results showed participants do not understand what flows in a circuit between protons and electrons. There is evidence participants also pictured a ‘fluid like′substance as the one flowing in the conductor. This question revealed a lot of alternative conceptions about how participants viewed circuits at a microscopic level:

> *Sir, I had a problem with question 18. Do they tell us whether it is direct current or alternating current? Which side is the positive terminal and negative terminal? Which one moves protons or electrons sir?*

Interview results also revealed that question 19 was challenging for them. As discussed earlier, this question tested their interpretation of combined circuits. What came out most was the inability of participants to switch between a series circuit and a parallel circuit. Participants could not recognise the implications of closing and opening up the switch and how it affected the whole circuit. They displayed what is termed ‘the local thinking model’ (Shipstone, 1988)

> *Question 19, Sir, it was difficult. I believed when the switch is opened current is not flowing like it’s at zero. I thought like current flows in one direction in the circuit and did not know that the closing of the switch introduced a parallel circuit. I realised this only when I played with simulations as I saw the current being divided as it flowed in the circuit.*

Further investigation revealed that participants were not familiar with qualitative questioning which had no calculations and that they were not aware the opening and closing of a circuit affected the total circuit resistance and current. One participant added a unique finding by sharing their thoughts about question 19.

> *Question 19 was confusing. I did not know what was meant by current increasing, decreasing and remaining the same as answers to the question when the switch is closed. I thought current is zero when switch is open and that it just flows when closed and does not increase or decrease.*

Question 8, 11 and 25 were testing the concept of short circuits. In a short circuit, current flows in a path of low resistance. Most participants could not see there was a short circuit and that the bulbs would not light up. This is consistent with quantitative data where participants performed badly in these questions

I did not understand that current does not pass to the rest of the circuit when a wire of low resistance is at a point of intersection. The question asked us to join a conductor from one point to the other. I did not know it would cause the bulbs to switch off. I thought that introducing a wire of low resistance would simply divide the available current making the bulbs to decease their brightness.

Data also revealed an interesting pattern in the questions and the concepts they were testing. Questions that were difficult also came out as confusing and most were guessed. These questions are shown in Figure 12 below.

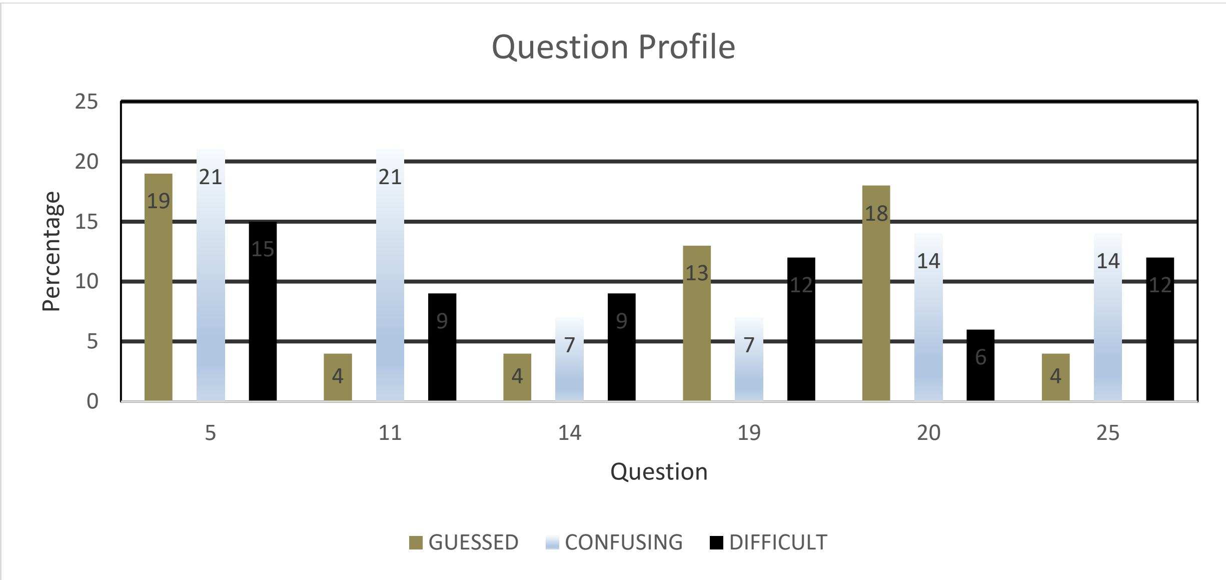


Figure 12. Graphical representation of guessed, confusing and difficult questions

This category showed a pattern in which the questions that were guessed were the ones that were confusing as well as difficult. Responses from participants showed that question 5 was the most confusing and difficult, and the most guessed.

After exposure to computer simulations, participants were asked to identify which questions they were able to answer after being exposed to computer simulations. In experimenting with computer simulations most participants, as shown above, found question 5, 11, 19 and 25 the most challenging. They had the chance to construct these questions during computer simulations and they cited that they improved their performance in these questions and this was also confirmed by quantitative data described in previous sections. The question profile for the most improved after using computer simulations are shown in Figure 13 below.

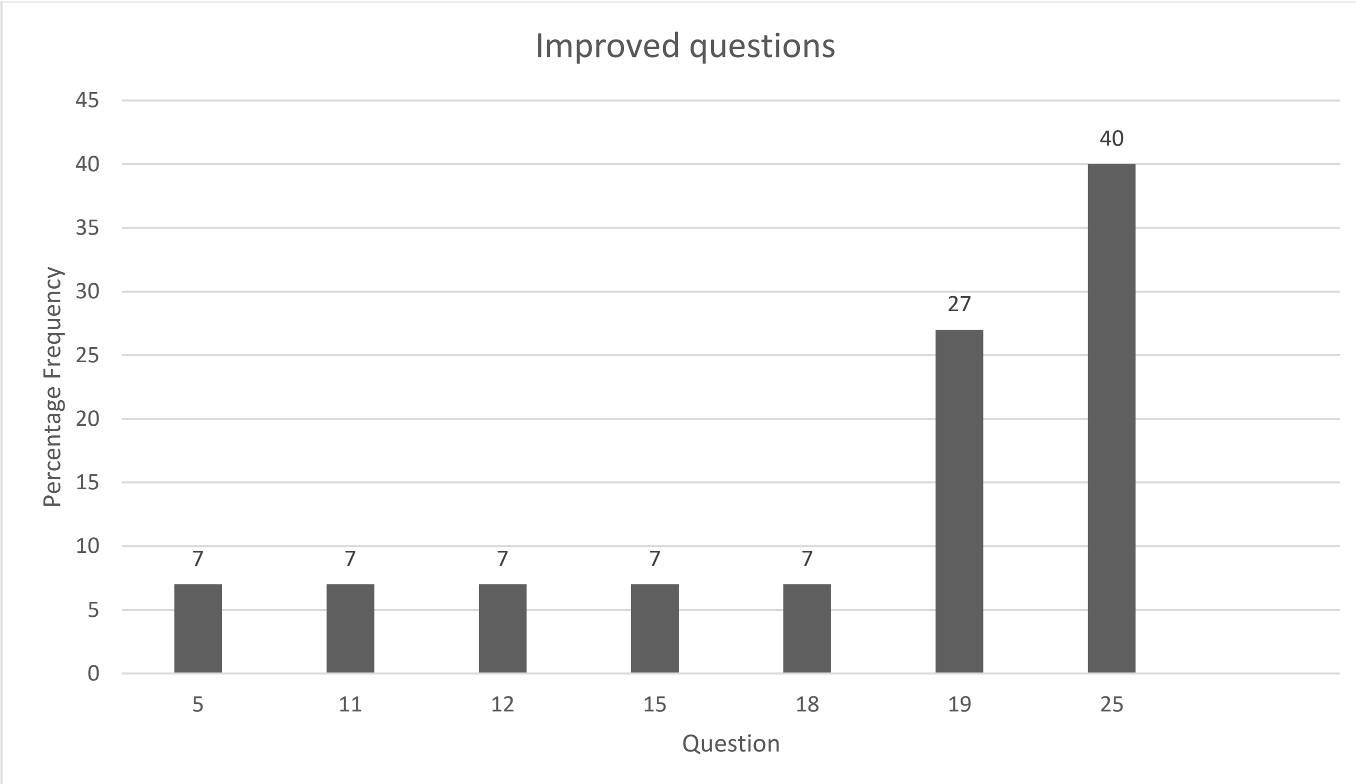


Figure 13. Summary of questions mentioned by participants as the most improved after

intervention with computer simulations

Asked whether computer simulations were helpful in answering the post-test, only one participant said they were not useful. The majority of the participants said they gained a lot in understanding electrical concepts. Participants used simulations to construct circuits of question 19 and 25 which they found difficult in the pre-test and sought to understand the question better. Asked which questions they understood better after exposure to computer simulations, one participant responded.

> *On question 25 Sir, I didn't understand there was a short circuit. It didn't make sense, but when I used computer simulations, I then remembered in grade 8 when my teacher said current follows a path of no resistance and then it becomes a short circuit.*

Although having been discussed extensively in the literature review, most participants cited some advantages of the simulations and reasons why they helped them perform better in the post-test. Participants cited reasons for how computer simulations helped in answering questions.

Participants cited computer simulations as having many advantages which helped them answer questions which included being cheap, flexible, safe, engaging, interesting, broadened their understanding and the ability to visualize the circuit. Figure 14 show the advantages cited by participants and frequency they were mentioned during the interview.

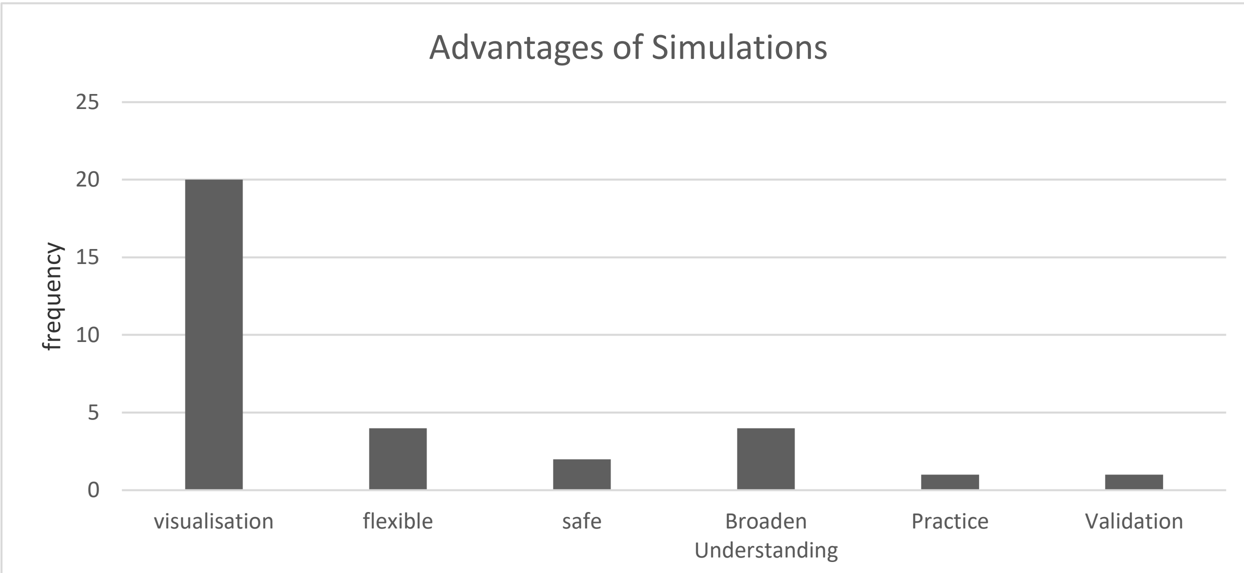


Figure 14. Summary of advantages of computer simulations mentioned by participants.

The most cited advantage was that simulations helped them to answer questions because they helped to visualize the behaviour of an electrical circuit. As shown above, almost all participants cited visualization as the main reason they improved on certain questions in the post-test.

> *I had to use simulations to make circuits and learned and saw how charged particles were and how they looked like. Simulations were visual and I could see the rate in which the charges were moving, and I also saw what happened to the bulbs when wires were connected wrong. I could see what was happening to the brightness of bulbs and resistance.*

Another interesting observation was how simulations helped in the validation of calculations. The inclination of participants to look for calculations without a deep conceptual understanding was evident.

> *"Simulations helped me to familiarize with different types of circuit connections. It helped me validate my answers, especially after calculations".*

One participant cited simulations are easy and flexible to use. Therefore, it was easy for them to make a follow up to classwork and understand concepts. This has also helped them to understand concepts and aided them in understanding electrical concepts. Simulations were able to motivate participants and one of them stated they help in understanding concepts. Some indicated that classroom circuits were boring and 'dead'.

> *Sir, when you connect the components right, you actually see and are able to analyse on your own. However, when you are staring at it (circuit in class) you don't see whether current is flowing or not. It helped imagination as it was visual.*

Some said that the ability to make mistakes and reset the apparatus saved time and made the whole simulation kit easy to use. Asked if simulations were useful, the following pie chart summarizes the responses from participants. Most participants thought that simulations were helpful in answering questions in the post-test. A quarter thought they were not helpful with almost one fifth not sure. The effectiveness of group work when working with simulations was also explored. Most participants felt that group work was sharing information as well as aligning computer skills with other group members. Others felt that they were not good with computers and learnt a lot from those with a better aptitude for them. They were able to work together and discuss difficult aspects of questions and simulations.

> *We were able to share answers to difficult questions. Some learners were better at using the laptop enabling us to work faster. We were able to compare our answers and come to reasonable conclusions.*

Participants were also given a chance to respond to the way they prefer being taught electricity. They suggested the need for working with real things instead of theory. They added that demonstration should precede a lesson so that they approach the lesson with a picture of the concepts. The majority suggested a practical way of learning electrical circuits.

"I would want to learn electricity by doing practical and real life electricity problems without really guessing what is really happening in life".

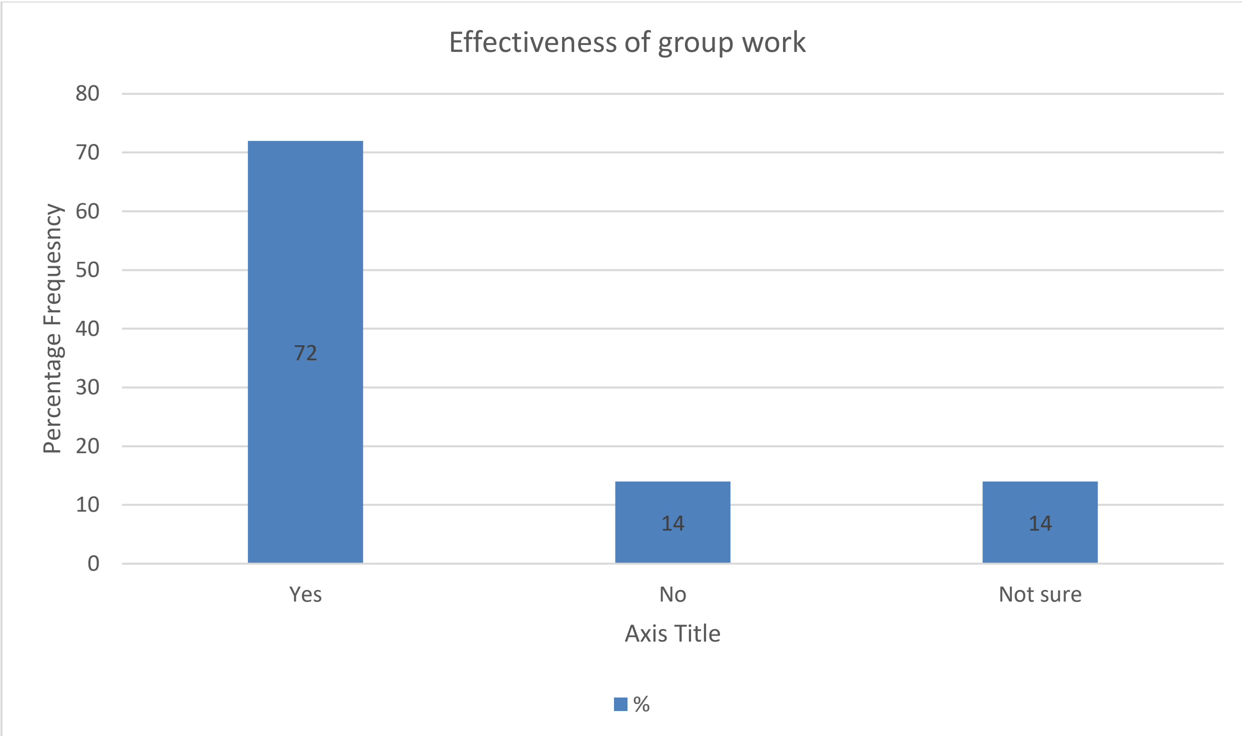


Figure 15. Summary of the effectiveness of group work during computer simulations.

4.9 Conclusion

This chapter looked at data analysis. The first task was to analyse ECT pre-test results. As discussed in the chapter, the pre-test results showed that participants held a lot of alternative conceptions about electricity in Grade 10. Most of the pre-test results confirm what has been researched before and a few new insights were revealed through the ECT, interview and video data. The second task that was analysed was the post-test experimental results. These results showed an improvement in average performance compared to the pre-test results. The third task was the analysis of the post-test control results. Post-test control results were similar in performance compared to the pre-test results and different to the mean average performance of the experimental group. The fourth task looked at statistical t-tests of the difference in the mean between the three groups. It was found that there was significant difference in the means between the pre-test group and the post-test experimental group. There was also a significant difference in performance between the experimental group and the control group. There was no significant difference in performance between the pre-test group and the control group. Both the pre-test group and the control group received traditional instruction without computer simulations. The fifth task looked at video results which analysed the behaviour of participants when engaging with computer simulations. This was undertaken to understand the theoretical implications of which conditions are best when dealing with computer simulations. The sixth and last task was the analysis of interview results. Interview results were used to make a follow up to the pre-test, post-test experimental, post-test control and video data. This was completed to gain deep insights into the thought process of participants as to why they found some questions difficult and also to explain their behaviour in the video results. Chapter 5 discusses these results, comes to conclusion and makes certain recommendations.

Chapter 5

Discussion of Findings and Recommendations

5.1 Introduction

The previous chapter presented data from pre-test results, post-test results, observation and interview results. This chapter is dedicated to discussing these results. The chapter will also discuss instrument reliability and research validity. Limitations of the research will also be discussed. Recommendations in light of these findings will be made towards the end of the chapter.

5.2 Pre-test results

Pre-test, as discussed earlier, was testing the understanding of grade 10 participants on some electricity concepts. The test was designed with questions which are known to test certain alternative conceptions in participants. The research question was:

What are Grade 10 learners understanding of electricity concepts prior to the implementation of computer simulations?

Alternative conceptions were categorized and it was found that no question in the test got a score of 100% and that no question in the pre-test obtained above 90% as a score. The category of above 90% was labelled as the ‘no misconception’ category. This reveals that participants had significant alternative conceptions in all areas tested. These alternative conceptions are discussed below.

Concepts that scored high in the pre-test include the concept of a complete circuit. However, there was a significant number of students who still had alternative conceptions on the idea. This is despite the fact that the concept is dealt with at lower levels such as primary school as well as in grade 8 and 9 of the GET phase in South African high schools. The fact that a significant number could not identify a complete circuit is worth noting. This finding is similar to embryonic research done by Brna (1988) who showed that most participants could not light up the bulb. Rankhumise (2012) also revealed that learners could not interpret a complete circuit. Participants think that current only flows to the bulb from the source and there is no need for it to have a complete circuit. This incorrect thinking had implications for other questions that required an understanding of complete circuits. The concept of complete circuit is a foundational concept that influence the understanding of other concepts. Although performed well in the pre-test, the idea still need more attention during teaching and learning.

The conceptual test also revealed that participants had problems understanding the relationship between current and voltage. As results show, most participants incorrectly understood that potential difference is a function of current. This finding is consistent with most literature (Engelhardt & Beichner, 2004; Hussain et al., 2012; Rankumise, 2012). Most participants incorrectly reasoned that if there is no current, there is no potential difference. As shown in chapter 4, majority of participants chose the wrong option of zero current with zero potential difference. Part of this is related the alternative conception that current is a primary concept and potential difference depend on current. This was also revealed by Psillos, Tiberghien and Koumaras (1988) that learners think that current is the prime concept. This means that most participants thought that current begins before potential difference. This erroneous reasoning could be due to participants' everyday usage of concepts such as power and energy and use it interchangeably as if they mean the same. This therefore implies that participants need clarity of terminology before they start learning the topic. Again it implies that the relationships between voltage and current should be clarified at the introductory stage of the topic. Again the dependent and the independent variable between these two variables should be emphasised that current depends on potential difference and not vice versa. This finding is consistent with the research undertaken by Brna (1988) where participants confused current, energy, electromotive force and potential difference. This is revealed by results in section 4.2 of chapter 4.

Results also reveal that participants had no clear understanding of the relationship between current and resistance. The reasoning revealed by the test and interview data shows that participants thought that the resistance of a component only exists when current is flowing. This is incorrect because component properties are independent of current. Participants had problems with question 13 which tested this concept. The low scores on all tests conducted shows that the concept is stable and tenacious. Again participants had no clarity on the concept of resistance in relation to current. Engelhardt and Beichner (2007) and Hussain et al. (2012) had similar findings. Part of the challenge was because the concept is qualitative in nature as there are no calculations involved and this shows that as teachers, we do not emphasize these qualitative concepts very well.

A closed circuit in which current is flowing is an energy system. In a circuit there are dynamic energy transformations that take place. A battery is a galvanic cell which converts chemical energy into electrical energy. When the switch is closed and the circuit is complete, depending on the components in the circuit, electrical energy is converted to heat and light energy. Question 6 showed that a significant number of participants did not realize an open circuit had electrostatic energy only since no current is flowing in an open circuit. However, evidence that 60% failed this question shows that participants did not understand the energy conversions in an electrical circuit. Implications for this are discussed below.

Definition of current was problematic for participants. Options given were able to reveal the model of thinking most participants had of this concept. The majority of participants could define current as the rate of flow of current. However, options chosen reveal that some participants still thought that current is ‘fluid like’ flowing substance. Roland (2006) and Beaty (1995) also had a similar observation where participants likened the flow of water to the flow of charge. This misconception is usually reinforced by an analogy approach that teachers use when they are defining current, which participants then erroneously assimilate. Since participants understand the definition of current as the rate of flow of charge, they also incorrectly reasoned that the battery is the source of charge. In the mind of some of the participants as the interviews revealed, there was deep confusion with the terms power, energy and current. As question 16 revealed, participants could not decide between battery as a source of charge and as a source of energy. Question 15 is where participants had difficulty understanding why a battery goes flat. Questions focusing on the battery had the similar theme of charge. A misconception of associating the battery with or energy. A significant number also thought that a battery is a source of power. This has implications for teaching. A battery is not well explained by teachers during the introductory phases and if done, their everyday understanding of a battery as a source of power and charge always is used in the classroom by participants. This revelation about the battery is further supported by results from question charge is prevalent. Results in section 4.2 illustrates this more. It is seen as a source of charge and becomes flat because all the charge is used up. This was also revealed by Rankhumise (2012).

When participants were asked the definition of Ohm’s law, they answered it well. Participants also showed an inclination towards the quantitative aspect of Ohm’s law. The test however, did not examine the quantitative aspect of Ohm’s law. This was problematic as participants expected to calculate in the test. During experimentation with simulation, the researcher saw participants holding calculators, an indication that they wanted to do some computations. As emphasised in chapter 3, the test was qualitative and no calculations were required. This was also revealed during interviews as participants expressed they were expecting to make calculations only to find no numbers and formulas. This revealed that participants do not have a meaningful understanding of Ohm’s law. Ohm’s law is a relationship between potential difference and current under controlled laboratory conditions. Question 20 directly tested Ohm’s law. Interview results reveal that participants were confused by the question. Firstly, they did not realise the question was testing the relationship between current and potential difference and secondly, they could not see the importance of the lack of internal resistance. Participants then incorrectly reasoned that the battery becomes hot when there is no internal resistance. When one touches a battery that has been in use, it feels hot. Therefore, participants are correct in their everyday experiences of batteries. In a practical sense the answer is correct but only if we take internal resistance into consideration. The over reliance and overemphasis of Ohm’s law is well documented (Brna, 1988; Hussain et al., 2012; Taber, 2011). Chen and Howard (2010) further assert that participants memorize definitions and formulas in order to pass examinations at the expense of understanding.

Interpreting parallel and series circuits presented problems to participants. Most circuits are drawn with one battery cell and then resistors and bulbs are placed in series or in parallel. Battery cells are commonly placed in series in most circuits. Participants were familiar with battery cells in series but not arranged in parallel. Question 4 (see Appendix A for test questions) is a question that shows battery cells in series and participants did well in this question. Question 5 shows batteries connected in series and parallel. Participants were challenged by this question. Question 23 shows bulbs which are connected in series and parallel. Participants had no problems with this question. Looking at question 22, battery cells are arranged in series and parallel as in question 5, and participants had problems understanding it. From this observation, it is clear that battery cells connected in parallel present a serious challenge for participants than bulbs and cells connected in series. Some participants’ stated it is their first time to come across such a battery cell arrangement in a circuit. Interestingly, the number of batteries was more important in determining the overall potential difference than the way they were arranged.) discovered that. Participants in their studies had a problem interpreting series and parallel circuit and scholars (Brna, 1988; Gaigher & van de

Merwe, 2011; Hussain et al., 2012) had the same observations. In one study, Engelhardt (1997) termed this misconception battery superposition. This finding shows that battery cells in parallel are rarely exposed to participants when they are learning about electricity.

The microscopic aspect of the circuit was not well articulated by participants. This study reveals that participants do not pay attention to the microscopic aspect of the circuit and as discussed above but they rush to do calculations where they apply the Ohm's formula. Participants were asked why a bulb switches on the moment a switch is closed. The popular response was because 'current flows fast' in the conductor instead of choosing the answer that charge is already in the conductor. This erroneous thinking reveals that participants have misunderstood the microscopic aspects of a conductor. This concept was tested by question 17. Related to this concept about nature and behaviour of charge in a conductor, is the concept of direction of flow of current as tested by question 24. This question revealed that participants have not clearly understood the difference between conventional flows of current and electron flow of current (Engelhardt & Beichner, 2004;Hussain et al., 2012; Rankumise, 2012). Question 24 posed a challenge as participants are told only electrons move in the structure of an atom. This is in contrast with other content material which emphasises that charge moves from positive to negative (Hussain et al., 2012; Rankumise, 2012). Clarification needs to be given to participants regarding what is meant by DC and AC current. This lack of understanding direction is further reinforced by question 18. A significant number of participants were unable to reason that since this is DC circuit, the direction of the pointers on the ammeters will not change (Shipstone, 1988). Related to this, is the belief of participants that a change before a component will not affect anything after the component. This erroneous reasoning is termed 'local thinking' (Shipstone, 1988) and is a 'local analysis problem' (Brna, 1988). This means that during lessons, participants should be aware that a change on one part of the circuit affects the rest of the circuit.

This study also revealed that participants did not show an understanding of the concept of conservation of current which was presented in a much more straightforward way by question 2 and question 7. Interestingly, they both had a score of 70% in the pre-test and this shows that there a pattern in which participants reason when given similar concept. It suggests the consistent way in which participants handle the concept. Participants think that there is more current at the source and as the current moves through the electrical components, it becomes less. This model of thinking was termed attenuation model by Osborne (1983). Reviewed studies (Gaigher & van de Merwe, 2011; Kucucozer & Kocakulah, 2007; Rankumise, 2012) also found the same pattern of thinking about the concept. There is a possibility the participants have been exposed to the concept extensively. However, there were participants that could not reason clearly about conservation of current in question 2 and question 7. These questions deserve attention as it cannot be a coincidence that questions testing the same alternative conception had the same number of participants with alternative conceptions (30% on both questions did not score well). Firstly, it shows that the misconception is persistent and stable. It also shows that participants do not think of electrical circuits in terms of conservation of energy, that energy cannot be created nor destroyed, and it only changes from one form to the other in an isolated system is a concept that is not well understood by participants. This shows that participants do not show a good understanding of fundamental and foundational concepts such as conservation of energy in Physical sciences. In series circuits of question 2 and 7 participants could conserve current (70%), but in question 12 and 19 where circuits were combined, participants had problems and this is further confirmed by interview data. This shows that there is rote learning of the concept of conservation of current as they could not apply the same energy principle on combined circuits. Electrical energy released by the battery should come back to the battery. This is the principle of the law of conservation of energy. Participants therefore reasoned that a different circuit configuration does not entail the application of the same concept. This was a misleading approach. As reported earlier in chapter 4, question 12 and 19 tested concepts that were poorly understood by participants. This model of thinking is termed 'the attenuation model' by scholars (Gaigher & van de Merwe, 2011; Hussain et al., 2012; Shipstone, 1984, 1988).

The short circuit concept recorded lowest scores. It is a situation where current diverts from its normal route and follows a path of low resistance back to the source in which electrical components do not receive enough current. If bulbs are part of the circuit, they will switch off. The concept was covered by question 8, 11 and 25. The idea that these questions received the lowest scores is telling. Firstly, results show that participants reasoned that an additional wire of low resistance would divide the current further making the bulbs dim but do not switch off. Instead, the popular was that brightness of the bulb would decrease and not switch off. Secondly, participants could not recognise that question 8 and 25 have the same structure but a different position for the low resistance wire and those bulbs would switch off in both cases. Thirdly, question 11 provided a good blind spot as participants could not easily recognise a short circuit. The wire with low resistance was already part of the circuit and the question had the lowest scores of all proving that the question had good distractors. Explanations from interviews reveal that this concept is covered in Grade 8 and earlier grades. Surprisingly, the concept is poorly done in grade 10. This means that either the concept was not covered in earlier grades or they have simply forgotten. Related to short circuits, is the idea that current is divided equally on a junction in a parallel circuit, irrespective of the number of resistors in each branch. About 54% of participants had problems with question 10 which tested this idea. Participants (18%), thought that current is divided equally among the branches. The tendency among participants to arbitrarily divide current is also revealed by Rankhumise (2012), who discovered in a related study on the concept, which says that resistors which are connected in parallel would divide current equally among them irrespective of circuit configuration. There is a tendency among participants to overemphasise Ohm's law (Brna, 1988) and to memorize formulas (Chen & Howard, 2010).

Changes of resistance in a circuit and interpreting its implications for current and potential difference still pose a challenge for participants. An increase and decrease in resistance has an effect on current. An increase in resistance decreases current and a decrease in resistance increases current. It is an inverse relationship. This concept was tested by question 9 and question 21. Question 9 tested interpreting resistance in a parallel circuit by moving from a parallel connection of resistors to a series connection, and question 21 tested the interpretation of resistance in a series circuit. Almost half of the participants failed to interpret the circuit correctly. This indicates the difficulty of the concept. Of the half that failed the question, interview results reveal that they thought an increase in the number of bulbs meant more sharing of current and a decrease in number of bulbs meant less sharing of the current. What participants did not realise was that by opening the switch, there was a change from a parallel circuit to a series circuit. Question 21 also confirms this pattern of thinking. By increasing the total resistance current, flow become less and bulbs dim. However, a significant number thought that by increasing resistance in series circuit, the brightness would increase (24%). These two questions therefore reveal that the relationship between current and resistance is not well understood (Engelhardt, 1997).

It is prudent to note that this conceptual test was able to reveal a lot of alternative conceptions that learners have about electricity. As the above paragraphs show, most of these alternative conceptions have been revealed by many studies. These alternative conceptions have been stable and what remains, is to now find ways to address these alternative conceptions in the classroom. There has been a lot of innovations concerning how to address these alternative conceptions and some have used analogies (Roland, 2006; Uger, Dilber, Sen., & Duzgun, 2012; Yener, 2012). Some have used inquiry methods, games, and laboratory experiments for many years however, these alternative conceptions persist (Gunstone & Tao, 1999). This study used computer simulations in to see if alternative conceptions about electricity can be addressed. The effect of these computer simulations were measured using the post-test experimental group's performance as well as interviews data. Observations of how they used the simulations were recorded using a video. This brings us to the second research question:

5.3 Post-test results

What are Grade 10 learners understanding of electricity concepts after the implementation of computer simulations?

This section will be divided into three parts. The first part will recast the nature of computer simulations. The second part will look at the results of the statistical analysis performed on the results to see if there is any significant difference in scores between the groups that did not receive a treatment with simulations and the groups that received the treatment with simulations. The third part will be an overview of what participants how effective computer simulations were effective in challenging alternative conceptions. The fourth and last part will look at the theoretical implications of the observational data during simulations.

The effectiveness of computer simulations were examined in chapter 2 but it would be helpful to recap briefly about them. Simulations offer an idealised, dynamic and visual representation of physical phenomena (Hennessy et al., 2007). They offer a platform for performing experiments which are hard to do in reality. Hennessey (2007) further asserts that simulations make it possible to perform practical tasks which are costly, dangerous, and to elaborate on topics whose concepts are not easy to perform in a normal laboratory. They are less laborious and they encourage participants to investigate and explore on their own. Simulations help participants to explore the micro world, are flexible and utilises the learner centred approach (Bell, Kanar, & Kozlowski, 2008). They are also known for being highly motivating (Bernstein, 2005), engaging (Blake &

Scanlon, 2007), very interactive (Kelly et al., 2008), making micro concepts visible (Gunstone & Tao, 1999) and aiding conceptual modelling (Rutten et al., 2012). Another good feature is that simulations can perform quantitative aspects on the circuit constructed and this is an automatic feature. One therefore, can switch from quantitative to qualitative aspects of the circuit. Simulations therefore, have been suggested as a good and effective pedagogical tool. However, some scholars point to some limitations. Hennessey (2007) points out that simulations lack sound theoretical grounding to be effectively used in the classroom, they are limited in an environment with tight curriculum control, teachers are not well trained to use them, and learners who with a low computer aptitude may not benefit. Simulations need instructional support in terms of reflection, modelling, collaboration, control and feedback (Van de Smale, Vermans, Van de Grant, & Jeuring, 2015). They further warn that without instructional support, learning can be difficult. The intention of the study as discussed earlier was to use simulations to help participants understand electricity concepts better. The pre-test group displayed a number of alternative conceptions as discussed earlier and shown in detail in chapter 4 section 4.2.

The post-test experimental group were treated to simulations and the post-test control group was treated to traditional instruction. Three independent t-tests were run using SPSS software. The t-tests results of the pre-test group and the post-test experimental group showed that there was a significant difference in performance between the two groups indicating that simulations were effective in addressing alternative conceptions participants had. This was further reinforced by Cohen’s d effect size that showed the two differences were practically significant. A similar independent t-test was also performed between the experimental group and the control group which received traditional instruction as the pre-test group and there was also a significant difference in scores and the Cohen’s d showed a practically significance difference in the mean scores. There was no significant difference between scores of the pre-test group and the control group both which received traditional instruction. Cohen’s d effect size showed that there was no significant practical significance between the two groups and this is shown in section 4.6.1. There was significant difference in scores of the pre-test and post-test scores and a Cohen’s d effect showed a practical significance difference between the two groups. This is a strong indication that computer simulations could enhance understanding of alternative conceptions that participants had about electricity. This a key and significant finding of the study. As the discussions on these results continue below, some questions however, did not show an increase in scores and some even showed negative change in scores (refer to table 6 and table 9 in section 4.6.2). This is intriguing. Although the general conclusion points towards an improvement in scores, the presence of questions that showed no difference and negative scores poses questions that need further discussion and exploration. This an exploration on whether simulations address all kinds of alternative conceptions, whether simulations reinforce certain alternative conceptions themselves, and under what conditions would computer simulations be effective.

Looking further into the post-experimental results, it can be seen that improvement in scores was only for a certain class of alternative conceptions as others shows no improvement in scores (table 6 in section 4.6.1). Alternative conceptions that showed an increase in scores after exposure to computer simulations are: interpreting series and parallel circuits, interpreting combined circuits and energy conversions. These alternative conceptions received a significant change in scores in comparison to the pre-test. Interviews revealed that these questions (5, 8, 11, 13, 19 & 25) were the most difficult for participants and were the most well performed after exposure to simulations except question 13 which showed no improvement after exposure to computer simulations. The first reason cited by participants was that they were curious about exploring these questions. Another reason was that they could have done further research on questions they did not understand during the pre-test. This includes consulting the internet and books to enrich their knowledge of these confusing and difficult questions. They also explained that they downloaded the software and practised these questions at home. This could explain an improvement in the scores on these concepts post-test. However, there was no significant change in scores in the misconception of current resistance and conservation of current (question 13). Participants did not cite these alternative conceptions as difficult for them and they also did not show from data that they were significantly explored during exposure to simulations. As noted earlier in chapter 4, alternative conceptions about the current definition, current voltage confusion and purpose of a battery received negative scores. Again, these alternative conceptions were not cited as difficult by participants and as the interviews revealed, they were also not widely explored by participants during computer simulations. This is concerning. It might show a strong possibility that when difficult alternative conceptions are investigated with computer simulations, they are corrected. It also shows that certain alternative conceptions such as the definition of current and the purpose of a battery might not be effectively corrected by computer simulations. This seems plausible. A computer simulation shows the processes of a current and the energy transformations taking place but it cannot literally define what current is. This is a factual concept. A computer simulation does not tell a participant the purpose of a battery nor does it show the kind of energy that is inside the battery. Again, this is a factual concept. What a simulation shows is the flow of charge of the battery into the conductor and the idea of ‘rate’ is remote to try and deduce from the simulation activities. As revealed in chapter 4, participants shifted their answer from ‘rate of flow of current’ to simply ‘flow of current’ as they witnessed in the simulation activity. These revelations are significant in that they show that simulations cannot effectively address all alternative conceptions and may even reinforce alternative conceptions as shown in question 1. This is an indication that computer simulations need guidance in exploring certain concepts. Smale et al., (2015), also noted that computer simulations also need instructional support, especially in transmitting factual knowledge such as definition of current. One advantage of using simulations that came out in the interview data were that they helped participants to visualize the circuit and its processes and hence, formulate thought processes that helped answer questions.

How do learners in Grade 10 engage with computer simulation activities about electricity?

As explained in chapter 4, themes were developed in order to analyse video data. Participants were engaged during computer simulations. However, the level of engagement varied from the beginning to the end of the lessons. Participants were intensely engaged at the beginning of the simulation, highly engaged in the middle of the activity and less engaged at the end of the activity. This behaviour could be caused by computer simulation software that was new to the participants. The intense engagement could be a way of familiarising themselves with the laptop and the simulation software. The less engagement towards the end could have been because participants were getting more comfortable with the use of the software as well as getting fatigued. A further behaviour noted during the simulation, was the level of calmness. Generally, participants were calm during the simulation and just a few were fidgety. This behaviour was due to their intense concentration on the simulation activity as noted earlier, and some participants indicated that they were learning how to use the software hence, the calmness and concentration. This also explains why there were so engaged at the beginning when participants were trying to learn how to use the computer. The classroom interactions and group simulation activity was ‘noisy as there was a lot of discussion on how to construct the circuit. It was however, more of a productive noise than a disruptive noise as participants continued with simulation activities. There was more intragroup interaction than intergroup interactions and this shown by figure 18 in section 4.7. Since most participants indicated they wanted to learn how to use the computer and simulation software, they relied on each other for accomplishing this activity hence, very few participants shifted between groups. On a few occasions, a few participants did some note taking during the activity in anticipation of the activity being tested which indicated that some participants took the activity seriously whilst others reduced it to a game. Participants showed a lot of enjoyment during the simulation activity with intermittent laughter and smiling. Looking at Figure 7 in chapter 4 section 4.7, most participants were pointing at the computer. This could be the nature of the group activity where participants were helping and correcting each other which could be evidence of collaboration. An interesting revelation from the data shows that no group called the teacher for assistance during the observation period. The teacher continued with his own activities and no incident was recorded of a teacher being called to assist a particular group. This could be an indication that participants wanted to be independent in their exploration of simulations and this showed their confidence in using technology. As noted earlier in chapter 3, the teacher only observed and video results show a teacher who facilitated by making sure participants did not struggle to access the software but was not actively involved in the construction of circuits. The teacher would sit in one position for a long time and gave instructions at the beginning on the ground rules and at the end to help with the wrapping up of the activity. The teacher was also involved in camera positioning so that it captured all the groups in the activity. At times, the teacher photographed group activities. In a summary, the teacher was not actively involved in the simulations activity. Since the teacher was a non-participant observer, it meant that participants had to investigate and explore the simulation activity on their own.

Working in groups helped a lot because some did not have a good computer aptitude. This resulted in other groups being larger making it difficult for some to practically experiment with simulations. However, they cited that they managed to observe what was happening and adjust their understanding. A few however, saw group work as a hindrance as they fought over who would control the circuit construction kit. The participants suggested much smaller groups for the activities to be effective. Advantages of computer simulations revealed by data were flexibility, safe to use, broadened their understanding, easy to practice by having a reset feature and validation of calculations are consistent with earlier research on computer simulations. However, an outstanding advantage was that computer simulations are a powerful tool for visualising the processes of a circuit and helped participants understand the processes of a circuit and this is shown by figure 14 section 4.8 under interview results. About three quarters of participants interviewed felt that computer simulations were useful and helped them understand electricity concepts.

Why did Grade 10 learners engage in computer simulations on electricity the way they did?

An explanation of the behaviour of participants requires that we briefly recast theories of education that have been covered in chapter 2. The behaviour of learners in a learning situation falls under the discipline of educational psychology. In framing research questions, two theories were used which are the conceptual change theory (Hewson, 1992; Posner et al., 1982; Posner & Strike, 1982) and social constructivism (Vygotsky, 1978). This study was about conceptual change and the conceptual change theory was clearer on how we can effect conceptual change in learners hence, it was more effective in the formulation of research question 1 and 2. Social constructivism as explained earlier in chapter 2 focuses on how learning takes place in a social situation including groups. Social constructivism informed research question 3 and 4. Briefly, conceptual change theory suggests that for conceptual change to take place, participants must be dissatisfied with the current concept, the new concept should be understandable, the new concept must be believable or authentic, and that the new concept must be fruitful in helping participants solve problems (Hewson, 1992; Posner et al., 1982; Posner & Strike, 1982). This framework was very useful in the identification of the alternative conceptions of electricity and even in the identification of simulations as the potent intervention strategy to confront the misconception. Social constructivism was also very critical in the design of how participants would work together to confront the alternative conceptions they had. Tenets of constructivism that were utilised in the study are, prior knowledge would be critical, participants would design their own knowledge, and that there should be social interaction among participants. There has to be collaboration among peers with those with more knowledge and expertise assisting those with less knowledge. These two theories however, mention use of tools such as culture, language and symbols as critical in the learning process.

There are many factors that could have influenced the behaviour of learners during the simulation activity. The first behaviour was the level of engagement participants had in the activity. As noted above, this was the first time participants were exposed to computer simulations. The fact that participants were intensely engaged at first and were not as engaged at the end shows that participants were getting comfortable with the activity and had gained confidence. This phenomenon was explained by Kari (1996) in his paper on activity theory. He refers to this encounter with computers as the first technical level where humans interact with the tools they use during learning. At this stage, participants are familiarizing and perfecting their motor skills so as to work effectively and efficiently with simulations. The nature of the simulations themselves can influence the level of engagement. There are highly visual and are like a game and participants being young and technologically savvy, there was no doubt participants were engaged. There was more intragroup interaction and more collaboration between group members. This could be explained in terms of group dynamics. Some participants had no confidence using computers and each group had participants who had a better knowledge of computers. This naturally provided an environment for collaboration and as interview data revealed, some participants actually learnt a lot from their peers on how to operate computer simulations. Evidence of collaboration was provided by the frequency at which participants pointed at the computer which meant that they were actively helping each other construct working circuits. From experience, the researcher noted that the level of ‘noise’ was relatively higher during use of computer simulations than that in the classroom. The researcher thought this as productive noise since he was not an active participant and not directly controlling what was happening in the task. Hence, there was bound to be some noise. In a traditional setting, noise levels are limited as the lesson is teacher centered. Although this was student centred and the researcher expected to be called to assist with a query, surprisingly participants never called for assistance throughout the whole observation period. It could be that some of the participants were quick to learn how to manipulate the simulations. Simulations had user friendly software and provided an interface in which participants could quickly solve a problem. It could be that they had the aim of being independent and exploring the activities without teacher control which further implies that participants learn better when they are in control of the learning process and it is evident that the current generation is technologically savvy. The assumption that participants are empty vessels and need guidance in every step was challenged in this activity. A few of the participants took notes but the majority did not. This could be due to some participants taking the task seriously whilst others thought that it more of a game. The calmness could be due to the awareness that they were being recorded and adjusted their behaviour. This phenomenon is known as the Hawthorne effect (Parsons, 1974).

It is important to note that the conceptual change theory and constructivism are widely used theoretical frameworks but as the discussions in the above paragraphs show, they cannot fully explain all learning situations and contexts. In this study, there were some competencies that participants should have. Firstly, basic ideas of the subject content, secondly, the ability to work in collaboration with others, thirdly, a certain level of computer literacy which includes the ability to work using and manipulating software. Both the conceptual change theory and constructivism theory are emphatic on the first and second competencies but they fail to address how a learning situation can be addressed using computers and computer software. This could be a generational problem as most of these theories were developed way before computers were used in education.

5.4 Limitations of the study

Instruments used might have had some problems. The first instrument used was the questionnaire with questions on electricity that tested alternative conceptions. An inherent weakness was the form of the test itself with multiple choice questions. Research (Cohen et al., 2007; Zimmaro, 2016) shows that the instrument can be compromised by the participants guessing the answers. Results showed that difficult questions were the most guessed (Figure 12) and this limited the ability of the instrument to measure performance on all questions being attempted by all the participants. This had an effect on the accuracy of the instrument in measuring certain alternative conceptions where learners guessed more. One of the principles of developing a test is to identify the common alternative conceptions that participants have and then design a test. However, not all alternative conceptions found in literature were tested. This might have limited the scope of the alternative conceptions investigated and by inference might have limited the insights discussed in the study. Research (Zimmaro, 2016) recommends the use of fewer questions in a test to avoid fatigue with the recommendation of 10 to 15 items. This study used 25 and this might have introduced fatigue as a factor in answering test items although this did not come out in the interview data. Again, multiple choice questions used could not test the ability to organise and express ideas. This limited the researcher's ability to analyse thought processes of how participants arrived at a certain answer. Another factor that was difficult to control was the reading and analytic ability of participants as participants with good reading and analytic ability tend to do better in multiple choice questions. This might to some extent have influenced the results as it was assumed that all participants had good reading ability. Video observations should have taken longer in order to gather more data to answer research question sufficiently. This is due to constraints in the school timetabling which limited an extended period of data collection.

Sampling was purposeful and selection of the school was deliberate since it was an underperforming school. The school was also semi urban. The sample was limited to Grade 10 Physical sciences participants of low income bracket parents. Although every effort was made to control for as many extraneous variables, one should be cautious to generalise the results and findings to other contexts and grades as the tests instrument was also adjusted to suit Grade 10 participants, not Grade 11 and 12 or tertiary participants. It could be prudent to use the same approach on middle income and high income schools and see if the same results can be replicated.

Research on alternative conceptions of electricity has been going on for over thirty years. Hence, alternative conceptions on the topic are well known although there is still room to discover more. Some are still coming out. What this study attempted to do was to find ways to improve the understanding of the topic. Research (Roland, 2006; Uger et al., 2012; Yener, 2012) before the advent of simulations extensively reported on analogies as an effective way for the conceptual change method. Some individuals have suggested games (Akilli, 2007), others have suggested multiple representation (Dufresne et al., 2004) and until recently, computer simulations (Baser, 2006; Blake & Scanlon, 2007; Chase, Shemwell, & Shwartz, 2010; Khan, 2011). Findings using computer simulations cannot be taken back to a time when computer simulations were not used as conceptual change tool. Most of these findings with simulations do not go back further than 10 years ago from this study which is a limitation. Hence, computer simulations are not time valid.

The awareness of participants that they were being researched was unavoidable during the video recording. There was an unusual calmness and composure amongst participants. This reduced the possibility of recording the true behaviour of participants and this might have reduced the type of data observed. There were time constraints as participants were following the curriculum pace; a mock session could have prevented this but it was not done.

There was an ethical dilemma posed by the research design. The experimental group was going to receive computer simulation intervention and the control group received traditional instruction. This means the control group lost out on the advantages of computer simulations. Although the control group was invited to work with the simulations after the post-test measurement, only ten turned up. This could be due to participants preparing for tests and examinations that were coming. This was an ethical limitation as all participants should benefit from the intervention as the researcher thought that computer simulation was a unique and beneficial intervention which is not found in many schools.

5.5 Conclusions

Research question 1: What are Grade 10 learners understanding of electricity concepts after the implementation of computer simulations?

This study confirmed that participants in Grade 10 had alternative conceptions about electricity. This was revealed by the use of the Electricity Concept Test (ECT) administered to all participants. Every question and concept tested showed that participants had alternative ways of understanding electricity concepts as no test item scored above 90%. However, not all concepts were difficult. Some were simple for participants, which included Ohm's law, complete and incomplete circuits, and interpreting series circuits. Other concepts proved more difficult for participants and these include understanding the role of a battery, current voltage confusion, current resistance confusion, combined circuits, interpreting short circuits and interpreting series and parallel circuits involving batteries. Interpreting short circuits proved the most difficult for participants. One major source of confusion was thinking that current was the prime concept and every other variable was dependent on the presence of current.

Since these alternative conceptions came after participants have been exposed to traditional instruction, this study reveals that traditional instruction is not effective in addressing alternative conceptions. This shows that alternative conceptions on the topic of electricity are stable and persistent. Although alternative conceptions are persistent and stable, evidence from the study revealed that traditional instruction is good at transmitting factual concepts such as the definition of current as well as stating Ohm's law. These concepts had high scores in the pre-test without the use of computer simulations.

Many participants were used to answering quantitative questions which involves calculations. This study shows that participants had difficulty with qualitative questions. Qualitative questions which test understanding. Participants had a tendency to calculate and the kind of questioning technique used through the ECT showed that qualitative questions are effective in revealing alternative conceptions. This is further aided by the multiple choice form of a test. Good distractors in the test effectively revealed alternative conceptions that participants had. The only limitation being that participants can guess when confronted with a difficult question and it is not easy to understand how they arrived at the answer.

Research question 2: What are Grade 10 learners understanding of electricity concepts after the implementation of computer simulations?

This study revealed that using technology such as computer simulations in the classroom has the capacity to improve the quality of instruction especially in addressing some alternative conceptions. The experimental group, which was exposed to computer simulations scored higher than the pre-test group as well as the control group. Again the difference in scores was found to be practically significant when a Cohen's d statistic was run. This shows that computer simulations can enhance understanding of electricity alternative conceptions. Alternative conceptions that showed a great improvement after exposure to computer simulations were interpreting series circuits, circuit energy conversions and interpreting short circuits. However, a further analysis of data showed that some alternative conceptions were not adequately addressed by computer simulations, especially ones that involved a battery. A battery connected in parallel confused participants indicating that textbooks and teachers do not expose participants to batteries that are connected in parallel. Again, the energy dynamics around the battery are not well understood. It came as a surprise that participants do not know what the purpose of the battery is and that they thought the battery goes flat because the charge is used up. Battery concepts are regarded as basic concepts and this study significantly reveals that no idea or concept in the topic of electricity should be taken for granted during instruction. As results show, concepts on battery dynamics were hard to address using computer simulations hence, the instructor needs to use computer simulations with an awareness that not all alternative conceptions are addressed by them.

Research question 3: How do learners in Grade 10 engage with computer simulation activities about electricity?

Interview and observational results also revealed that computer simulations come with many advantages. These include high engagement by learners, safety from dangerous procedures, flexibility, interactive, validation of calculations and very good visualisation of circuit processes. The idea that they could visualise the circuit and manipulate variables were distinctive advantages and were cited during interviews. The only setback was that it demanded more time and a familiarization with the software. Hence some participants were not able to manipulate the computer simulations to help them address alternative conceptions. Results also showed that there is a possibility that simulations if not carefully guided, might reinforce misunderstanding. One such example is question one where without computer simulations participants answered correctly that current is the measure of the rate of flow of current. After being exposed to computer simulations they changed to an incorrect answer that current is the flow of charge. Simulations do not define current but show the processes of current depending on the circuit one has constructed. The negative score of the definition of current on the post-test experimental group in defining shows that some concepts need guided instruction even when using computer simulations.

Research question 4: Why did Grade 10 learners engage in computer simulations on electricity the way they did?

Computer simulations are highly engaging. Hence, learners were glued to the computer during the simulation activities. Observational results show that most of the time participants were always pointing at the computer and telling each other what to do. Computer simulations and learning with computers fosters collaboration among participants. Interview results showed that some participants had no confidence in using computer as well as manipulating the PhET simulation software. This made those with less confidence using computers learn from those who had a better aptitude and learn some skills in the process. Use of computer simulations enhances independent inquiry. Observational results shows that participants used computer simulations without calling the teacher. This level of independence is an additional indication that PhET simulations are user friendly as participants could manipulate them without the need of expert advice. Use of computer and computer software in learning disrupts the normal classroom discourse. As noted in the observational results, there was a lot of noise during computer simulation activities. Participants were in groups too. This is different from a classroom set up without computers, without collaboration and where the teacher is command. In a constructivist classroom, disruption and productive noise is the norm. In a summary, computer simulations are highly engaging, fosters collaboration among participants, and encourages independent inquiry and reinforces a constructivist approach to teaching.

5.6 Recommendations

The topic of electricity is a challenging topic not only among South African learners, but across the globe. Research undertaken in America and Europe produced similar results with the results from this study. It becomes imperative that classroom discourse, especially in this topic needs revision. Changes suggested are in the teacher pedagogy, learners' classroom activities and at policy level.

At the teacher level, teachers need to be aware of the misconceptions that learners have in planning their lessons. This awareness is not widespread. This would go a long way to reduce the level of misunderstanding uncovered in this study. Currently, learners are technologically savvy yet the classroom discourse still remains unchanged. Most learners are computer literate. This means use of technology such as computer simulations would help teachers achieve conceptual understanding in a topic. However, as this study has revealed, use of technology should be a guided activity. Alternative conceptions are not the same in terms of level of difficulty. If the teacher or instructor is aware of them, they should approach their pedagogy starting with simple concepts and moving to more complex concepts. As revealed by the results, participants had problems with understanding the battery, could not perceive what was happening in the conductor, they confused current with voltage, could not efficiently interpret combined and short circuits. These concepts, as a suggestion, should start with energy dynamics of the circuit, the microscopic nature of the circuit, current-variable relationships, combined circuits and finally, short circuits. It is also important that teachers should reduce their emphasis of Ohm's law. This means qualitative thinking of concepts should be balanced with quantitative thinking. As interview data showed, some participants were surprised that there was no calculation involved in the test.

Those involved in educational research need to aware of the inadequacy of the constructivist approach to teaching and learning, especially when using technology. Conceptual change theory was inadequate to explain all classroom data collected in this study. Hence, there is need to develop grounded and adequate theoretical frameworks that can explain and inform how to use technology in the classroom. It would be helpful to integrate emerging technology-oriented theories such as systems theory and activity theory when developing the much needed framework. These theories adequately explain the behaviour of learners in the classroom especially when engaging with technological tools in the classroom whilst constructivist and conceptual change theories address mainly classroom conditions. Learners would therefore benefit from an integration of these theories as some (constructivist theory and conceptual change theory) would inform design of classroom conditions whilst other theories (systems theory and activity theory) would inform how to effectively use technology to enhance teaching and learning.

At a policy level, the topic of electricity needs more attention. It is poorly performed in the national end of year examinations as shown in chapter 2 table 1. The structure of the policy statements does not adequately address the issue of alternative conceptions of electricity. An analysis of the Physical sciences policy statement showed that only one misconception was mentioned; the battery as a constant source of current. Most of those uncovered in this study were not highlighted. It is important to highlight these alternative conceptions as early as Grade 8 since misunderstanding at this level has a cascading effect in understanding the topic at higher levels as Table 1 shows. Learners these days use technology and there is need to deliberately integrate technology in the delivery of the curriculum as a matter of policy and not choice. As noted in this study and elsewhere, computer simulations have an impact to some extent on resolving alternative conceptions. There is a problem with alternative conceptions in textbooks. Textbooks are designed to conform to curriculum statements. Therefore, they do not address alternative conceptions uncovered from this study.

This study did not cover every aspect that needs to be in order to address the issue of alternative conceptions of electricity. Teachers are at the centre of curriculum delivery. If teachers themselves hold alternative conceptions about the topic, then the problem will persist. Therefore, further research should be conducted to investigate teachers' alternative conceptions in the topic of electricity. There is need to have an extensive study on teachers' alternative conceptions of electricity. Textbooks do not address alternative conceptions in the topic. An investigation of the extent to which textbooks contribute to alternative conceptions of electricity would be helpful. Theoretical frameworks to use when dealing with technology in the classroom still need more grounding. An effort in covering this aspect will be more helpful as the use of technology in the classroom is still haphazardly implemented without theoretical insight. This study focused on one school. It would be helpful if an extensive study was undertaken that covers more schools in different settings and circumstances within South Africa.

6. References

Abimbola, O. I., & Salihu, B. (1996). Misconceptions and alternative conceptions in science textbooks. The role of teachers as filters. *The American Biology Teacher, 58*(1), 14-19.

Aikenhead., G.S., & Jegede, O.J. (1999). Cross-cultural science education: A cognitive explanation of a cultural phenomenon. *Journal of Research in Science Teaching, 36*(3), 269-287.

Ainsworth, S. (1999). The functions of multiple representations. *Computers and Education, 33*(2), 131-152.

Akilli, G. K. (2007). *Games and simulations: A new approach in education.* California: Hershley Information Science Publishing.

Applefield, J. M., Huber. R., & Moallem. M. (2001). Constructivism in theory and practice: Toward a better understanding . *The High School Journal, 84*(2), 35-53.

Bahar, M. (2003). Alternative conceptions in biology education and conceptual change strategies. *Educational Sciences: Theory & Practice, 3*(1), 1-10.

Baser, M. (2006). Effects of conceptual change and traditional confirmatory simulations on pre-service teachers understanding of direct current circuits. *Journal of Science Education and Technology*, *15*(5), 367-381.

Baser, M., & Durmus, S. (2010). The effect of computer supported versus real laboratory inquiry environments on the understanding of direct current among pre-service elementary school teachers. *Eurasia Journal of Mathematics, Science and Technology Education*, *6*(1), 47-61.

Beaty, W. J. (1995). Electricity alternative conceptions in K-6 textbooks. Retrieved from http://amasci.com/miscon/eleca.html

Beauchamp, G., & Kenwell, S. (2010). Interactivity in the classroom and impact on learning. *Computers and Education*, *54*, 759-766.

Bell, B.S., Kanar, A.M., & Kozlowski, S.W.J. (2008). Current issues and future direction in simulation-based training in North America. *The International Journal of Human Resources Management*, *19*(8), 1416-1434.

Bernstein, W (2005). *Unlocking Maths and Science potential. CSI Handbook* (8th ed.). Retrieved from http://www.cde.org.za/article.php?a_id=233

Blake, C., & Scanlon, E. (2007). Reconsidering simulations in science education at a distance: Features of effective use. *Journal of Computer Assisted Learning*, *23*, 491-502.

Brna, P. (1988). Confronting alternative conceptions in the domain of simple electrical circuits. *Instructional Science, 17*, 29-55.

Bronster, P., James, H., Carter, P., & Horn, W. (2013). *Oxford successful physical sciences. Learner's book. Grade 10*. Pretoria: Oxford Printers.

Brecht, B., & Vesey, D.I. (1974). The Life of Galileo. London: Eyre Mathuen.

Brock-Utne, B., & Hopson, R. K. (Eds.). (2005). *Languages of instruction for African emancipation: A focus on post-colonial contexts and considerations*. Cape Town: Centre for Advanced Studies of African Society (CASAS).

Bulger, M. E., Mayer, E., & Almeroth, C. K., Blau, S.D. (2008). Measuring engagement in computer equiped college classrooms. *Journal of Education, Multimedia and Hypermedia, 17*(2), 129-143.

Caldwell, K., & Atwell , A. (2005). Do health and social care professionals interact equally. A study of interactions in multi-disciplinery teams in United Kingdom. *Scandanavian Journal of Caring Science. 19*(3). 268-273.

Cameron, R. (2009). A sequential mixed model research design: Design, analytical and display issues. *International Journal of Multiple Research Approaches, 3*(2), 140-152.

Campbell, T., Wang, S. K., Hsu, H. Y., Duffy, A., & Wolf, P. G. (2010). Learning with Web Tools, Simulations and other Technologies in Science Classrooms. *Journal of Science Educational Technology, 19*, 505-511.

Carlsen, D. D., & Andre, T. (1992). Use of a micro-computer simulation and conceptual change text to overcome student preconceptions about electric circuits. *Journal of Computer Assisted Learning, 19*(4), 105-109.

Chase, C. C., Shemwell, J. J., & Shwartz, L. D. (2010). Explaining accross contrasting cases for deep understanding in science: An example of using interactive simulations. *Interactive Collaborative Learning. 1*, 153-160.

Cheng M., Gilbert J.K. (2009). Towards a better utilization of diagrams in research into the use of representative levels in chemical education. In J.K. Gilbert & D. Treagust. (eds.), *Multiple representations in chemical education. Models and modelling in science education*. Dordrecht: Springer.

Chen, C. H., & Howard, B. (2010). Effect of live simulation on middle school students attitude and learning toward science. *Education, Technology & Society. 13*(1), 133-139.

Chickering, A. W., & Gamson, Z. F. (1987). Seven principles for good practice in undergraduate education. *American Association for Higher Education, 80*(120), 3-7.

Chin-Liu, H. (2002). *Web-based simulations on chemistry and physics lab activities*. In D. Willis, J. Price., & N. Davis (Eds.). Proceedings of SITE. Nashville: Tennessee.

Christensen, L.B., Johnson, B.R., & Turner. L.A. (2014). Research methods, design and analysis. Global edition. New York: Pearson Education Limited.

Cohen, R., Eylon, B., & Ganiel, U. (1983). Potential difference and current in simple electric circuits. A study of student concepts. *American Journal of Physics, 51*, 407-412.

Cobern, W.W. (1996). Worldview theory and conceptual change in science education. *Science Education*, *80*(5), 579-610.

Cohen, L., Manion, L., & Morrison, K. (2007). *Research methods in education.* (6^{th} Ed.). New York: Routledge.

Commision, N.N. P. (2011). *The National Development Plan*. Pretoria. Government Printer. Retrieved from: file:///E:/NDP%20Vision%202030.pdf.

Creswell, J. W. (2012). *Planning, conducting and evaluating quantitative and qualitative research.* New York: Pearson.

Cuban, L. (1984). *How teachers taught: Constancy and change in American classrooms, 1890-1980*. New York: Longman.

Dega, B. G. (2012). *Conceptual Change through Cognitive Perturbation using Simulations in Electricity and Magnetism: A Case Study in Ambo University, Ethiopia.* (Doctor of Philosophy in Mathematics, Science and Technology Education), University of South Africa, Pretoria.

Dosi, G., Freeman, C., & Fabiani, S. (1994). The process of economic development: Introducing some stylised facts and theories on technologies, firms and institutions. *Industrial and Corporate Change*, *3*(1), 11-45.

Driver, R. (1989). Students conceptions and learning of science. *International Journal of Science Education*, *11*(5), 481-490.

Department of Science and Technology. (2016). *Annual Report 2015-2016*. Pretoria: Government Printer. Retrieved from: https://nationalgovernment.co.za/department_annual/150/2016-department:-science-and-technology-(dst)-annual-report.pdf

Dufresne, R. J., Gerace, W. J., & Leonard, W. J. (1997). Solving Physics Problems with Multiple Representations. *The Physics Teacher, 35*, 270-275.

Dunn, R., Honigsfeld, R., Doolan., L.S., Bostrom., L., Russo., K., Schiering., M.S.et.al. (2009). Impact of learning-style instructional strategies on student achievement and attitude:

Perceptions of education diverse institutions. *Journal of Educational Studies, Issues and Ideas, 83*(2), 135-140.

Eckhardt, M., Urhahne, D., Conrad, O., & Harms, U. (2013). How effective is instructional support for learning with computer simulations. *Instructional Support for Computer Simulations, 41*, 105-124.

Department of Basic Education. (2011). Physical Science national curriculum statement (NCS). Curriculum and Assessment Policy Statement. Further Education and Training Phase Grade 10-12. Pretoria. Department of Basic Education. Retrieved from: https://www.education.gov.za

Department of Basic Education (2012). *National senior examination report. National diagnostic report on learner performance*. Pretoria: Department of Basic Education. Retrieved from: https://www.education.gov.za/Resources/Reports.aspx

Department of Basic Education (2013). *National senior certificate. National Diagnostic Report.* Pretoria: Department of Basic Education. Retrieved from: https://www.education.gov.za/Resources/Reports.aspx

Department of Basic Education (2014). *National senior certificate. National Diagnostic Report.* Pretoria: Department of Basic Education. Retrieved from: https://www.education.gov.za/Resources/Reports.aspx

Department of Basic Education (2015). *National senior certificate. National Diagnostic Report.* Pretoria: Department of Basic Education. Retrieved from: https://www.education.gov.za/Resources/Reports.aspx

Department of Basic Education (2016). *National senior certificate. National Diagnostic Report.* Pretoria: Department of Basic Education. Retrieved from: https://www.education.gov.za/Resources/Reports.aspx

Ellington, H., Addinall, E., & Percival, F. (1981). Games and simulations in science education. New York: Nichols Publishing.

Engelhardt, P.V. (1997). *Examinining students understanding of electrical circuits through multiple-choice testing and interviews* (Published Doctoral Dissertation), North Carolina State University, North Carolina.

Engelhardt, P., & Beichner, R. J. (2004). Students understanding of direct current resistive electrical circuits. *American Journal of Physics, 72*(1), 72-98.

Engestrom, Y., Daniels, H., Edwards, A., Gallagher, T., & Ludvigsen, S.R. (2010). *Activity theory in practice. Promoting learningaccross bounderies and agencies*. Routledge: New York.

Finkelstein, N. D., Adams, W. K., Keller, C. J., Kohl, P. B., Perkins, K.K., Podelflisky.N.S.,et al. (2005). When learning about the real world is better done virtually. *The American Physics Society, 1*(1), 1-8.

Freddette, N., & Lockhead, J. (1980). Students conceptions of simple circuits. *The Physics Teacher, 18*(3), 194-203.

Gaigher, E., & van de Merwe, O. R. (2011). *Teachers insight into alternative conceptions about simple circuits*. University of Pretoria. Pretoria.

Gall, M. D., Gall, J. P., & Borg,W.R (2005). *Applying educational research: A practical guide*. (5th ed.). New York: Pearson.

Geduld, E., Green, W., Mkwanazi, V., Mzolo, P., & Whitfiled, D. (2007). *Focus study guide. Grade 10 Physical sciences*. Cape Town: Maskew Miller Longman.

Gilbert, J.K., Bulte, A.M.W., & Pilot, A. (2011). Concept development and transfer in context-based science education. *International Journal of Science Education, 33*(6), 817-837.

Govender, N. (2012). *Pre-service students experiences of ICT simulations and hands on practicals on light and the photoelectric effect.* Faculty of Mathematics, Science and Technology. University of KwaZulu Natal. Durban.

Greddler, M. E. (1996). Educational games and simulations: A technology in search of a paradigm. *Soft Technologies: Instructional and Informational Design Research, 12*(4), 521-541.

Gubuz, R., & Birgin, O. (2011). The effect of computer assisted teaching in remedying alternative conceptions. The case of subject probability. *Turkish Journal of Technological Education, 3*(5), 34-52.

Gunstone, R.F., & Tao, P.K. (1999). Conceptual change in science through collaborative learning at the computer. *International Journal of Science Education., 21*(1), 39-57.

Guzzetti, B. J., Snyder, E. T., Glass, V. G., & Gamas, S. W. (1993). Promoting conceptual change in science: A comparative meta-analysis of instructional interventions from reading education and science education. *Reading Research Quarterly, 28*(2), 116-159.

Halonen, J. S., & Santrock, W. J. (1996). *Psychology. Context of behaviour*. Boston: McGraw Hill.

Hennessy, S., Wishart, J., Whiteload, D., Deany, R., Brawn, R., LaVelle, L., et al. (2007). *Pedagogical Approaches for Technology Integrated teaching*. University of Cambridge. Cambridge.

Hewson, P. W. (1992). *Conceptual change in science teaching and teacher education.* Paper presented at a meeting on Research and Curriculum Development in Science Teaching.

National Center for Educational Research, Documentation, and Assessment. Madrid. Retrieved from: https://www.learner.org/workshops/lala2/support/hewson.pdf

Hewson, P. W., & Hewson, B. A. G. (1984). The role of conceptual conflict in conceptual change and the design of science instruction. *Instructional Science, 13*(1), 1-13.

Heywood, D. (2010). The place of analogies in science education. *Cambridge Journal of Education, 32*(2), 233-247.

Hodson, D. (2008). Philosophy of science and science education. *Studies in Science Education, 12*(1), 25-57.

Huppert, J., Lomask, S. M., & Lazarowitz, R. (2002). Computer simulations in the high school: Students cognitive stages, science process skills and academic achievements in microbiology. *International Journal of Science Education, 24*(8), 803-821.

Hussain, N. H., Latiff, L. A., & Yahaya, N. (2012). Alternative conceptions about open and short circuit concepts. *Social and Behavoural Science*, *56*, 466-473.

Ihantola, E. M., & Kihn, L. A (2011). Threats to validity and reliability in mixed methods accounting research. *Qualitative Research in Accounting and Management 8*(1), 39-58.

Ivankova, V. N., Creswell, J. W., & Stick, L. S. (2006). Using mixed methods sequential explaratory design:From theory to practice. *Field Methods*, *18*(1), 3-20.

Jaakola, T., Nurmi, S., & Veermans, K. (2011). A comparison of students conceptual understanding of electrical circuits in simulation-only and simulation-laboratory contexts. *Journal of Research in Science Teaching, 48*(1), 71-93.

Jiao, Q. J., Onwuegbuzie, A. J., & Collins, M. T. K. (2007). A mixed methods investigation of mixed methods sampling designs in social and health science research. *Journal of Mixed Methods Research*, *1*(3), 267-294.

Jimoyiannis, A., & Komis, V. (2001). Computer simulations in physics teaching and learning: A case study on students understanding of trajectory motion. *Computers and Education, 36*(2), 183-204.

Johnson, B., & Turner, L.A. (2003). *A handbook of mixed methods in social and behavioural research*. London: SAGE.

Johnson, R. B., & Christensen, L. B. (2014). *Educational research methods.* Alabama: SAGE.

Johnson, R.B., & Christensen, L.B. (2016). Educational Research: Quantitative, Quantitative and mixed approaches. Alabama: SAGE.

Jonassen, D. (1992). *Instructional-design theories and models: A new paradigm of instructional theory*. New York: Routledge.

Kari, K. (1996). *Activity theory as a potential framework for human-computer interaction research.* Cambridge: MIT Press.

Kelder, K. H., Repsold, C., Bridgeman, J., Finnemore, D., & Daniels, T. (2008). *Study & Master*. Cape Town: Cambridge University Press.

Keller, J. (2000). *How to integrate learner motivation into lesson planning:The ARCS model approach.* Florida State University. Santiago.

Kelly, J., Bradley, C., & Gratch, J. (2008). *Science Simulations: Do they make a difference in student achievement in the Physics laboratory*. Retrieved from: https://www.files.eric.ed.gov/fulltext/ED-01653.pdf

Khan, S. (2011). New pedagogies on teaching science with computer simulations. *Journal of Science Education and Technology, 20*, 215-232.

Kluge, A., & Bakken, S. V. M. (2010). Simulations as science discovery: Ways of interactive meaning-making. *Research and Practice in Teaching and Learning, 19*, 245-285.

Kotoka, J., & Kriek, J. (2014). The impact of computer simulations as intaractive demonstation tools on the performance of grade 11 learners in electromagnetism. *African Journal of Research in Mathematics , Science and Technology Education*, *18*(1), 100-110.

Kriek, J., & Basson, I. (2009). *The effect of physics computer simulationson teachers misconceptionson DC circuits.* Proceedings of the 17th Annual Conference of Southern African Association for Research in Mathematics, Science and Technology Education. Grahamstown.

Kucucozer, H., & Kocakulah, S. (2007). Secondary school students alternative conceptions about simple electric circuits. *Journal of Turkish Science Education, 4*(1), 101-115.

Kuhn, S. T. (1962). The structure of scientific revolutions. In O. Neurath (Ed.), *International Ecyclopedia of Unified Science*. Chicago. University of Chicago Press.

Lauer, P.A. (2006). *An educational research primer. How to understand, evaluate and use it.* San Francisco: Jossey-Bass.

Liegeois, L., Chasseigne., G., & Mullet, E. (2003). Improving high school students understanding of potential difference in simple electric circuits. *International Journal of Science Education. 25*(9), 1129-1145.

Liegeois, L., & Mullet, E. (2002). High school students understanding of resistance in simple series electric circuits. *International Journal of Science Education, 24*(6), 551-564.

Limson, M., Witzlib, C., & Desnarnais, R. A. (2007). Using web-based simulations to promote inquiry. *Science Scope, 30*(6), 36-44.

Lin, L. F., Hsu, Y. S., & Yeh, Y. F. (2012). The role of computer simulations in an inquiry-based learning environment: Reconstructing geological events as geologist. *Journal of Science Education and Technology, 2*, 370-383.

Lindgren, E. (2010). *How does the use of student-centered interactive technology in the classroom affect student understanding of concepts.* (Master of Education), Bemidji University, Bemidji.

Lindgren, E., & Schwartz, D. L. (2009). Spartial learning and computer simulations in science. *International Journal of Science Education, 31*(3), 419-438.

Luxman, K., & Chin, Y. K. (2011). Impact of simulations on mental models of students in the online learning of science concepts. *Journal on School Education Technology, 7*(2), 1-12.

Lyons, T. (2006). The puzzle of falling enrolments in physics and chemistry courses: Putting some pieces together. *Research in Science Education, 36*, 285-311.

Mandinach, E. B., & Cline, F. H. (1992). *The Impact of technological curriculum innovation on teaching and learning activities.* Paper presented at the Annual Conference of the American Educational Research Association., San Francisco.

Mautjana, R.T. (2015). *The role of symbols in learners in understanding direct current resistive electrical circuits in rural and peri-urban schools* (Master of Science Dissertation). Faculty of science and Agriculture. University of Limpopo, Polokwane. Retrieved from: http://ulspace.ul.ac.za

Mallis, V. I. S., Martin O. M., Foy, P., Olson, J.F., Preuschoff, C., Eberber., E., et al.(2007). *TIMMS 2007 international report: Findings from IEA's trends in international mathematics and science study at the fourth grade and eigth grades.* Boston: TIMMS & PIRLS study center.

Millar, R., & King, T. (1993). Students understanding of voltage in simple series electric circuits. *International Journal of Science Education. 15*(3), 339-349.

Muwanga-Zake, J. W. F. (2001). Is science education in South Africa in a crisis? The Eastern Cape experience. *Journal of the Southern African Association for Research in Mathematics, Science and Technology Education, 4*(1), 1-11.

McDermot, L. C., & Shaffer, P. C. (2000). *Preparing teachers to teach physics and physical sciences by inquiry*. University of Washington. Washington. Retrieved from: https://www.researchgate.net/profile/Costas_Constantinou2/publication/231051551_

McFarlane, A., & Sakellariou, S. (2002). The role of ICT in science education. *Cambridge Journal of Education, 32*(2), 219-225.

Mergerndoller, J. R., Bellisimo, Y., & Maxwell, N. L. (2006). The effectiveness of problem based instruction: A comparative study of instructional methods and student characteristics. *The Inter-Disciplinary Journal of Problem Based Instruction and Student Charecteristics, 1*(2), 49-69.

Mhlongo, R. M., Kriek, J., & Basson, I. (2011). The contribution of simulations to the practical work of foundation physics students at the University of Limpopo. *Multicultural Education & Technology Journal, 5*(4), 288-302.

Mingireanu, F., & Breharu, F. (2013). *The 9th International Scientific Conference*. Paper presented at the e-Learning and Software for Education. Bucharest.

Moosa, S. (2015). *The use of simulations in supporting grade 10 learners from underperforming Dinaledi schools in Soweto to eliminate their misconceptionson in simple electric circuits*(Master of Education). Faculty of Education. University of Johannesburg. Retrieved from: https://ujdigispace.uj.ac.za

The Planning commision (2011). The National Development Plan 2030. South African Government. Pretoria. Retrieved from: https://www.gov.za/issues/national-development-plan-2030.

Nelson, G. S. (2014). *Educational technology and mindful learning in the classroom.* (Unpublished Doctor of Education Dissertation), Georgia Southern University, Georgia.

Nersessian, N. J. (1989). Conceptual change in science and in science education. *Philosophy of Science and Science Education, 80,* 163-184.

Nersessian, N. J. (2001). *Concept formation and commensurability* (Vol. 216). Boston: Springer.

Nesbitt-Hawes, J. P. (2005). *Higher order thinking skills in a science classroom computer simulation.* (Unpublished Master of Education Dissertation). Queensland University of Technology. Brisbaine.

Novak, J. D. (2002). Meaningful learning: The essential factor for conceptual change in limited or inappropriate proportional hierachies leading to empowerment of learners. *Science Education, 86*(4), 548-571.

O'Keefe, P. A. (2014). Learning from multiple representations: An examination of fixation patterns in a science simulation. *Computers in Human Behaviour*, *35*, 234-242.

Onwuegbuzie, A. J., & Collins, M. T. K. (2007). A typology of mixed methods sampling designs in social science research. *The Qualitative Report*, *12*(2), 281-316.

Osborne, R. (1983). Towards modifying children's ideas about electric current. *Research in Science and Technological Education, 1*(1), 73-82.

Pace, D. K. (2004). Modelling, simulation, verification and validation challenges. *Johns Hopkins Applied Technical Digest, 25*(2), 163-172.

Palinscar, S. A. (1998). Social constructivist perspectives on teaching and learning. *Annual Review of Psychology, 49*, 345-375.

Palmer. (2005). A motivational view of constructivist-informed teaching. *International Journal of Science Education, 27*(15), 1853-1881.

Parsons, H. M. (1974). What happened at Hawthorne? *Science Education, 183*(1428), 922-932.

Pey-Tee, O., & Subramaniam, R. (2011). On the declining interest in physics among students from perspectives of teachers. *International Journal of Science Education, 33*(5), 727-746.

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change:The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *American Educational Research Association*, *63*(2), 167-199.

Posner, G. J., Strike, K. A., & Hewson, P. W. (1982). Accomodation of a scientific conception. Toward a theory of conceptual change. *Science Education, 66*(2), 211-227.

Potvin, P. (2013). Proposition for improving the classical models of conceptual change based on neuroeducational evidence:conceptual prevalence. *Neuroeducation, 2*, 1-28.

Pyat, K., & Sims, P. (2011). Virtual and physics experimentation in inquiry-based science labs: attitudes,performance and access. *Journal of Science Education and Technology, 21*, 133-147.

Psillos, D., Koumaras, P., & Tiberghien, A. (1988). Voltage presented as a primary concept in an introductory teaching sequence on DC circuits. *International Journal of Science Education. 10*(1), 29-43.

Ramnarain, U., & Moosa, S.(2017). The use of simulations in correcting electricity misconceptions of grade 10 South African Physical science learners. *International Journal of Innovation in Science and Mathematics Education. 25*(5), 1-20

Rankumise, P. M. (2014). *The effects of activity based istructional approaches in ameliorating conceptions about electric circuits held by students from the national curriculum statement* *and the old school curriculum.* (Unpublished Doctor of Philosophy), University of Zululand.

Redish, E. F. (1994). Implications of cognitive studies for teaching physics. *American Journal of Physics, 62*(9), 45-73.

Richards, J., Barowy, W., & Levin, D. (1992). Computer simulation in the science classroom. *Journal of Science Education and Technology, 1*(1), 67-69.

Riley, M. S., Bee, N. V., & Mokwa, J. J. (1981). Representation of knowledge in basic electricity and its use in problem solving. Intervention work on problems concerning students representation of physics and chemistry knowledge. *Pedagogues Hoschschule*, 107-173.

Roberts, N. (1994). *Using simulations for learning science*. Paper presented at the Annual Meeting of the American Educational Research Association. Massachusetts. Retrieved from: https://files.eric.ed.gov/fulltext/ED404999.pdf

Roland, N. (2006). A hydrodynamic analogy to energy losses in capacitors. *Physics Education, 41*, 217-218.

Ronen, M., & Eliahu, M. (2000). Simulation. A bridge between theory and reality: the case of electric circuits. *Journal of Computer Assisted Learning, 16*, 14-26.

Roth, M. W. (2007). Emotion at work: A contribution to third generation cultural-historical activity theory. *Mind, Culture & Activity, 14*(1-2), 40-63.

Roth, M. W., & Lee, S. R. (2003). Science education as/for participation in the community. *Science Education, 88,* 263-291.

Rowley, J. (2012). Conducting research interviews. *Management Research Review, 35*(3), 260-271.

Rutten, N., van Jooligan, W. R., & van der Veen, J. T. (2012). The learning effects of computer simulations in science education. *Computers and Education, 58,* 136-153.

Saleh, M. I., & Khine, M. (2009). *Promoting science advancing learning and fostering scientific habits of mind*. New York: Sense Publishers.

Sauter, M., Uttal, D. H., Rapp, D. N., Downing, M., & Jona, K. (2013). Getting Real: The authenticity of remote labs and simulations for science learning. *Distance Education, 34*(1), 37-47.

Schultz, J. (2000). *Computers and collaborative writing in the foreign language curriculum. Network-based language learning: Concepts and practice*. Cambridge: Cambridge University Press.

Shipstone, D. (1984). A study of children's understanding of electricity in simple DC circuits. *European Journal of Science Education, 6*(2), 185-198.

Shipstone, D. (1988). Pupils understanding of simple electrical circuits. *Physics Education, 23*(2), 92-96.

Shipstone, D., Rhoneck, C., Jung, R. W., Karqvist, C., Dupin, J. J., Joshua, S., et al. (1988). A study of students understanding of electricity in five European Countries. *International Journal of Science Education, 10*(3), 303-316.

Strauss, R. T., & Kinzie, M. B. (1991). Hi-tech alternatives to dissection. *The American Biology Teacher, 53*(3), 154-138.

Strike, K. A., & Posner, G. J. (1982). Conceptual change and science teaching. *European Journal of Science Education, 4*(3), 231-240.

Suter, W.N. (2012). *Introduction to educational research. A critical thinking approach*. London: Sage.

Swain, T. (2012). *Meaningful use of animation and simulation in the science classroom.* (Unpublished Master of Education Dissertation). State University of New York. New York. Retrieved from: http://digitalcommons.brockport.edu/ehd_theses/143

Taber, S. K. (2011). *Constructivism as educational theory: Contigency in learning and optimally guided instruction.* Cambridge: Nova Science Publishers.

Treagust, D.F., Chittleborough, G., & Mamialla, T.L. (2002). Students understanding of the role of scientific models in learning science. *International Journal of Science Education, 24*(4) 354-368.

Tas, E., Cepni, S., & Kaya, E. (2012). The effects of web-supported and classical concept maps on students cognitive development and misconception change: a case study on photosynthesis. *Energy Education Science and Technology Part B: Social and Educational Studies, 4*(1), 241-252.

Tashakkori, A., & Teddlie, C. (1998). *Mixed method:Combining qualitative and quantitative approaches. Applied social research series*. London: Sage Publications.

Taylor, N. (2007). *Equity,efficiency and the development of South African Schools.* Dordrecht: Springer.

Thacker, B.A. (2003). Recent advances in classroom physics. *Reports on Progress in Physics, 66*(10), 1833-1864.

Uger, G., Dilber, R., Sen, P. Y., & Duzgun, B. (2012). The effects of analogy on students understanding of direct current and attitude towards physics lessons. *European Journal of Educational Research*, *1*(3), 211-223.

UMALUSI. (2011). *Report on 2011 national senior certificate examination: Post examination analysis*. Council of Quality Assurance in General and Further Education and Training. Pretoria. Retrieved from: https://www.umalusi.org.za/docs/research/2011/pea_dbe.pdf

Van de Smale, S., Vermans, T., Van de Grant, L., & Jeuring, J. (2015). *The effect of simulations and games on learning objectives in tertiary education. A systematic review*. Department of Information Science. Utrecht University. Retrieved from: http://www.cs.uu.nl/research/techreps/repo/CS-2015/2015-017.pdf

Vygotsky, L. S. (1978). *Mind in Society*. Cambridge: Havard University Press.

Waks, S. (1994). Science-technology dimensions in physics education: Prospects and impact. *Physics Education. 29*(64), 64-70.

Wambugu, P. W., & Changeiywo, J. M. (2008). Effects of mastery approach on secondary school students physics achievement. *Eurasia Journal of Mathematics, Science and Technology Education*, *4*(3), 293-302.

Wandersee, J. H., Mintzes, J. J., & Novak, J. D. (1994). *Determining cognitive structures and alternative conceptions on the concept of reproduction.* New York: Simon Schuster and Prentice Hall International.

Wang, T., & Andre. T. (1991). Conceptual change text versus traditional text and application questions versus no questions in learning about electricity. *Contemporary Educational Psychology, 16*(2), 103-116.

Wang, F., Kinzie, M. B., McGuire, P., & Pan, E. (2010). Applying technology to inquiry-based learning in early childwood education. *Early Childhood Education., 37*, 381-389.

Wells, M., Hestenes, D., & Swackhamer, G. (1995). A modelling method for high school physics instruction. *American Journal of Physics, 63*(7), 606-620.

Wieman, C., Adams, W., Loblin, P., & Perkins, K. (2011). Teaching Physics using PhET Simulations. Retrieved from http://phet.colorado.edu/teacher_ideas/classroom-use.php

Wiens, J. J., Graham, H. C., & Kozak, H. K. (2008). Integrating GIS-based envirionmental data into evolutionary biology. *Trends in Ecology & Evolution, 23*(3), 141-148.

Yener, D. (2012). A study on analogies presented in high school physics textbooks. *Asia-Pacific Forum on Science Learning and Teaching, 13*(1), 1-17.

Yu-Fen, F., Guo, Y., & Juho, H. (2008). Exploring effective use of computer simulations for physics education. *Journal of Computers in Mathematics and Science Teaching, 27*(4), 443-446.

Zacharia, Z. (2003). Beliefs, attitudes, intentions of science teachers regarding the educational use of computer simulations and inquiry-based experiments in Physics. *Journal of Research in Science Teaching*, *40*(8), 792-823.

Zacharia, Z. (2007). Comparing and combining real and virtual experimentation:An effort to enhance students conceptual understanding of electric circuits. *Journal of Computer Assisted Learning*, *23*(2), 120-132.

Zimmaro, D. M. (2016). *Writing good multiple choice questions.* Faculty Innovation Center. Univesity of Texas. Austin. Retrieved from: https://facultyinnovate.utexas.edu/sites/default/files/writing-good-multiple-choice-exams-fic-120116.pdf

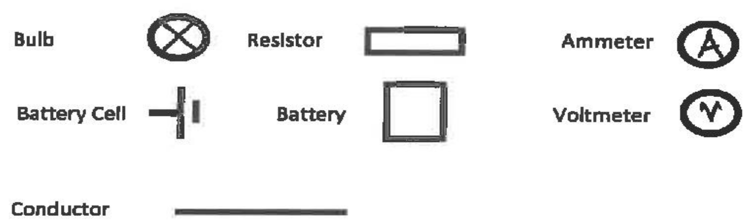
Appendix A

ELECTRICITY CONCEPTUAL TEST

<u>Information</u>

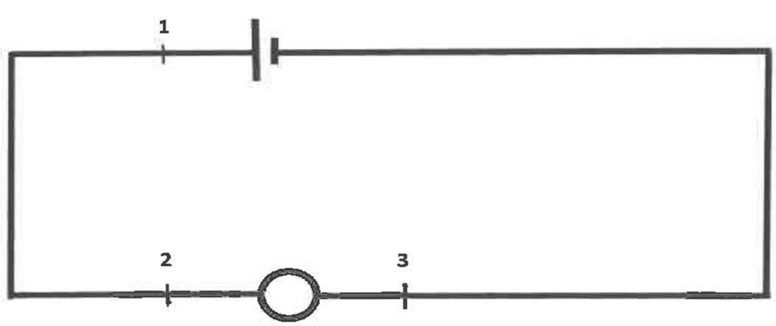
Respond to all test items
Circle the correct answer with a pencil
All conductors are assumed of negligible resistance
All bulbs, battery cells, resistors and conductors are considered identical
Assume all cells have negligible internal resistance

<u>Symbols</u>



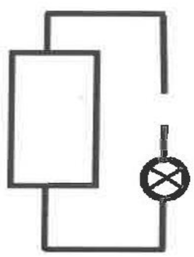
1. Which one of the following is the correct definition of current?
A. It is the flow of electrical fluid in a conductor
B. It is the movement of charge in a conductor
C. It is the rate of flow of charge in a conductor
D. It is work done to move charge in a conductor

2. Current is measured at the three points 1, 2 and 3. Which of the statements below is correct concerning the amount of current at points 1, 2 and 3.

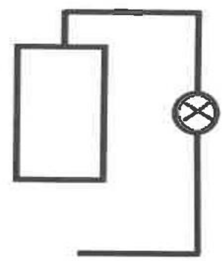


A. Current at 1 is greater than current at 2
B. Current at 1 is greater than current at 3
C. Current at 1 is greater than current at 2 and 3
D. Current at 1 is equal to current at 2 and 3

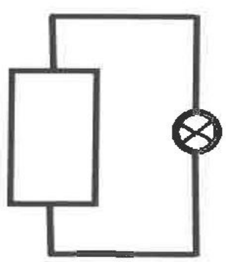
3. Which of the following connection will the bulb light up?



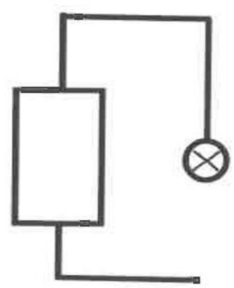
A



B



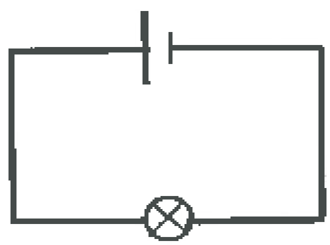
C



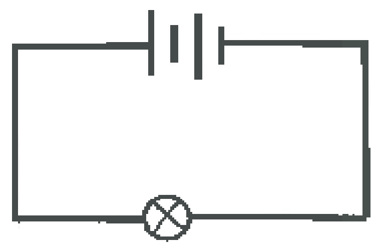
D

4. You are given four circuits below. In which circuit will the bulb glow the brightest?

A



B

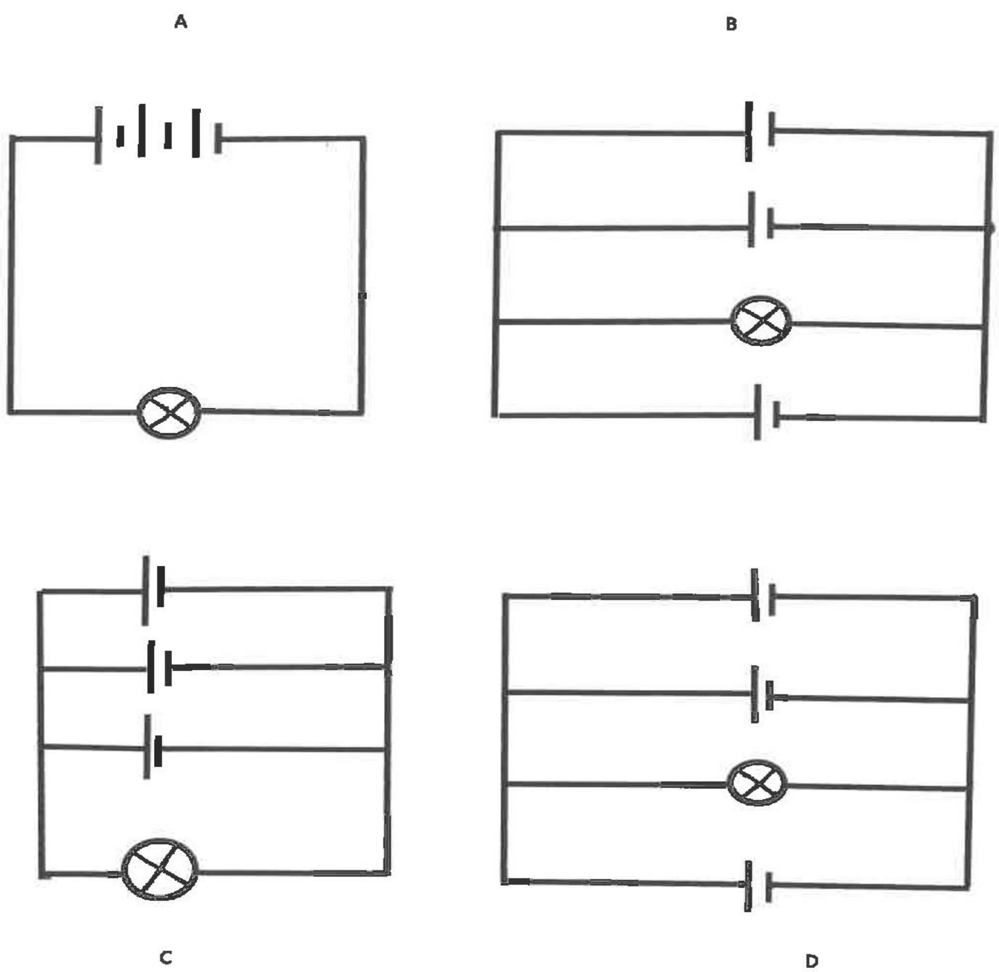


C

D

A. A
B. B
C. C
D. D

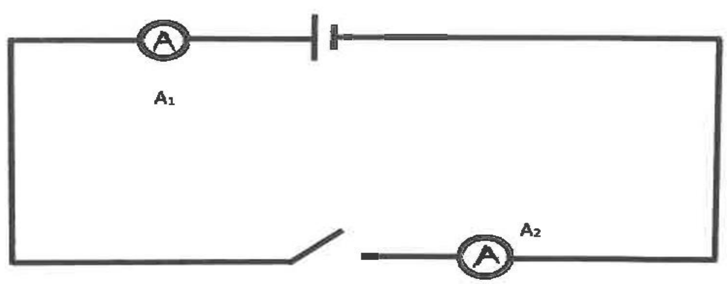
5. Given four circuits below. Which circuit will the bulb glow the brightest?



6. Which one of the following forms of energy is found in an electrical circuit that is OPEN?

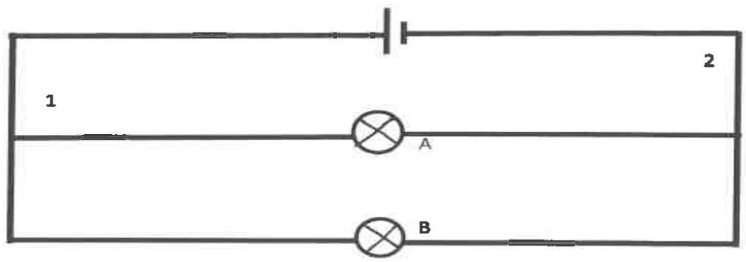
A. Heat
B. Light
C. Electrical
D. Electrostatic

7. Study the circuit below. Which of the statements below is true of the reading of ammeter A_1 and ammeter A_2.



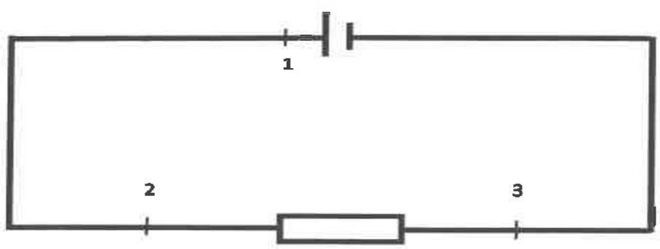
A. Reading A_1 is greater than Zero
B. Reading A_1 is less than Zero
C. Reading A_1 is equal to A_2 equal to Zero
D. Reading A_1 is greater than A_2

8. Study the circuit diagram below. What will happen to bulb A and bulb B when a wire of low resistance is connected between points 1 and 2.



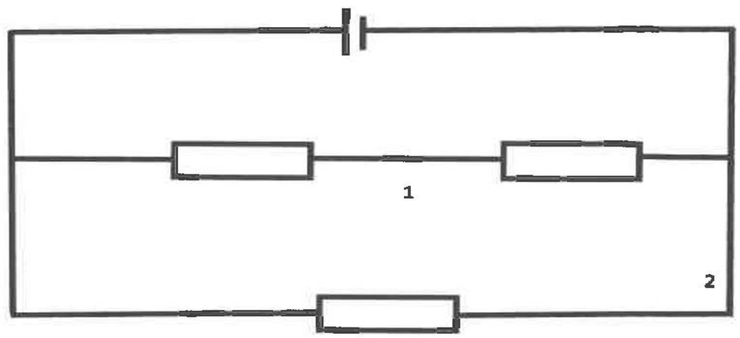
A. Bulb A glows brighter
B. Bulb A glows dimmer
C. Bulb A and B turns off
D. Bulb B glows brighter

9. Study the circuit below. Which of the following is TRUE of the current at points 1, 2 and 3.



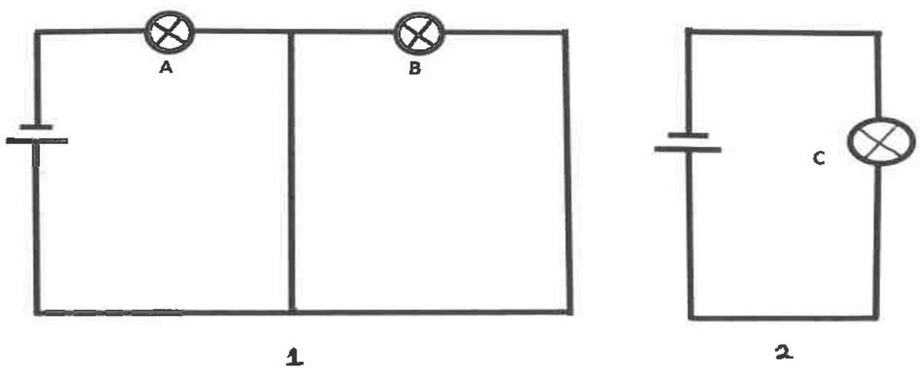
A. Current at 1 is greater than at point 2
B. Current at 2 is greater than at point 3
C. Current at 1 is equal to current at 2 and 3
D. Current at point 3 is less than at 1 and

10. Study the circuit diagram below showing resistors in a circuit. Which of the options below is true of the current passing through points 1 and 2.



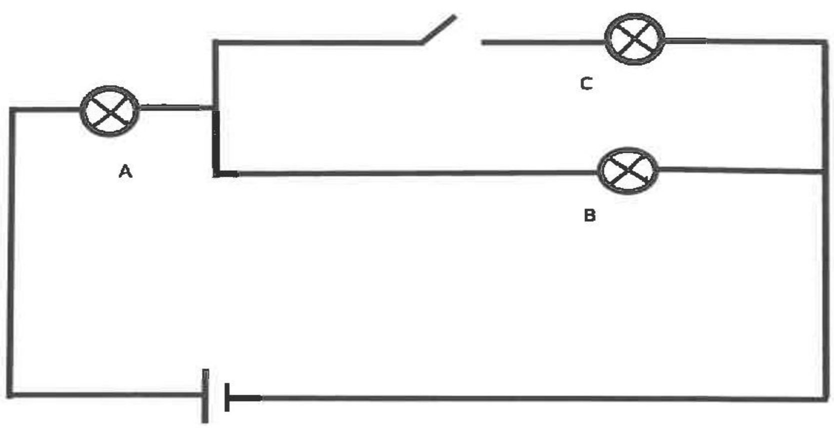
A. Current at 1 is greater than current at 2
B. Current at 2 is greater than current at 1
C. Current at 1 is equal to current at 2
D. Current at 2 is less than current at 1

11. Compare the brightness of bulb of A and bulb B in circuit 1 and bulb C in circuit 2. Which bulb is brightest?



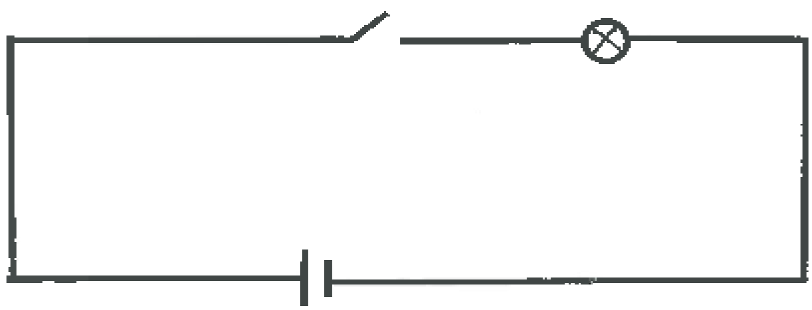
A. A=B
B. B=C
C. A=B=C
D. A=C

12. Study the circuit below. What will happen to the brightness of bulb A and bulb B when switch is closed?



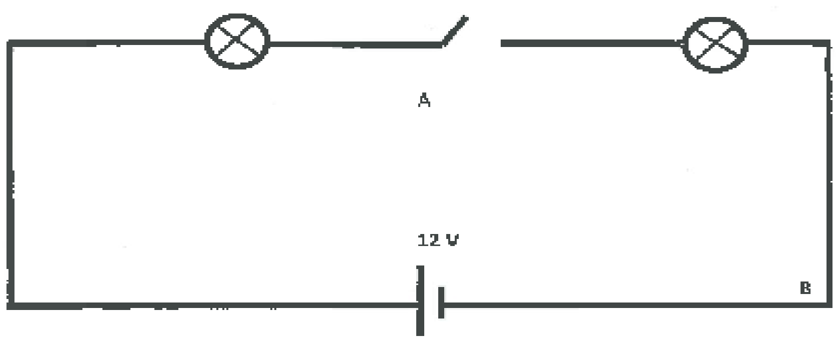
A. A stays the same and B dims
B. A is brighter and B dims
C. A and B increase brightness
D. A and B remain the same

13. Immediately when the switch is opened, what happens to the resistance of the bulb?



A. The resistance increases
B. The resistance decreases
C. The resistance stays the same
D. The resistance goes to zero

14. Study the diagram below with the switch open. What is the potential difference between points A and B?



A. 0 V
B. 3 V
C. 6 V
D. 12 V

15. A battery cell goes "flat". What is the reason?

A. All Electrical power in the cell is used up
B. All charge in the cell is used up
C. All chemicals in the cell are used up
D. There no more electrical field

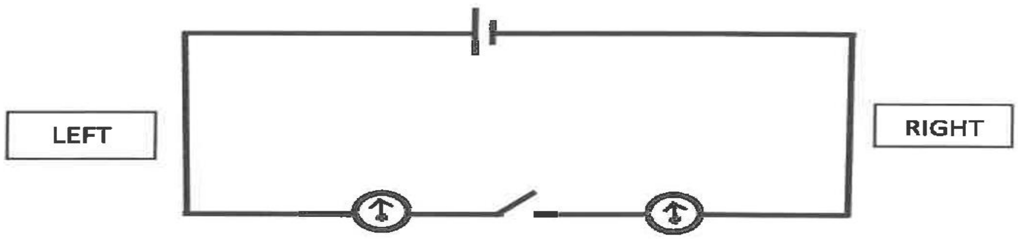
16. In an electrical circuit, a battery is a source of :

A. Electrical power
B. Electrical energy
C. Electrical charge
D. Electrical field

17. When a switch at home is turned on, the lights come on same time (instantaneously). What is the reason?

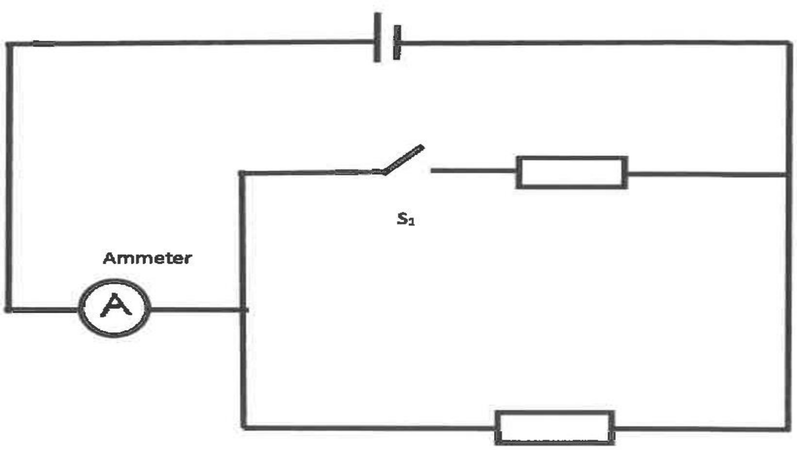
A. Charges are already in the wire.
B. Energy is released at the same time
C. Charges in the wire travel fast
D. Current was already flowing in the wire.

18. What is the direction of pointer of the pointer in ammeter 1 and ammeter 2 when the switch is closed?



A. Ammeter 1 points to the right and ammeter 2 points to the left.
B. Ammeter 1 point to the right and ammeter 2 points to the right.
C. Ammeter 1 points to the left and ammeter 2 points to the left
D. Ammeter 1 and Ammeter 2 pointers remain stationary

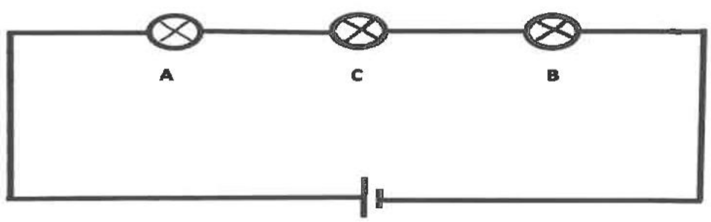
19. Study the circuit diagram below. Switch 1 is now closed. What will happen to the reading on the ammeter?



A. It will increase
B. It will decrease
C. It will increase then decrease
D. It will remain the same

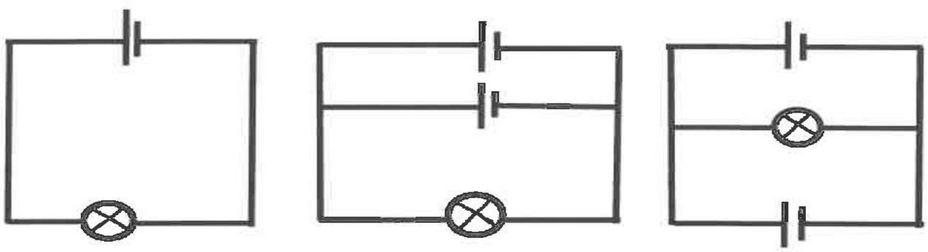
20. Assume there is no internal resistance in the battery. If the current through the battery is doubled, what will happen to the potential difference across the battery?
    A. It will be doubled
    B. It will be halved
    C. It will remain the same
    D. Battery becomes hot

21. What will happen to the brightness of bulb A and B if you increase the resistance of C?



A. A dims, B dims
B. A and B increase in brightness
C. A dims and B increase
D. A and B remain the same

22. **Study the circuits below. Which statement below is true of the energy delivered?**

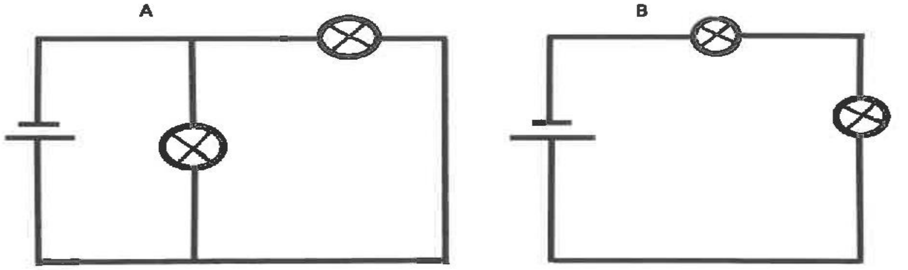


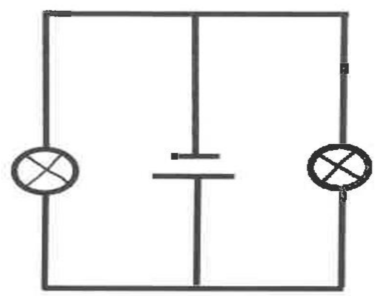
1 2 3

A. Circuit 1 < Circuit 2 < Circuit 3
B. Circuit 1 < Circuit 2 > Circuit 3
C. Circuit 1 < Circuit 2 > Circuit 3
D. Circuit 1 = Circuit 2 = Circuit 3

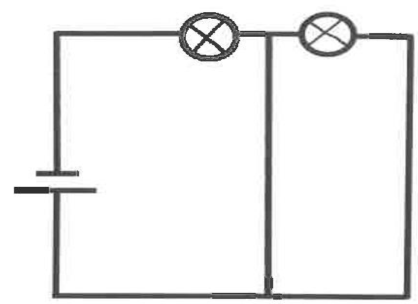
23. **Which of the circuits below shows bulbs which are connected in parallel?**

A B





C



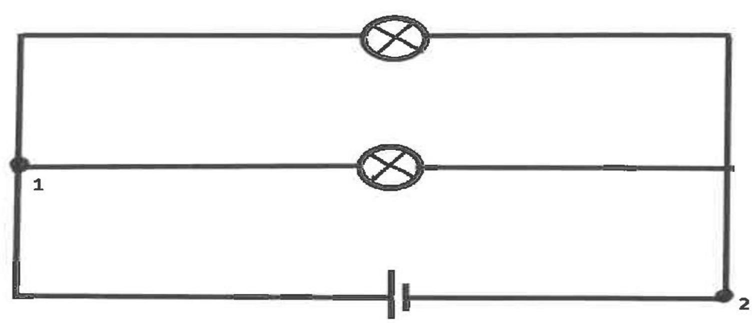
D

A. A, B and C
B. B, C and D
C. A, C and D
D. A, B, C and D

24. Which of the following statements is TRUE about charge in an electrical circuit?

A. It is protons moving from positive terminal to negative terminal
B. It is electrons moving from the positive terminal to the negative terminal
C. It is water like fluid flowing from positive terminal to negative terminal
D. These are charged electrons which move when the electrical circuit is complete

25. What will happen to the brightness of bulb A and B when a wire of low resistance is connected between points 1 and 2?



A. Increases
B. Decreases
C. No bulb lights up
D. They stay the same

Appendix B: Principal Letter

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

17 January 2014

The Principal

Thembalihle Combined School

Dear Mrs. Hadebe

I am currently registered for a Master's degree in Education at the University of KwaZulu-Natal. The title of my dissertation is:

Exploring the effect of computer simulations on learners' understanding of electricity in Grade 10 at a school in KwaZulu-Natal.

I would like to conduct my research at your school as I am a teacher here (persal number 64725014) and my familiarity with the context of the school will facilitate my data collection. As you are aware, learners' performance in Physical sciences has been poor in the past and I am confident that my research may assist in developing strategies to improve the pass rate in Physical sciences. Furthermore, learners who participate in the project will benefit by improving their science knowledge.

Anonymity of the school and all the participants in the study will be maintained by using pseudonyms. The data obtained will be treated confidentially and will only be disseminated within the research community. Participants will not be placed in harm's way. As this is a study towards the fulfilment of a Master's Degree there is no financial gain to be obtained. The school will not be implicated in any of the costs involved in this study. Participation is voluntary and all participants are free to end their involvement at any time.

Should you have any questions or desire further information, please contact:
Researcher: Rudolph Gadzikwa Telephone: 0834469941
Email: rgadzikwa@gmail.com
Supervisor: Dr. Nadaraj Govender Telephone: 0312603469
Email: govender37@ukzn.ac.za

Research Office: Ethics

Govan Mbeki Centre

Tel +27312604557 **Fax: +27312604609**

I, **Mr. Z.S.Hadebe,** Principal of Thembalihle Combined School, hereby give my permission for Mr. R Gadzikwa to conduct his research in my school. I understand that anonymity of the school and all participants will be ensured and that all participants will have the right to withdraw from the research project if they so wish. I give my permission for lessons to be audio and video recorded.

Signature of Principal Date

Research Office: Ethics

Govan Mbeki Centre

Tel +27312604557

Fax +27312604609

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

Appendix C: Letter to Parent

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

17 January 2014

Dear Parent /Guardian

I am currently registered for a Master's degree in Education at the University of KwaZulu-Natal. The title of my dissertation is:

Exploring the effect of computer simulations on learners' understanding of electricity in Grade 10 at a school in KwaZulu-Natal.

I am also a teacher in Physical sciences at Thembalihle Combined School and I am requesting your consent for your child to participate in my research. As you may be aware, learners' performance in Physical sciences has been poor in the past and I am confident that my research may assist in developing strategies to improve the pass rate in Physical sciences. Furthermore, your child should benefit by improving his/her knowledge of Physical sciences concepts as well as computer skills

Your child's anonymity will be maintained by using pseudonyms. The data obtained will be treated confidentially and will only be disseminated within the research community. Participants will not be placed in harm's way. As this is a study towards the fulfilment of a Master's Degree there is no financial gain to be obtained. Participation is voluntary and all participants are free to end their involvement at any time.

Should you have any questions or desire further information, please contact:
Researcher: Rudolph Gadzikwa Telephone: 0834469941
Email::rgadzikwa@gmail.com
Supervisors: Dr. Nadaraj Govender Telephone: 0312603469
Email: govender37@ukzn.ac.za /

Research Office: Ethics

Govan Mbeki Centre

Tel +27312604557

Fax +27312604609

I, ____parent/ guardian of

____hereby give my consent for my child to participate in the research mentioned above and I give my permission for his/her lessons to be audio and video recorded. I understand that anonymity of the school and all participants will be ensured and that all participants will have the right to withdraw from the research project if they so wish.

____

Signature of Parent/ Guardian   Date:

Research Office: Ethics

Govan Mbeki Centre

Tel +27312604557

Fax +27312604609

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

Appendix D: Participant Letter

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

17 January 2014

Dear Learner

I am currently registered for a Master's degree in Education at the University of KwaZulu-Natal. The title of my dissertation is:

Exploring the effect of computer simulations on learners' understanding of electricity in Grade 10 at a school in KwaZulu-Natal.

As your Physical sciences teacher I am requesting your consent to participate in my research. I am confident that my research may assist in developing strategies to improve the pass rate in Physical sciences. Furthermore, you should benefit by improving your knowledge of Physical sciences concepts as well as computer skills

Your anonymity will be maintained by using pseudonyms. The data obtained will be treated confidentially and will only be disseminated within the research community. You will not be placed in harm's way by participating in this research. As this is a study towards the fulfilment of a Master's Degree there is no financial gain to be obtained. Participation is voluntary and you will be free to end your involvement at any time, should you so wish.

Should you have any questions or desire further information, please contact:
Researcher: Rudolph Gadzikwa Telephone: 0834469941
Email::rgadzikwa@gmail.com
Supervisors: Dr. Nadaraj Govender Telephone: 0312603469
Email: govender37@ukzn.ac.za /

Research Office: Ethics

Govan Mbeki Centre

Tel +27312604557

Fax +27312604609

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

I, ____hereby give my consent to participate in the research mentioned above and give permission. For my lessons to be audio or videotaped. I understand that my anonymity will be ensured and that I will have the right to withdraw from the research project at any time should I wish to do so.

____

Signature of learner Date:

Research Office: Ethics

Govan Mbeki Centre

Tel +27312604557

Fax +27312604609

Appendix E: Ethical Clearance Letter

UNIVERSITY OF
KWAZULU-NATAL
INYUVESI
YAKWAZULU-NATALI

28 January 2014

Mr Rudolph Gadzikwa 209538457
School of Education
Edgewood Campus

Dear Mr Gadzikwa

Protocol reference number: HSS/1529/013M
Project title: Exploring the effect of computer simulations on learners' understanding of electricity in Grade 10 at a school in KwaZulu-Natal

Provisional Approval - Expedited

This letter serves to notify you that your application in connection with the above has been approved, subject to gatekeeper permission being obtained

This approval is granted provisionally and the final approval for this project will be given once the above condition has been met. Please quote the above reference number for all queries/correspondence relating to this study.

Kindly submit your response to the Chair: Dr S Singh % Prem Mohun, Research Office as soon as possible

Yours faithfully

....

Dr Shenuka Singh (Chair)
Humanities & Social Science Research Ethics Committee

/pm

cc Supervisor: Dr N Govender & Dr M Stears
cc Academic Leader: Dr MN Davids
cc School Admin: Mr Thabo Mthembu

Humanities & Social Sciences Research Ethics Committee
Dr Shenuka Singh (Acting Chair)
Westville Campus, Govan Mbeki Building
Postal Address: Private Bag X54001, Durban 4000
Telephone: +27 (0) 31 260 3587/8350/4557 **Facsimile:** +27 (0) 31 260 4609 **Email:** ximbap@ukzn.ac.za / snymanm@ukzn.ac.za / mohunp@ukzn.ac.za
Website: www.ukzn.ac.za

1910 - 2010
100 YEARS OF ACADEMIC EXCELLENCE

Founding Campuses: Edgewood Howard College Medical School Pietermaritzburg Westville

Appendix F. Interview questions

1. Which questions did you find difficult the pre-test and why?
2. Where these questions easy to answer in the post-test?
3. Describe your experience with computer simulations.
4. Did computer simulations help you to answer questions in any way?
5. Did you find them useful in answering questions in the post-test?
6. Which other method, besides computer simulations would you suggest might help you understand the topic on electricity.

Appendix G: Schools in which the test was piloted

School	Location	Grade	Number of Learners
X	Pietermaritzburg	10	20
Y	Pietermaritzburg	10	20
Z	Wartburg	10	10
R	Pietermaritzburg	10	30

Appendix H: Experts consulted in the design of the test

Name of official	**School**	**Specialization**	**Experience**
Professor N.Govender	University of KwaZulu-Natal School of Education	Physics	30 years
Juliet Imbayago	Pietermaritzburg Girls High	Physical sciences	15 years
Clare Bekedell	Pietermaritzburg High	Physical sciences	10 years
Mr. Sedze	Alexandra High School	Physical sciences	26 Years
Mr. P. Mhanda	Mayizekanye High	Physical sciences	25 years