Exploring Understandings of Key Concepts in Electric Circuits: A Case of 20 Grade 11 Physical Sciences Learners in uMgungundlovu District Collaboratively Constructing Concept Maps

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ABSTRACT

This study presents an action research project on teaching and learning where understanding of fundamental concepts and their relationships in electric circuits were explored. A sample of 20 Grade 11 Physical Sciences learners was conveniently selected from one of the township schools in the uMgungundlovu District. A single case design was used, treating learners as both a case and the unit of the study. An interpretive approach was used to collect data in the form of concept maps, audio discussions, and a semi-structured interview. A series of three concept mapping sessions were conducted to probe and deepen learners' understanding of the relationships between key concepts in circuits as reported in the literature, including the Department of Basic Education's diagnostic reports over the years. A semi-structured interview focused learners' conceptual understanding of key concepts in electric circuits after undergoing teaching activities and collaborative concept mapping.

Analysis and interpretation of the results indicated that learners understand that there is a significant relationship between the potential difference, resistance, and current in an electric circuit known as the Ohm's Law. This relationship was expressed both descriptively and in mathematical form. Although learners showed expected understanding of the relationship between key concepts in electric circuits, they still had issues when it came to providing scientific reasons as to why the circuit behaved that way. This was an indication that more emphasis needed to be put in the discussion of the cause and effect of concepts in electric circuits. The findings of this study also revealed that learners rarely use their prior knowledge when constructing a concept map to deepen their understanding of new concepts as suggested by the literature.

While there were some noticeable improvements in their understanding of the Ohm's Law, it was also found that some learners had alternative conceptions regarding the relationship between the power source and the electric current in a circuit. Another alternative conception was related to the views that learners have about the voltmeter readings which hindered them from fully understanding the concept of potential difference. Learners also showed alternative understanding related to windmills and how they are used in the real world. Some alternative conceptions, such as the power supply alternative conception, were successfully addressed

during teaching. However, the meanings attributed to the voltmeter reading alternative conception remained unchanged throughout the study despite attempts to address them. The study therefore proposes that concept maps should be used with several other teaching aids such as PhET simulations to help learners navigate through their difficulties and simplify the process of learning key concepts in electric circuits.

DECLARATION

i. The work described in this thesis, except where otherwise specified, is my original work.

ii. This study represents my original work, and has not been submitted for any degree or examination at any other tertiary institution.

iii. Where information from other written sources have been used,

   a. their words have been paraphrased and referenced;
   b. general information attributed to them has been referenced; and
   c. where their words have been used in their exact form, their writing has been placed inside quotation marks and referenced.

iv. The research reported in this thesis was carried out in the School of Education, University of KwaZulu-Natal, from March 2018 to November 2019 under the supervision of Dr. L. Kolobe (supervisor).

v. An Ethical Clearance No. HSS/2096/018M was granted before undertaking the fieldwork.

Signed:

As the candidate's supervisor, I, Lebala Kolobe, agree to the submission of this dissertation

Signed:

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DEDICATION

I dedicate this work to my late father, Patrick Dumisani Gumede, who lost his life after a long battle with cancer as I was doing my first year of this degree.

CHAPTER ONE – INTRODUCTION

1.0. Introduction

For several years now, learners in the school where I teach Physical Sciences have experienced difficulties in this subject. Internal analysis of the situation and results suggests that one of the causes of poor performance can be attributed to the learners' attitudes towards the subject, and the way science is taught in this school. It is, however, unclear as to why learners have such negative views of Physical Sciences as a subject. Nevertheless, it can be hypothesized that the changes that took place within the school have impacted how learners view some subjects. The school started as a vocational institution that focused on skills development subjects such as Motor Mechanics, Electrical Technology, and Civil Technology; and was later separated into a Further Education and Training (FET) College and a Technical High School. This change was met with hostility as learners were forced to do Physical Sciences which they didn't like because they had enrolled in the school to learn practical skills such building, mechanics, and electricity. Since then, the stigma surrounding this subject has been tough to remove; hence, the results have been affected over the years.

The Technical High School has three teachers who teach Physical Sciences from Grades 10 to 12. One teacher has Bachelor's degree in education (B.Ed.) qualification, the other has a Bachelor of Science (BSc) degree in Chemistry qualification with a post-graduate certificate in education (PGCE), and I have a B.Ed. degree and a post-graduate Honor's degree in Science education. The school is relatively big, with the number of classes that are doing Physical Sciences in each grade being, three (3), two (2), and three (3), in grades 10, 11, and 12 respectively. The average number of learners in each class is 40. Teaching learners with negative attitudes towards Physical Sciences, and the pressure from the Department of Basic Education (DoBE) poses a challenge for teachers to be inventive in their instructional approaches. In consequence, most of us mainly focus on drilling learners for the National Senior Certificate (NSC) examination in order to help them get minimum pass mark in Grade 12.

The focus on teaching for the exams has caused more harm than good for these learners as they learn to memorize concepts without holistic knowledge of the subject. Hence, learners are failing to demonstrate the foundational knowledge that they are expected to master for the NSC examination. Kolobe (2017) argues that school science should be taught and learned in a manner that allows learners to reflect deeper understanding of the basic concepts and their relationships in Physical Sciences. Teaching and learning which focus mainly on preparing for the exams perpetuates the existing problem of rote memorization of certain concepts in Physics, instead of improving the situation. It is therefore important to research the source of the problem, and find out where learners' knowledge is deficient in order to help them improve. This can be achieved by conducting an action research study which incorporates some of the well-researched teaching and learning strategies that promote meaningful learning of concepts instead of rote learning. From this, we are likely to explore the learners' understanding of important concepts in Physics and how their knowledge of these concepts develops over time.

The ongoing conflict between the need to improve learner performance in the NSC examinations and the competing need to ensure meaningful teaching and learning in science education are of immediate concern for educators and the DoBE in South African secondary schools. Recent studies in science education reveal difficulties that South African teachers are facing in the classroom concerning the influence of external examinations on the experiences of learners (Binns & Popp, 2013; Hobden, 1998; Kolobe, 2017; Mokiwa, 2017). Hobden (1998) argues that one of the many consequences of this is the relegation of meaningful science learning to a secondary position, with external examination preparation and drilling being the main focus of classroom activities. The challenge posed by the high stakes examination system is still as it was more than 20 years ago when Hobden (1998 p. 3) pointed out that, "it puts more pressure on teachers to 'teach for the exams' rather than conceptual understanding; consequently, the classroom activities become routine in order to accommodate this system". Hobden (1998) further argues that learning that focuses only on exam preparation is not effective in developing learners' conceptual understanding of key scientific concepts.

Narrow focus on passing the NSC examination increases the risk of poor performance whereas prioritizing meaningful learning actually increases chances of doing well in the examinations. The lack of focus on meaningful learning of topics, such as electric circuits in Physical Sciences, has caused many challenges for learners who are expected to write it in their final NSC examination. There is a vast body of literature that shows that learners of all ages have difficulty in understanding the relationships between critical concepts in electricity (Anita, Assagaf, & Boisandi, 2018; Lombard & Simayi, 2019; Önder, Şenyiğit, & Sılay, 2017). Even the diagnostic reports from the DoBE report that learners find several aspects in electric circuits challenging (Department of Basic Education, 2015, 2016, 2017). Issues raised in these reports include shallow understanding of the behavior of the circuit, shallow conception of the relationships between key concepts such as resistance, current, and voltage, difficulties in linking microscopic aspects of electric circuits as described in the Ohm's Law equation, and that many learners are unable to draw and interpret graphs when given a set of data. According to the *South African Curriculum and Assessment Policy Statement (CAPS): Physical Sciences* (Department of Basic Education, 2011), electricity is covered from Grades 7 to 12, while the concept of internal resistance is introduced at Grade 12, where the focus is on the application of the equation $\varepsilon = I.R + Ir$. Thus, learners need to have developed a sound knowledge and understanding of this topic by the time they get to Grade 12 in order to do well in their final NSC examination.

One of the ways in which understanding of concepts in electric circuits can be developed is through concept mapping. According to Govender, Good, and Sibanda (2016), "Concept mapping is a learning aid that embodies the principles of meaningful learning and can deepen discussions among learners about scientific concepts". Since Novak and Gowin (1984) first introduced it, concept mapping has been the subject of many research studies, such as Bressington, Wong, Lam, and Chien (2018) and Govender et al. (2016) to name but a few. There is a standard view amongst scholars that collaborative concept mapping can assist both individual and group learning in science (George-Walker & Tyler, 2014; Govender et al., 2016; KiliÇ & ÇAkmak, 2013). Similarly, collaborative learning is one of the strategies that are promoted as supporting and reinforcing learning in a positive manner (Govender et al., 2016). Thus, engaging in the process of collaborative concept mapping could prove to be beneficial for learners as they develop their understanding of key concepts in electric circuits. Although the focus on collaborative learning is on the co-construction of meanings and developing shared understanding of concepts and ideas, alternative conceptions will still occur, and this can impede a group from developing a holistic understanding of the topic under study.

To identify the problem for this study, I looked at the Grade 12 NSC examination results and diagnostic reports between 2015 and 2017, where I found this topic to be problematic. The findings in the reports over these three years show a similar trend on some of the common alternative conceptions and difficulties that the learners have in electric circuits. In this case, for example, it was found that learners could not distinguish between the concepts ‘electromotive force’ and the ‘potential difference’; questions that require integration of two topics, namely power in the gravitational field and power to the electric field, were also challenging to them; when it comes to graphical interpretation of a series-parallel context, leaners could not understand that the gradient of the potential difference vs. current graph gives resistance and that the parallel connections of resistors give a lower resistance hence a less steep graph; moreover, some of these learners found it difficult to answer questions related to the operation of an electric circuit and the application of Ohm’s Law in problem-solving; additionally, the reports also revealed that learners had alternative conceptions when it came to the flow of electric current (Department of Basic Education, 2015, 2016, 2017). However, the majority of the content for this topic in the FET phase is mostly in Grade 11. It is, therefore, highly likely that learners do not have the necessary foundation supposedly built in the previous grades. Consequently, this study will focus on the learning of electric circuits done in Grade 11 to try and build a solid foundation for Grade 12. The findings of such a study would help us determine why learners experience difficulties in understanding the relationships between important concepts in electric circuits, and hopefully improve the teaching practices of most teachers.

1.1. Rationale for the research

The present study has the potential to bring about change in the way science teachers help their learners overcome difficulties in the study of electric circuits. The motivation to undertake this study was to help in-service teachers, who are under constant pressure from the DoBE to improve the performance of learners in Physical Sciences, by clearly identifying and unpacking the challenges they face as well as providing practical and effective ways of overcoming it. By improving concept-specific teaching and enabling constructive learning strategies, positive results will be achieved. Therefore, a study of this nature could help science teachers improve their practice by proposing an alternative topic-specific instructional strategy such as collaborative concept mapping, which helps learners construct knowledge, thus removing their focus from merely trying to pass an examination. The present study will also raise awareness of the potential alternative conceptions in electric circuits that learners might bring to the classroom. The intention was to explore learners' understanding of key concepts in electric circuits while they collaboratively construct concept maps. It was hoped that collaborative concept mapping could assist in addressing some of the problems which have been reported in the literature and the diagnostic reports. The suggestions for learners' improvement in this topic mentioned in the diagnostic reports indicate that teachers need to help learners gain a holistic understanding of critical concepts and their interdependence. However, the CAPS does not suggest any learning strategies for teachers to introduce to their learners when engaged in the process of learning electric circuits. Literature, however, suggests that collaborative construction of concept maps is one of the well recommended learning strategies to improve understanding of key concepts in any knowledge domain (Bressington et al., 2018; van Boxtel, van der Linden, Roelofs, & Erkens, 2002). It was therefore believed that the use of a learning strategy like collaborative concept mapping could assist Grade 11 Physical Sciences learners in grasping essential concepts and overcome difficulties in solving problems related to electric circuits. Hence, the rationale for conducting a study of this nature was to explore understanding of 20 Grade 11 Physical Sciences learners who made use of collaborative concept mapping strategy to deepen their knowledge of key concepts in the topic of electric circuits.

1.2. The objectives of the study

Two main objectives guided this study. First, the study sought to explore 20 Grade 11 Physical Sciences learners' understanding of key concepts in electric circuits as they collaboratively constructed concept maps. The second objective of the study was to examine how the 20 Grade 11 Physical Sciences learners' understanding of key concepts developed over time as they made use of collaborative concept mapping strategy to deepen their knowledge of electric circuits.

The research questions addressed in this study are:

1. What are Grade 11 Physical Sciences learners' understanding of key concepts in electric circuits?
2. How have Grade 11 Physical Sciences learners' understanding of key concepts in electric circuits developed as they collaboratively constructed concept maps to deepen their knowledge of these concepts?

1.3. A summary of the chosen methodology

This study explored 20 Grade 11 Physical Sciences learners' understanding of key concepts in electric circuits through collaborative concept mapping. An action research approach of planning, action, analysis, and reflection was used during the process of teaching and learning of this topic. The focus of the study was on a single case of 20 learners who were divided into four groups of five in three rounds of collaborative concept mapping tasks that were designed to assist in deepening their knowledge of key concepts in electric circuits. The study made use of qualitative design, and data were collected using concept maps collaboratively constructed by learners, audio recordings, and a semi-structured interview schedule. Concept maps were analyzed using a model designed by Novak and Gowin (1984). Inductive reasoning was used to analyze the semi-structured interview. Themes for the interview came from the available data and literature. For this study, social constructivism was used to examine the learning of key electric circuits concepts through collaborative concept mapping exercises which formed the basis of my instructional approach (Fergusson, 2007).

1.4. Outline of the dissertation

Succeeding this chapter, Chapter 2 outlines the theoretical framework for the current study. This study is guided by social constructivism and concept mapping theory in its quest to understand how learning takes place in the classroom.

In Chapter 3, I review literature on studies that have been undertaken on the teaching and learning of electric circuits. Research which have shown learners' difficulties in this area are discussed, and others highlighting the importance of prior knowledge on teaching and learning are also reviewed. The South African Curriculum on the teaching of electric circuits is also reviewed.

Chapter 4 is an outline of the research methodology undertaken in this study. It explains in detail methods that were adopted, data collection instruments, and how the participants for this study were identified. Justification of the chosen instruments and the approach to the research are also included. I conclude this chapter by outlining the ethical considerations, validity, and reliability of the study.

The findings of the overall research are presented in Chapter 5. The reporting of the qualitative findings starts with a description of the context of the study. This is followed by the presentation of the concept maps constructed by learners over three rounds. The chapter concludes by presenting responses from the semi-structured interview of four of the 20 learners.

In Chapter 6, I present the analysis and interpretation of the research findings. Answers to each research question are presented. A discussion ensues, comparing and contrasting the results from the current study with those from previous studies. I conclude this chapter by reflecting on the main problem, the method followed, and the data collected. The limitations of the study are discussed, and suggestions for future work are made.

CHAPTER TWO – THEORETICAL FRAMEWORK

In this chapter, I discuss the social constructivist theory as a theoretical framework used to guide and frame this study. I also discuss the epistemological approach of concept maps by showing how they can be used within constructivism. For purposes of this study, social constructivism was used to understand learning of key electric circuits concepts through the use of collaborative concept mapping exercise, which formed the basis of my instructional approach. Social constructivism is discussed in terms of how it informed and shaped this study.

2.1. Social constructivist theory

To understand the meaning of social constructivism, one must be familiar with a definition of the term constructivism. In a nutshell, constructivism is a theory of learning which stems from the notion that people use their prior knowledge to make sense of new knowledge (Bennett, 2005). Collaborative concept mapping is based on the notion that learning is born through social interactions as individuals work together to make meaning of concepts within a given topic (Novak & Cañas, 2006). Bodner, Klobuchar, and Geelan (2001) highlight three different forms of constructivism: personal/cognitive constructivism, radical constructivism, and social constructivism. This study is located within the social constructivism theory, which is the view that knowledge is a result of co-construction of meaning within a social context. For the classroom practice of the study a socio-constructivist approach was used, which meant providing learners with opportunities to work in groups in collaborative learning and develop their concept maps together.

The philosophical basis of collaborative concept mapping lies in Lev Vygotsky's (1978) social constructivism theory. Social constructivism emerged in response to limitations in Jean Piaget's (1936) theory on how individuals learn and process information. Piaget (1964) developed the notion that an individual's prior experiences influence the learning of new information. Essentially, Piaget believed that people construct their own meanings from what they experience. However, constructivist research shows that the use of Piagetian ideas on the individual's reaction to experience and to the process through which understanding are formed has some limitations. Vygotsky (1978) was one of those who led the criticism of Piaget's emphasis on construction of meaning based on individual experiences. He argued that our learning and thinking patterns are shaped by social interactions. Vygotsky (1978) observed that the interaction between learners in a collaborative task results in co-construction of meanings; as such, knowledge can be seen entirely as a negotiated human construct. Consequently, during a collaborative concept mapping task, learners are constantly engaged in meaningful discussions about the relationships between critical concepts in a particular knowledge domain, thereby, developing meanings of these concepts as they construct and reconstruct their concept map.

Vygotsky's social constructivism theory posits that we learn best from interactions with persons who are more knowledgeable in that particular content area than us. In the classroom, Vygotsky maintains that rather than a teacher giving learners information (direct instruction), teachers and learners should collaborate so that learners are playing an active role in the construction of meaning. Furthermore, Vygotsky acknowledges that often a knowledge gap exists between what the learner can do independently and what the learner can only do with the guidance of a teacher. He called this gap a "zone of proximal development" (ZPD). Within the ZPD, Vygotsky believed that a learner could benefit from the assistance of an adult or teacher (referred to as the more knowledgeable other) to develop within this zone (Vygotsky, 1978). Fergusson (2007) argues that social constructivism assumes that knowledge is held collectively within a group or society, and learning is embedded within a social context. Furthermore, Ferguson also contends that the social constructivism theoretical framework, is most appropriate for studies that focus on meaning-making, concept construction, or diagnosing alternative conceptions. Exploring learners' understanding of key concepts in electric circuits as they worked in groups to construct concept maps in collaborative learning was underpinned by socio-constructivist theory when learners learnt about key concepts in electricity in class, and when they constructed concept maps in three different stages of the concept mapping process.

2.2. Social constructivism in collaborative concept mapping

Concept maps were first developed by Joseph Donald Novak in the early 1970s based on Ausubel (1963) theory of meaningful learning. A concept map is regarded as a valuable tool for helping learners acquire and understand knowledge structure (Govender et al., 2016). It is the process of creating knowledge, organising and representing it as well as establishing links between various elements of a given body of knowledge or topic (George-Walker & Tyler, 2014). The collaborative construction of a concept map is based on the socio-constructivist view that meaningful learning occurs when a group of individuals chooses to relate new knowledge to its own experiences and prior knowledge to form understanding of the new knowledge (Kinchin, Hay, & Adams, 2000). Scholars contend that concept mapping, as a collaborative learning activity, is successful in encouraging learner-learner or learner-teacher interactions during a discussion, and allows for visual representation of ideas within a given topic (Duit & Treagust, 2003; KiliÇ & ÇAkmak, 2013; Novak & Gowin, 1984). The interactive platform that collaborative concept mapping provides stimulates knowledge co-construction rather than knowledge discovery. van Boxtel et al. (2002) argue that as peers work together on a common task, mutual understanding is created. This, in turn, stimulates 'abstract talks' about concepts, which results in improved understanding of the topic as a whole. Thus, these scholars argue that the strength of collaborative concept mapping is to provoke co-construction of meanings. In this way, the elaborate input of each individual group member in constructing the concept map provides the basis for enhanced conceptual understanding.

The development of a concept map tool was due to the need to show explicitly the relationship between concepts and propositions in order to make sense of new knowledge (KiliÇ & ÇAkmak, 2013). Concept maps not only show how learners think concepts are related, but they also provide a record of a learner's cognitive structure (Bramwell-Lalor & Rainford, 2014). Literature reveals that concept mapping not only allows organizing and presenting the knowledge but also promotes meaningful learning because it provides clarity concerning the relevant relationships between concepts within a given knowledge domain (González, Palencia, Umaña, Galindo, & Villafrade M, 2008). Novak and Cañas (2006) assert that meaningful learning via concept mapping requires three conditions:

1) Meaningful material: It is the role of a teacher to provide the learning material which is conceptually clear and relates to the learners' prior knowledge.
2) Relevant prior knowledge: This condition can be met by a learner from their early childhood development for any domain of subject matter.

3) Learner's choice to learn meaningfully: Teachers or mentors can assist in this condition through motivation of learners.

Novak and Gowin (1984) argue that instructional strategies should enhance learners' understanding by first establishing learners' prior knowledge and develop activities that give learners an opportunity to learn from each other and from their teacher to construct their own knowledge. This idea stems from socio-constructivism, which puts a strong emphasis on constructive knowledge sharing where learners learn from their peers through sharing of ideas as they make meaning of new concepts. The link between socio-constructivism theory and Novak's theory of collaborative concept mapping is shown in the concept map (Figure 2.1) below.

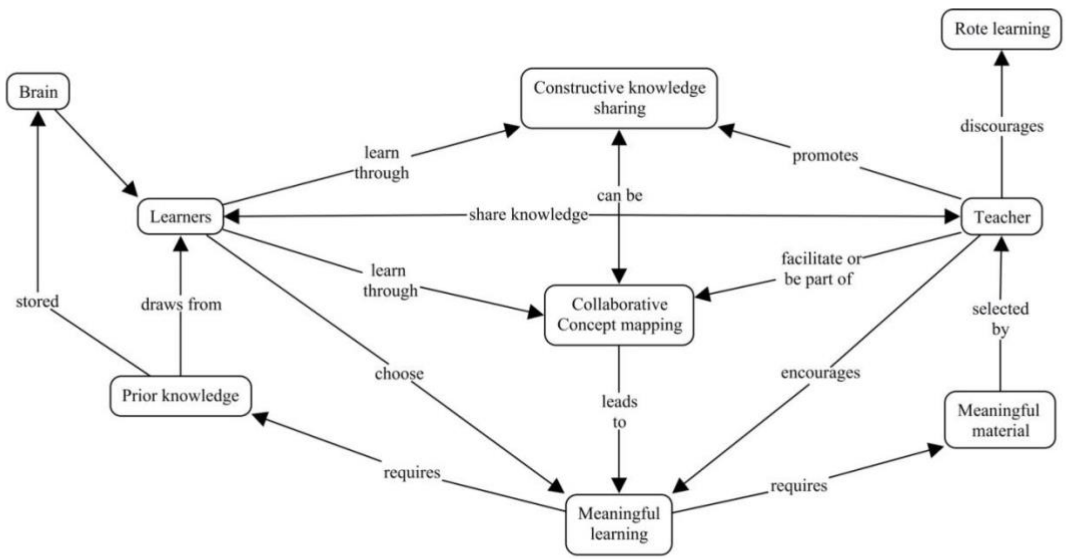

Figure 2.1: Constructivism in concept mapping: Adapted from (Cañas & Novak, 2010)

As noted in Figure 2.1 above, the epistemological approach of collaborative concept mapping lies in the socially constructed process of new knowledge creation. The instructional approach adopted follows Vygotsky's (1978) ZPD. The Novak and Gowin (1984) concept map data analysis framework was used in studies that dealt with assessing learners' understanding of key concepts in a specific topic, improving science learning and teaching, and identifying alternative conceptions, amongst many others (Cheema & Mirza, 2013; González et al., 2008). The same model was explored as a way to determine Grade 11 Physical Sciences learners' understanding of key concepts in electric circuits as they collaboratively constructed concept maps.

Analytical framework – The Novak model of qualitative analysis of a concept map

Meaningful relationships between key concepts are made explicit in the way they are presented through a resource like a concept map. A concept map highlights several processes that underlie learning, which include a network of concepts and links, propositions made by individuals, integration of prior knowledge and new knowledge, and alternative conceptions (Novak & Cañas, 2006). Analysis of concepts and propositions in concept maps provides a valuable way of evaluating learners' scientific understanding of a given object of learning. According to Novak and Gowin (1984), a concept map is a diagram that shows how two or more concepts are related. Analysis of concepts and propositions provide a valuable way of evaluating learners' understanding of a given object of learning. Below (Figure 2.2) are some of the aspects of the Novak analytical framework for concept maps.

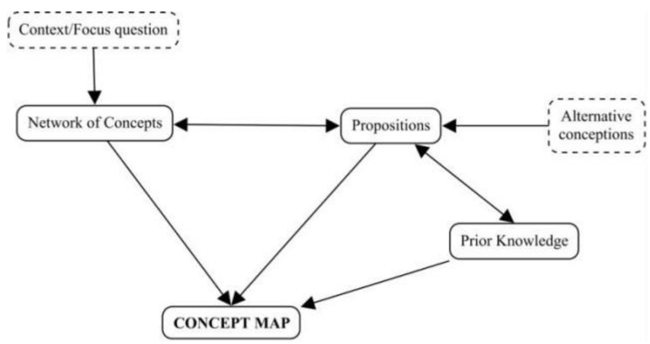

Figure 2.2: Key Aspects of the Novak Analytical Framework for Concept Maps: Adapted from (Cañas & Novak, 2010)

Novak's concept map data analysis framework consists of network of proposed concepts and links between these concepts in the form of scientific propositions, alternative conceptions, and prior knowledge. Below, I unpack these constructs in more detail, including how they have informed the current study.

Network of concepts and links

Novak and Gowin (1984) define a concept as an idea or a mental image that one has when thinking about an object or a word. During concept mapping, a teacher may pose a focus question to the learners based on the specific subject matter being studied at the time. Learners are therefore expected to generate key concepts (usually in a "parking lot" format) in response to the focus question (George-Walker & Tyler, 2014). These concepts can be arranged in a hierarchical order, ranging from more general to specific concepts and creating cross-links with linking words to form meaningful statements (George-Walker & Tyler, 2014; Novak & Gowin, 1984). Concepts therefore play an essential role in revealing meanings that learners have about that particular topic. In the case of this present study, meanings that learners have about key electric circuit concepts were revealed.

Scientific propositions

Rebich and Gautier (2005) write, "A basic element of a concept map is a proposition". The term proposition refers to an idea that a person has about how two or more concepts are related (Clay, 2018). According to Cañas and Novak (2010) a proposition is a connection between two or more concepts with linking words to reveal a meaningful statement. It therefore appears that a proposition is an integral part of concept mapping that refers to the learner's understanding of meaning of a concept. This proposition is shown by the form of a linking word, linking it to another concept, as shown in Figure 2.3 below (Rebich & Gautier, 2005).

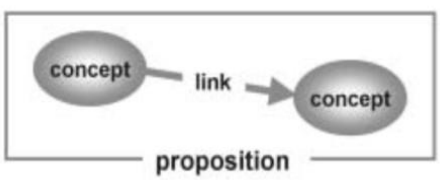

Figure 2.2: Two concepts connected by a link that show a relationship between them (Rebich & Gautier, 2005)

Propositions play a vital role in the scientific process by revealing a meaningful relationship between concepts (Clay, 2018). Scientific propositions were important in this study because they showed learners' understanding and helped reveal the development of these understanding as learners constructed concept maps.

Prior knowledge

Prior knowledge refers to the content that a learner has related to the domain studied which is present before new knowledge is introduced (Gurlitt & Renkl, 2010). Alexander (1996) observes that a learner judges how information is relevant and what s/he is able to understand based on the knowledge s/he already possesses. With this in mind, Rebich and Gautier (2005, p. 356) argue that a “learner’s knowledge base can be thought of as a scaffold for all of his or her future learning”. This means that prior knowledge can serve as a building block for new knowledge and can help focus the learner’s attention on new information that is relevant, thereby making the process of learning easy. Concept mapping was established on the foundation of activating prior knowledge to learn new knowledge and helps by revealing propositions linking prior knowledge with new knowledge (Gurlitt & Renkl, 2010; Novak & Gowin, 1984; Rebich & Gautier, 2005). Cañas and Novak (2010) posit that one of the characteristics of meaningful learning is that concepts must be taught and learned in a manner that allows learners to link their prior knowledge to new knowledge. Therefore, prior knowledge provides a framework in which new information can be organised and fully understood (Gurlitt & Renkl, 2010). Hay, Kinchin, and Lygo-Baker (2008) argue that “prior knowledge is the baseline from which learning can be calculated and its quality assessed”. Concept maps help reveal learners’ cognitive structures due to prior knowledge and experiences (Misfades, 2009). Therefore, it is necessary that prior knowledge be established as the first step towards documenting learning (Hay et al., 2008).

Alternative conceptions

Hammer (1996) defines an alternative conception as a stable cognitive structure that affects a learner’s understanding of scientific concepts. Alternative conceptions are a result of failure to understand fully the underlying scientific concepts (Gilbert, Osborne, & Fensham, 1982). In some cases, alternative conceptions reveal misunderstanding of what was taught in class. A concept map offers a means by which alternative conceptions are externalized for teachers and learners to observe (Novak & Gowin, 1984). Concurring with that are many studies which have been conducted on concept maps (Bak Kibar, Yaman, & Ayas, 2013; Govender et al., 2016; KiliÇ & ÇAkmak, 2013). In this present study, alternative conceptions were an important construct of my learners’ concept maps because they helped inform me of their learning difficulties. This allowed me to address any non-scientific point of view that the learners had. Hence, Vygotsky's ZPD became relevant in terms of what learners are able to do on their own and where they need assistance. Subsequent teaching then became remedial as well as scaffolded.

2.3. Summary

This study is underpinned by social-constructivism where learners collectively construct understanding of key concepts of electric circuits. Vygotsky's theory of ZPD, also located within constructivist theory, informed the instructional approach employed so as to guide learners in their collaborative construction of concept maps. The constructivist theoretical framework discussed above focused on ways in which learners make sense of learning material within a constructivist paradigm. Within this paradigm, knowledge construction can be shown visually using a concept map (Kinchin et al., 2000). A data analysis framework suggested by Novak and Gowin (1984) was used as a lens to analyze and draw conclusions on the data collected from Grade 11 Physical Sciences learners who collaboratively constructed concept maps as a way to deepen their understanding of the topic of electric circuits. Past research shows that collective concept mapping is a valuable strategy in remediating and enhancing learning outcomes for learners. The principle of constructing a concept map helped answer my research questions by showing relationships between a hierarchy of ideas which helped reveal learners' understanding in electric circuits and how their knowledge developed as they collaboratively constructed concept maps.

CHAPTER THREE – LITERATURE REVIEW

Reports from as early as the 1980s indicate that learners have difficulties learning about electric circuits (Driver, Guesne, & Tiberghien, 1985; Dupin & Joshua, 1987; Shipstone, 1984). Learners find the relationships between specific theoretical concepts in physics, for example, potential difference, electric current, and resistance, particularly complicated because of the abstract nature of these key concepts (Kock, Taconis, Bolhuis, & Gravemeijer, 2014). Marks (2012) contends that the primary cause for learners' difficulties in electric circuits stems from their lack of understanding of the key concepts in this topic. Although there are many studies from South Africa and abroad on electric circuits, most studies that have taken place over the last decade tended to focus on alternative conceptions, instead of learners' understanding of this topic (Nkopane, Kriek, Basson, & Lemmer, 2011; Önder et al., 2017; Van der Merwe & Gaigher, 2011). Focusing on alternative conceptions can only bring awareness to the difficulties learners face in the classroom; it does not, however, equip science teachers with well-researched teaching and learning strategies that have been proven to assist learners master this topic. In an attempt to fill this gap, South African scholars have investigated some of the instructional strategies that teachers could adopt in order to improve their learners' understanding of key concepts in electric circuits (Rankhumise (2014); Rankhumise and Imenda (2014). The present study follows in Rankhumise's (2014) footsteps as it aims to bring about improvement in the way electric circuits are taught and learnt in schools.

The purpose of this literature review is to critically outline studies that have been done on learning about electric circuits. I start by highlighting the important relationships between key concepts that learners need to understand in this topic. I then review some of the research studies that have investigated learners' understanding of electric circuits. I also highlight some of the researched alternative conceptions in electric circuits. I focus on research participants, their methods, and their findings. I pay attention to effective teaching-learning strategies such as concept mapping, and the impact of prior knowledge on knowledge construction. The South African Physical Science Assessment Policy is also discussed with particular focus on electric circuits.

3.1. The important relationships between key concepts in electric circuits

It is often the case that when scholars research electric circuits, they emphasize potential difference (voltage), resistance, and electric current as key concepts (Anita et al., 2018; Marks, 2012; Rosenthal & Henderson, 2006). The same concepts and their mathematical relationship are also the focus of this study. The relationship between potential difference, electric current and resistance is explained through Ohm's Law by describing how electric circuits work. A German physicist George Ohm discovered this relationship in the 1800s. It is probably the most critical mathematical relationship in electricity and helps us understand how an electric current operates in the circuit, and how it can be controlled by the resistance together with the energy source. In a world where most machines and electrical equipment in homes use electricity, understanding of this relationship is essential in our day-to-day use of electronic devices.

Ohm's Law states that the potential difference across an ideal conductor is directly proportional to the current that passes through it, provided the temperature remains constant. The resistance is the constant of proportionality between the potential difference and electric current. The mathematical expression of Ohm's Law is: $V = IR$, where 'V' is the potential difference across resistors, 'R' is the resistance of a resistor, and 'I' refers to an electric current flowing in a circuit. According to Liégeois, Chasseigne, Papin, and Mullet (2003) understanding this equation indicates understanding the following: the fact that the potential difference is directly proportional to the resistance (when an electric current is constant); relationship between the potential difference and an electric current is direct (when the resistance in a circuit is constant); the fact that the position of the ammeter does not affect these two relationships; and that the relationship between the resistance and an electric current is inversely proportional.

Learners in secondary schools are therefore expected to be able to grasp how these theoretical concepts are related in order to understand how electric circuits work. Literature suggests that the learning of electric circuits should pay attention to the understanding of the interdependence of above-mentioned vital concepts, which can be viewed as a system where all parts are working together (Anita et al., 2018; Kock et al., 2014; Marks, 2012). Marks (2012) stresses the importance of understanding that the relationship between potential difference, resistance, and electric current forms the basis of the study of electric circuits. He argues that learners should learn in such a way that they understand the meanings attributed to potential difference/voltage; and acknowledge the fact that while there can be no current flow without the potential difference across the battery terminals, it is when current flows that a potential difference can be measured across resistors in the circuit. Therefore, it is crucial that instructional strategies used in the teaching-learning of electric circuits facilitate meaningful learning of the relationships between potential difference, electric current, and resistance as key concepts.

3.2. Research on learners' understanding of electric circuits

A large body of literature on electric circuits exists. Studies that have investigated learners' understanding in electric circuits in South Africa and abroad have found that this topic still holds many difficulties for learners because of the abstract nature of its concepts (Lin, 2016; Lombard & Simayi, 2019; Rankhumise, 2014, 2015). A more recent local study conducted by Lombard and Simayi (2019) with 78 Grade 8 learners from two peri-urban schools in the Eastern Cape, revealed that schematic diagrams used by teachers (and found in textbooks and examinations) generated no engagement with tasks. The researchers used interviews and questionnaires to collect their data. It was also found that one of the reasons learners experienced challenges in understanding concepts in electric circuits when taught using the schematic diagrams was because these were associated with the examinations that learners believed they would fail. However, these findings do not paint a full picture of learners' difficulties in understanding key concepts in electric circuits. The conclusion that learners have shallow understanding in this topic because of schematic diagrams used in class, which are also present in the tests or exams, appears to be vague and misleading. In this regard, one could argue that schematic layouts of electric circuits provide learners with a simple version of what happens inside a real electronic device, which by the way, can have complex interconnections, which can be difficult to comprehend even for the most learned mind (Lim, 2019). Lim (2019) argues that schematic diagrams are intended to convey necessary information that is easy to understand. Therefore, how teachers present learning material must be relatable to the learner.

The issue surrounding difficulties in the understanding of relationships between critical concepts in electric circuits is not just a South African problem. A research article published by Saglam (2015) at the state university in Turkey shows that prospective teachers lacked understanding of the effect of parallel-connected resistors on the potential difference in the electric circuit. The study explored the relationship between the accuracy of performance and confidence among 114 (43 male and 71 female) pre-service teachers in answering diagnostic questions on the potential difference in parallel circuits. The results showed that many students had difficulties in understanding the effect of parallel-connected resistors on the potential difference of the circuit. Furthermore, the diagnostic questions also indicated that many of the students' incorrect answers were a result of alternative conceptions or inappropriate use of some formulae. Saglam (2015) recommend that students improve their understanding of concepts in electric circuits. Otherwise, they will carry their alternative conceptions to the schools where they will teach.

In an effort to address some of the challenges learners face in understanding key concepts in electric circuits, a local study conducted by Rankhumise (2015) compared the performance of students who were taught electric circuits under the National Curriculum Statements (NCS) and Old School Curriculum (OSC) eras. The research sample consisted of 100 first year students that were enrolled in a South African university, both from the NCS and OSC. A single pre-test/post-test was administered to determine their prior knowledge concerning electric circuits, which was then used for developing the relevant instructional strategy within this topic. Data were analyzed using the "t" test statistic. The results showed that there was no significant difference between the performance of students who studied under the NCS and the OSC. The reason for this was that teachers did not infuse the Outcomes Based Education (OBE) orientation to the teaching and learning of electric circuits. As such, students were found to have alternative conceptions related to understanding of this topic. The study also included intervention for students who were diagnosed with alternative conceptions in electric circuits. The intervention designed by the researcher included collaborative learning strategies, activity-based instructional approach, and analogy-based instructional approach. It was also found that students benefitted from these strategies and teachers were encouraged to make use of them in their classrooms. This follows a study that was done a previous year by the same researcher on the effect of using a bicycle analogy in addressing the alternative conceptions and other difficulties in learning the relationship between concepts in electric circuits (Rankhumise (2014). The researcher conducted a comparison study of 100 first year science education students at a South African university. Data were collected using a pre-test/post-test comparison group design. It was found that instructional intervention involving the constructivist bicycle analogy instruction was beneficial in addressing alternative conceptions and overcoming learning difficulties related to this topic. These findings are in agreement with what Paatz, Ryder, Schwedes, and Scott (2004) found in their case study of a 16-year old learner doing Grade 10 in a German high school who used analogical reasoning to learn electric circuits. The researchers collected data using video recording and learning activities. Similar to what Rankhumise (2014) found, the use of analogy-based instructional approaches showed significant learning gains to the learner in terms of improved understanding of how key concepts are related in electric circuits. However, these authors also warn that the misappropriate use of analogical knowledge can also leave students with alternative conceptions. They therefore advise teachers who use this instructional strategy to be clear when presenting concepts and their meanings. These studies provide evidence that difficulties in understanding the relationship between key concepts in electric circuits can be overcome if teachers are willing to create a learning environment that allows students to construct scientifically acceptable meanings of electricity and electric circuits.

Apart from the analogy-based instructional strategies, literature also reports that the use of a technology-driven and inquiry-based instructional approaches can help improve conceptual formation (Jack, 2013; Kock et al., 2014; Rankhumise & Imenda, 2014; Zacharia & de Jong, 2014). Zacharia and de Jong (2014) conducted a study on 194 undergraduates (52 males and 142 females) who were enrolled for an introductory physics course at a university in Cyprus. Their study revealed that the use of teaching and learning aids such as Virtual Manipulations (VM) and Physical Manipulatives (PM) could help impact students' development of appropriate conceptual understanding of electric circuits. Zacharia and de Jong (2014) made use of conceptual tests, interviews, instructor's journals, and video recordings to collect data on students' understanding of this topic. Their study also revealed that the use of VM and PM helped address some of the well documented alternative conceptions related to current-flow-based models that students have about current flow in electric circuits (Driver et al., 1985).

Kock et al. (2014) investigated how physics instruction aimed at improving the culture of inquiry in a Grade 9 classroom could help improve learners' understanding of theoretical concepts in direct current electric circuits at a school in Taiwan. They employed a cyclic methodology approach to generate data. The researchers also made use of a variety of data collection instruments such as video and audio recordings, field notes, learner's work, conceptual quiz, pre and post-tests, interviews, as well as observation and reflections. The researchers found that there was an increase in understanding of concepts in electric circuits in an experimental class where inquiry instruction was adopted. Learners developed an ability to interpret circuit diagrams, distinguish between the concepts of electric current, voltage, and resistance, and clearly explain the role of a battery or power supply. The authors recommend the implementation of teaching and learning strategies that promote the nature of science as an inquiry. These strategies should consider the social and cognitive aspects of doing science and meaning-making processes which involves knowledge sharing between learners and their peers, as well learners and their teacher (Kock et al., 2014).

While the reviewed studies may show technology-driven and inquiry-based learning approaches producing positive learning outcomes, it is also important to highlight some of the disadvantages of using these strategies. An essay published by Universityhomeworkhelp.com (2019) noted 15 disadvantages of technology use in education, some of which include issues of affordability by some schools (especially in South Africa), lack of alignment between technology and curriculum, the disruptive nature of gadgets to the learners, and complications which may arise as most software needs to be updated constantly, to name a few. Kock, Taconis, Bolhuis, and Gravemeijer (2013) in their study of 26 Grade 9 learners (11 girls and 15 boys, aged 14/15 years old) in a school in the Netherlands, found that the inquiry-based instructional approach had its pros and cons. Their research revealed that, when this approach was used in the classroom, it often left learners unprepared for the examination because it depended too heavily on learners' willingness to participate. As such, learners that were unwilling to participate were often left behind because they were not ready to take responsibility of their own learning. This present study argues that, during a process of learning, challenges in understanding the object of the learning often occur and that teachers need to be aware of the pros and cons of their choice of instructional approach. Hobden (2018) asserts that teachers can be astonished to learn that, despite trying their best to teach content in a meaningful way, learners do not grasp essential ideas covered in class. Learners' failure to understand the underlying concepts entirely results in alternative conceptions being formed in their cognitive structure, thus forming a barrier to understanding science. Whereas, therefore, it is established that there are learning difficulties related to the electric circuits topic, the collaborative concept mapping learning approach advanced in this study could be one of the ways to address said problems. This approach is discussed in greater detail in section 3.4. of this chapter.

3.3. Research on alternative conceptions of electric circuits

An alternative conception is a stable cognitive structure that affects a learner's understanding of scientific concepts (Hammer, 1996). This is the understanding employed in this study. A major point advanced in the literature is that, as learners are engaged in the process of learning, there are alternative conceptions that form, irrespective of any instructional or learning strategy. Persistence of alternative conceptions often leads to learning difficulties as learners find it challenging to grasp new knowledge. Alternative conceptions can, therefore, form a barrier to meaningful understanding of concepts. As such, it is necessary to highlight some of the studies that focused on learners' alternative conceptions. Studies dating back to as early as the 1980s have documented alternative conceptions in electric circuits (Driver et al., 1985; Dupin & Joshua, 1987; Shipstone, 1984). Research mostly attributes alternative conceptions to shallow understanding of the relationships between the key concepts: potential difference, electric current, and resistance.

Over the last decade, there has been a sharp rise in local studies, which also focus on alternative conceptions of electric circuits (Moodley, 2013; Moodley & Gaigher, 2015; Nkopane et al., 2011). Shipstone (1984) work influences much of the work reported by the researchers (Nkopane et al., 2011; Pesman & Eryilmaz, 2010; Van der Merwe & Gaigher, 2011).

His work was instrumental in exposing different ways in which South African learners look at electric current as they try to understand it by linking it to their prior experiences. According to Shipstone (1984), it is unwise to think that just because children speak about electricity they have grasped the concept of electric current. Pesman and Eryilmaz (2010) also warned of the implications of the alternative conceptions learners may hold regarding this crucial concept. Their study of 124 Turkish high school learners confirms Shipstone's claim that some learners do not fully grasp the concept of current flow in an electric circuit. The aim of their study was to develop a three-tier test to assess alternative conceptions about simple electric circuits which were reported in the literature they reviewed. The researchers collected data using one-on-one interviews. The responses from participants showed that they had several alternative conceptions on this topic. For example, some learners believed that current within wire-like water flows in a pipe. The authors attributed this alternative conception to the water-circuit mostly used by teachers when teaching electric circuits, and warned teachers on the implications of analogy-based instructional approaches. Other alternative conceptions found in the literature include, the power supply as a constant source of current (Dupin & Joshua, 1987; Marks, 2012), and the clashing current model (Nkopane et al., 2011; Sencar & Eryilmaz, 2004).

Local studies on alternative conceptions in electric circuits

Moodley and Gaigher (2015) conducted an exploratory case study on teachers' awareness and perceptions of alternative conceptions with regard to electric circuits. Six participants from six different schools in an urban setting in Pretoria, Gauteng Province, were investigated. Questionnaires and interview were used to gather data. Results from the study showed that teachers' understanding of alternative conceptions ranged from minimal to insightful, while the strategies to correct alternative conceptions included teaching factually, mathematically, practically and conceptually. The researchers also found that those teachers who were well aware of their learners' alternative conceptions also believed that science teaching should focus on conceptual understanding and that various methods should be employed to achieve that goal. Conversely, teachers who lacked awareness of alternative conceptions tended to view and teach concepts as isolated and concrete facts.

Nkopane et al. (2011) investigated alternative conceptions about simple electric circuits in a school in the South African province of Gauteng. Three high school learners per grade were randomly selected, and a conceptual test was administered to probe their conceptual understanding in electric circuits. The researchers also used semi-structured interviews to further probe learners' responses to the test. The findings revealed some of the alternative conceptions reported in literature, and some that are peculiar to South African learners, such as the inability to conceive that circuits work as a system and that changing one part affects the rest of the circuit, battery as a source of constant current (Cohen, Eylon, & Ganiel, 1983; Dupin & Joshua, 1987; Pesman & Eryilmaz, 2010), the notion that electric current gets used up (Sencar & Eryilmaz, 2004), and shallow understanding of the roles of resistance in a circuit. The discovery of these and other alternative conceptions in a South African school points to the need for learning strategies that help identify and address them in order to improve and enhance learners' understanding of electric circuits.

The main focus of this present study, however, is not on alternative conceptions. On the contrary, the study explores learners' understanding of key concepts in electric circuits and demonstrates how collaborative concept mapping can be used to promote meaningful learning and deepen learners' understanding of key concepts in this topic. The study, however, acknowledges that knowledge and awareness of existing alternative conceptions should inform the teacher's lesson planning. The study argues that educators should take logical steps to provide learners with opportunities that will allow them to construct knowledge, thereby enhancing their understanding of scientific concepts. To achieve this, teachers need to understand the concepts, related alternative conceptions, and possible causes thereof. Teaching and learning tools, such as concept maps, which facilitate the attainment of that goal, come highly recommended by many teacher-researchers who have used them in their own classrooms (Cañas & Novak, 2010; Govender et al., 2016; KiliÇ & ÇAkmak, 2013).

3.4. Research on concept mapping as a means to enhance learners' understanding of topic-specific concepts

Concept mapping is an instructional and/or learning tool used to ensure meaningful learning. As mentioned in the theoretical framework section above, a concept map is a graphical tool that organizes, connects, and synthesises information in the form of concepts and propositions (KiliÇ & ÇAkmak, 2013). González et al. (2008) conducted a study in Colombia with students enrolled in medicine at Universidad Autonoma de Bucaramanga to evaluate the impact of articulating the concept mapping strategy with the mediated learning experience on meaningful learning during the cardiovascular module of a medical physiology course. They made use of a randomized controlled experiment with students enrolled in the third semester of medicine. Two groups of students experienced two different instructional strategies (i.e., concept mapping vs. traditional methodology). The study revealed that students who experienced concept mapping performed better than those who were taught by traditional methodology. Gonzalez et al. (2008) concluded that the use of concept mapping could promote meaningful learning and allowed students to transfer their knowledge to solve problems. Improved performance due to concept mapping is also reported by Cheema and Mirza (2013) who investigated its effect on the academic achievement of 167 male and female 7th grade learners in Pakistani schools. Cheema and Mirza employed the quasi-experimental research design. Both González et al. (2008) and Cheema and Mirza (2013) compared concept mapping (used with an experimental group) with traditional methodologies (used with a control group). These studies concluded that concept mapping could improve the learning atmosphere, promote significant cognitive modifications, stimulate metacognition, and is an effective alternative teaching and learning tool. Although these studies were conducted in different countries, they both underscore the advantages that concept mapping has over traditional methods of instruction.

A study by Misfades (2009) revealed that students of the De la Salle University of the Philippines had significant learning gains when using concept maps to learn the subject matter. Reports from the literature he reviewed showed that concept maps gave educators insight into the learning process of a student by showing students' cognitive structures in the context of prior knowledge and experience. Misfades found that concept mapping increased students' conceptual understanding and critical thinking in Chemistry. He recommended concept mapping to educators as an instructional and learning tool as well as a tool to diagnose alternative conceptions. He also recommended that students work in small groups when constructing concept maps to promote cooperation and interest to learn subject matter for positive cognitive outcomes.

The idea of collaborative concept mapping was also explored by van Boxtel et al. (2002), in their experimental studies of learners from secondary schools in the American State of Ohio. Van Boxtel et al. made use of concept mapping tasks in introducing a new course on electricity. Their study revealed that collaborative concept mapping was appropriate for learning electricity concepts in a setting where learners were given a platform to discuss ideas and relationships between various concepts in electricity. Contrary to many studies on concept maps, van Boxtel et al. used concept mapping as a learning tool instead of an instructional one in order to promote thinking through peer learning.

Though few, authors did, nevertheless, identify negatives in collaborative concept mapping, namely, learners' scientifically incorrect notions might go unchallenged, group discussions often stray from the topic under study, collaborative construction of a concept map takes too long, no individual thinking, and learners often find it easy to avoid work. As a result, various studies recommend that educators become aware of these negatives surrounding the collaborative concept mapping learning strategy so that they can find ways to address them when planning to use this strategy with their learners.

Studies on concept mapping as a means of getting to understand key concepts of a topic

Literature shows that collaborative concept mapping (CCM) can be used for meaningful learning and help learners take responsibility for their learning (George-Walker & Tyler, 2014; Govender, 2015; Govender et al., 2016; van Boxtel et al., 2002). Van Boxtel et al. (2002) show that collaborative construction of concept maps in the domain of electric circuits by learners helps create a dialogical process to achieve shared learning goals and co-construction of meanings, thus maximising the learning process. A case study that was conducted by George-

Walker and Tyler (2014) made use of CCM with 14 higher degree students in the Capacity Building Research Network in Australia. Students worked as a team to collaboratively construct concept maps in a capacity building workshop. The use of CCM gave students an opportunity to have dialogues with their team members during the construction of meaning that was focused, hands-on, and visual. George-Walker and Tyler (2014) observe that CCM provided the team with a meaning-making mechanism which allowed them to share understanding and explore the team's potential capacity. Govender (2015) conducted a case study on two pre-service teachers (PST) to improve their subject matter knowledge (SMK) of electromagnetism by integrating concept maps and collaborative learning. The study revealed that the PST benefitted in many ways in consolidating their SMK of electromagnetism through CCM activities. Another study that was conducted by Govender et al. (2016) on twenty-seven preservice teachers (PST) made use of CCM to explore their understanding of gases and Kinetic Molecular Theory. The researchers divided the PST into nine groups in a CCM task using an online software CMapTool©. The analysis of the concept maps showed that PST have superficial understanding of gases and KMT. Govender et al. (2016) recommend that teachers explore concept mapping and collaborative learning to enhance their teaching strategies and improve their learners' understanding of key concepts. The point advanced in the literature is that CCM can help learners deepen their understanding of scientific concepts through discussions and co-construction of meaning. Research also showed that CCM activities could be used as a means to identify learners' inconsistent reasoning and, consequently, an opportunity for conceptual change. Following on the recommendations made by reviewed studies that explored the used of concept maps in a classroom setting, this present study made use of CCM to explore learners' understanding of key concepts in electric circuits as it was most relevant to the objectives of the study.

3.5. The impact of prior knowledge on learning electric circuits

In this section of the literature review, I look at studies that investigated the impact of incorporating prior knowledge to learning about electric circuits. Scholars contend that learners learn topic-specific concepts by relating them to their relevant prior knowledge (Hesti, Maknun,

& Feranie, 2017; Novak, 2010; Rankhumise & Imenda, 2014). As such, teachers are often encouraged to introduce their learners to learning strategies that stimulate their present understanding in order to make sense of new concepts. Rankhumise and Imenda (2014) argue that learning strategies that embody the learner's prior knowledge are most effective because they serve as a bridge between familiar and new situations. This view is also expressed by Paatz et al. (2004) who contend that the use of instructional practices that focus on prior knowledge helps develop learners' understanding in an unknown topic by referring to the causal relations in a well-known topic. From the point of view of teaching-learning approaches in electricity, Rankhumise and Imenda (2014) explain that, given that electricity is very common in everyday situations, the use of teaching-learning strategies that evoke the learners' prior understanding could help them overcome alternative conceptions and conceptual difficulties in this topic.

Reviewed literature on electric circuits shows that teachers make use of analogical approaches (prior knowledge) to explain abstract concepts in electricity (Hesti et al., 2017; Paatz et al., 2004; Rankhumise & Imenda, 2014). Marks (2012) argues that teachers know that learners generally come to the classroom with ideas about any topic based on their 'everyday life' experiences. As a result, teachers often choose to use instructional strategies that tap into their learners' prior experiences. These prior experiences are a foundation of learning and are used to make sense of new knowledge received in the classroom, including learning new concepts in electric circuits. Thus, Marks notes that teachers of young learners who have not yet had any formal lessons on the electricity topic prefer to first work on the meaning of electric current, which learners can derive it from everyday electricity talk. Such experiences can play a vital role in learners' understanding of new concepts if the teaching and learning process allows learners to construct their meanings. A study on understanding of key concepts in electric circuits that Marks (2012) conducted on post-secondary college students in Malta revealed that the use of activities directed at stimulating learners' prior ideas could assist in the understanding of this topic. He (2012, p.54) refers to these ideas as "mental models". Marks described mental models as "personal knowledge each of us builds as we perceive the world" (p.37). The study found that the prior knowledge that learners bring into the classroom influences mental models. These mental models can be used in teaching and learning of electricity to help improve understanding of this abstract topic. The role of a teacher, in this case, is to guide learners around these mental models, using discussions to help learners become aware of their intuitive ideas and to build upon them.

Clement and Steinberg (2002) conducted a case study tutoring experiment on one student learning the electric circuits topic. They used a pre-test and interviews to collect data. They found that the learner easily grasped new knowledge when teaching activities stimulated knowledge construction. Rammiki (2016) arrived at the same conclusion in her case study of exemplary physics teachers' instructional practices in two (2) secondary schools in Botswana. Rammiki used interviews and observations as well as audio and video recordings to capture and collect data. Her research showed that hands-on activities were an essential aspect of instruction, and linking learners' prior knowledge helped develop experimental skills and understanding of new concepts. The physics teachers in Rammiki's study created an environment which stimulated learners' need and competencies for accessing new physics concepts and skills. They did this by using discussions written work to provide learners with opportunities to demonstrate their understanding of key concepts. As a result, these learners acquired skills and understanding of concepts that were expected by the Botswana Examination Council.

Although these researchers are from different parts of the world, their findings and conclusions suggest that learning approaches that focus on the learner's construction of meaning using his/her prior knowledge are not an outdated notion. Most of the studies which look at prior knowledge in electric circuits focused on analogy-based instructional approaches. This present study used the collaborative concept mapping strategy, which is one of the learning strategies that is recommended by many scholars (Campbell & Campbell, 2009; Heinze-Fry & Novak, 1990; Novak, 1990). These scholars suggest that concept mapping is an effective tool for activating a learner's prior knowledge in the process of constructing meaning. With that in mind, this study used collaborative concept mapping as a learning tool to help deepen Grade 11 Physical Sciences learners' understanding of key concepts in electric circuits.

Although prior knowledge is an essential element in understanding new concepts, some studies show that activating learners' personal experiences can also lead to the formation of alternative concepts (Bernhard & Carstensen, 2015; Önder et al., 2017; Taber, 2001). They reported that certain ideas from a learner's 'everyday life' often lead to an unscientific understanding of concepts in electricity. Rankhumise and Imenda (2014) argue that learners often come across concepts of electricity from different situations, making it a fertile ground for alternative conceptions to flourish. Bernhard and Carstensen (2015) argue that the problem is that, whereas educators may still firmly believe in learners' prior knowledge, their view may be variance with the latest research. Unscientific understanding that are deeply rooted in a learners' prior knowledge result in alternative conceptions that can persist even after attempts to correct them (Taber (2001). A study conducted by Bernhard and Carstensen (2015) on 56 engineering students on their conception of circuit theory and electricity at a Swedish University, revealed that students often had problems in translating their 'real world' or prior knowledge into a mathematical representation of observed data in electric circuits. They also found that the students had alternative conceptions from their everyday life, which resulted in their failure to understand the relationship between critical concepts such as voltage and current, as well as energy, and current. These alternative conceptions persisted even after instruction. The same results were found by Önder et al. (2017) in their study of preservice teachers at Dokuz Eylul University, in Turkey. Önder et al. (2017) used open-ended questions and semi-structured interviews to collect their data. They found that one of the causes of alternative conceptions was misleading terminologies used in everyday speech and past experiences in electricity. The alternative conceptions stemmed from the students' daily life experiences, were persistent and affected their understanding of simple electric circuits. Önder et al. (2017) conclude that students need repeated practice in interpreting physics formalism and relating it to the real world.

Evidence from the reviewed literature shows that there are pros and cons in using teaching-learning strategies that activate learners' prior knowledge in the process of learning. In particular, the literature recommends that teachers be aware of the risk of alternative conceptions arising from knowledge that a learner brings in the classroom. Teachers therefore need to ensure that the learning strategies they adopt in their classrooms prevent alternative conceptions instead of promoting them.

3.6. The teaching of electric circuits in the South African school curriculum

The term curriculum refers to a scheme of work that learners learn during their study (Khoza, 2015). It guides teachers in the process of teaching and learning. The South African curriculum comprises of the content, time allocation for each topic, teaching guidelines, assessment criteria, concepts, and skills set for achieving identified educational outcomes (Department of Basic Education, 2011). Furthermore, it places its focus on achieving the following goals: (a) bringing awareness of the environment that learners live in; (b) promoting knowledge and skills in scientific inquiry; (c) problem-solving; (d) knowledge construction; (e) application of scientific knowledge; (f) understanding the nature of science, and how it relates to technology, society, and the environment. This section of the literature review focuses on the Curriculum Assessment Policy Statement (CAPS) and, in particular, its coverage of the electric circuits topic. The CAPS section on electric circuits includes the content of electric circuits for grade 11, general aims in Physical Sciences, specific aims, assessment, and time allocation for teaching-learning.

The Physical Sciences chapter of the CAPS stipulates the following content objectives for electric circuits in Grade 11: "(a) determine the relationship between resistance, potential difference and current at constant temperature using a simple circuit; (b) state the difference between Ohmic and Non-Ohmic conductors, and give an example of each; (c) application of Ohm’s Law, $R=V/I$, for series and parallel circuits" (Department of Basic Education, 2011, p. 88). Thus, the CAPS provides teachers with insight into the scheme of work they are supposed to cover, and the purpose of that work.

The general aims in Physical Sciences teaching and learning

General aims in Physical Sciences are outlined in the CAPS document to inform a teacher about the purpose and objectives of teaching and learning in the subject. According to the CAPS, the general purpose of Physical Sciences is to equip learners with investigation skills relating to physical and chemical phenomena. These aims, among others, can only be achieved if the learning process is transparent and meaningful, which depends on the method of instruction.

Specific aims in the CAPS document inform teachers about the teaching-learning objectives set out explicitly for a particular topic. Regarding electric circuits in general, the CAPS specifies that learners ought to know that (a) an electric charge is a property of subatomic particles; (b) current is the movement of charges in a conductor; (c) voltage is the electric potential that causes charges to move; (d) power is the rate at which energy is flowing in an electric circuit; (d) the mathematical expression of Ohm's Law is: voltage = current × resistance, and power = voltage × current; (e) resistance is a physical property that calculates how well a charge can move through a material; (f) electric circuits provide means to harness electrical energy and use it in everyday lives; (g) electric circuits require a voltage source to work; (h) circuits require a closed loop that serves as a path for the electric current; (i) circuits can be connected either in series or in parallel; (j) components connected in series have identical current, but different voltage; and (k) components connected in parallel have identical voltage, but different current. It is essential that learners grasp these concepts in Grade 11, as well as acquire understanding in order to do well in this topic when assessed.

Assessment of electric circuits in the South African Physical Sciences curriculum

The formal program of assessment for the Physical Sciences serves as a guide for teachers on the assessment tasks that should be administered during the year. In Grade 11, learners are expected to do an informal experiment. The recommended experiment in the CAPS document requires learners to determine the current and voltage data for a resistor and light bulb in order to determine which one obeys Ohm's Law. However, this does not count towards their school-based assessment (SBA) marks.

The external examination is written at the end of the year, and comprises two separate papers of chemistry and physics. The topic of electric circuits is in physics paper one in the external examination. Electricity and Magnetism are allocated 55 marks, which is 37% of the total. External examinations are written under controlled conditions within a specified time to assess performance at different cognitive levels. The emphasis is on assessing critical thinking and process skills as well as the ability to investigate and solve problems (Department of Basic Education, 2011).

In the CAPS, the weightings on cognitive levels are as follows: level one task that requires learners to recall information (15%); level two and three assesses comprehension, analysis, and application (35% and 40% respectively); level four assesses evaluation and synthesis (10%). The allocation of marks in the cognitive levels informs us that learners are required to show a deeper understanding of the concepts in physics in order to pass the examination. Therefore, if teachers are to achieve the aims set by the CAPS, they ought to incorporate instructional strategies that foster meaningful learning and a clear understanding of the concepts, especially since recent diagnostic reports from moderators point to the fact that learners still lack in-depth understanding of critical relationships between key concepts in electric circuits (Department of Basic Education, 2015, 2016, 2017). These reports identify some of the crucial aspects that learners are failing to master in the examination, leading to underachievement in this topic. The common alternative conceptions that occur most frequently include shallow understanding of the effect of parallel-connected resistors on the electric current and potential difference, the application of the basic principles of series and parallel circuits in problem-solving, the relationship between the potential difference and resistance, the application of Ohm's Law in problem solving, and the difference between the emf and potential difference concepts.

In order to improve learners' performance in this topic, the moderators suggest the following strategies:

- teachers should make use of short informal assessment tasks to reinforce basic concepts and principles;
- learners should be given the opportunity to do hands-on activities, with special emphasis on drawing graphs (to understand the relationships between key concepts), and mathematical manipulation of formulas in problem-solving tasks;
- Grade 11 work should be included in class activities, homework, and tests in Grade 12;
- learners should be given frequent practice calculations involving multiple resistors in series and parallel within the same circuit;

- experiments stated in the CAPS in order to understand electric circuits should be conducted; and
- teachers should include at least two conceptual questions in every classwork and homework exercise to improve deeper understanding of concepts in electric circuits.

The above-mentioned strategies point to the need for teachers to create an environment in which learners play an active role in the learning process through engaging in learner-centered activities. According to Rankhumise (2014), activity-based instructional approaches are constructivist in nature and are beneficial to learners since they provide opportunities for them to express their pre-knowledge, which can then be remedied by the teacher if and when necessary. A critical feature of the constructivist teaching approach is that it fosters critical thinking and motivates learners to think for themselves in the process of meaning-making (Duit & Treagust, 2003). This present study is therefore in line with the call of the CAPS and the moderators for the effective teaching and learning of electric circuits.

Time allocation

The time allocated for teaching electric circuits in grade 11 is 4 hours (an equivalence of four lessons). Teachers such as myself believe that this time is not enough to cover all the work on this topic and still include a practical assessment. Studies by Kolobe (2017); Mji and Makgato (2006) reveal that teachers often thought that the time allocated to teach the syllabus content was inadequate. In my experience, the pressure to cover all the work in a short space of time often leads to abrupt teaching or, in some cases, syllabus incompletion. Although learners in grade 11 are familiar with the basic concepts in electricity, as teachers, we are still expected to revise these concepts before introducing new knowledge within this topic. However, the CAPS only allocate time for teaching new concepts, with less consideration for revising what has been covered previously. To ensure that learners are ready for examination, teachers have to use inventive ways to better teach the topic despite the inadequacy of the time allocated to it.

Summary of the literature review

The review of the literature has shown that electric circuits are one of the topics that learners find difficult to understand because of the abstract nature of the concepts. Reports show that the most crucial relationship in electric circuits is Ohm's Law. Teaching and learning in electric circuits should focus on the understanding of the relationship between physical properties such as voltage, current, and resistance. Literature recommends technology-driven inquiry-based instructional approaches, text-based analogies as well as concept mapping tasks as some of the ways to help learners understand electric circuits. Furthermore, reports affirm that prior knowledge plays a vital role in the process of knowledge construction. Studies reviewed here recommend instructional approaches that activate learners' prior knowledge in order to make it easier for them to learn new information. However, studies also show that the use of prior knowledge can lead to the formation of alternative conceptions in the learner's cognitive structure. Much of the literature that exists around electric circuits focuses on learners' alternative conceptions on this topic and warns that these alternative conceptions can be deep-rooted in a learner's mind and persist even after instruction. The literature recommends that teachers familiarize themselves with common alternative conceptions that learners tend to hold in order to address them in their lessons. Furthermore, the use of technology during demonstrations and discussions, analogical reasoning, concept mapping tasks, conducting experiments, and inquiry-based learning comes highly recommended in the study of electric circuits. The present study focuses on the use of collaborative concept mapping to enhance learners' understanding of electric circuits while addressing any potential alternative conceptions that learners may hold.

The CAPS does not shed light on potential alternative conceptions in electric circuits that learners in Grade 11 may hold regarding electric circuits; and provides teachers with very few guidelines on the methods of instruction that foster meaningful learning of science. The time for teaching this topic is only allocated for instruction, with no expanded opportunities to assist learners to grasp the difficult and abstract concepts in this topic. Additionally, there is only one recommended practical assessment in this topic, yet learners are expected to have adequate practical knowledge and skills to be able to write it at the end of the year external examination one year later. Therefore, teachers need to find alternative ways to help learners grasp the knowledge of electric circuits, as this will be essential in the examination. A study of this nature can assist both teachers and learners with ways in which electric circuits can be taught and learned under the CAPS, which does not offer much guidance on meaningful teaching and learning of the topic.

3.7. Positioning of the study

In the literature review, I looked at research initiatives undertaken to investigate learners' understanding of concepts in electric circuits, and noted that most of them found that learners experience difficulties in this topic. An aim of the literature review was to identify learning strategies that have been proven to assist learners in understanding this topic. I also noted and highlighted the limited number of studies that focused on the teaching and learning of electric circuits within the South African context. What emerged from the literature was that learners had problems making sense of concepts when being taught using schematic diagrams found in textbooks and exam questions. The South African CAPS was also reviewed. The inadequacy of the time allocated to the teaching and learning of this challenging topic was noted. On another note, reviewed research and official diagnostic reports revealed that learners had alternative conceptions related to key concepts, which teachers needed to be aware of. It was established that teachers who were aware of alternative conceptions taught this topic far better than those who were not. Even though these alternative conceptions are well researched and documented, they still occur frequently in our classrooms. Studies that explored and recommended various instructional approaches were also reviewed. They found that learners' understanding of concepts in electric circuits improved when exposed to certain teaching and learning methods. However, most of these studies focused on teacher instructional strategies.

In this present study, I focus on how learning strategies that embrace the concept of social constructivism can help learners improve their understanding of key concepts in electric circuits. There is need for research which explores some of the learning skills with which teachers can equip their learners in order to take control of their own learning. In this present study, I take an in-depth look at how a learning strategy such as collaborative concept mapping can help learners overcome difficulties related to the electric circuits topic.

CHAPTER FOUR – RESEARCH DESIGN

Literature reveals that learners often lack understanding of the relationships between concepts in electric circuits (Mavhunga, Ibrahim, Qhobela, & Rollnick, 2016; Moodley & Gaigher, 2015; Wade-Jaimes, Demir, & Qureshi, 2018). Moodley and Gaigher (2015) argue that due to the abstract nature of concepts such as potential difference, current, and resistance, learners tend to understand the relationship between these concepts differently and it is often inconsistent with what teachers intend to achieve during instruction. Bennett (2005) reveals that despite the teachers' best efforts to teach scientific ideas in a manner that makes sense, learners still struggle to understand the ideas they encounter in science lessons. In an effort to shed light on the issues related to learning in this topic, many studies have documented learners' alternative understanding of electric circuits (Budiman, Sukarmin, & Supriyanto, 2019; Stott, 2017; Wade-Jaimes et al., 2018). This study focuses on learners' shallow understanding of the relationships between key concepts within the domain of electric circuits. I work within the interpretive paradigm, using action research involving my Grade 11 Physical Sciences learners in order to explore and deepen their understanding of the key concepts in electric circuits through collaborative concept mapping.

This chapter outlines the overall research design I used to undertake this study. I discuss the research paradigm, community of practice, research approach, methods, sampling and data generation process followed. Furthermore, I provide reasons why I think these were the best ways to answer the research questions. Finally, I indicate the ethical considerations made and address the credibility and trustworthiness of the study.

The research questions addressed in this study are:

3. What are Grade 11 Physical Sciences learners' understanding of key concepts in electric circuits?
4. How have Grade 11 Physical Sciences learners' understanding of key concepts in electric circuits developed as they collaboratively constructed concept maps to deepen their knowledge of these concepts?

4.1. Research paradigm

Terre Blanche and Durrheim (1999) define a research paradigm as a systematic approach to conducting research and thinking that defines the nature of inquiry along the three dimensions of ontology, epistemology, and methodology. Kuhn (1977) first popularized the term itself in the early 1960s as he used it to describe the overall philosophical approach shared by a community of scientists, which provided them with a convenient model for examining problems and finding solutions. He defined it as an integrated cluster of substantive concepts, variables, and problems attached to similar methodological approaches and tools consisting of a set of beliefs, values, and assumptions that researchers have in common regarding the nature and conduct of research (Kuhn, 1977). This present study is situated in the constructivist paradigm. Thomas (2010) postulates that the constructivist paradigm is concerned with understanding the world as it is from the subjective experience of individuals. Willis (1995) argues that the ontological assumptions of constructivists are anti-foundational because they believe that there is no single route to a particular inquiry and knowledge. Constructivists assert that the nature of knowledge is subjective because it is socially constructed and mind-dependent. They attempt to derive their constructs from the field by an in-depth examination of the phenomenon of interest (Thomas, 2010). The constructivist approach does not predefine dependent and independent variables but instead focuses on the full complexity of the human sense-making of a situation (Kaplan & Maxwell, 2005). Constructivist researchers often make use of a qualitative research approach to understand peoples' experiences in their natural setting (Neuman, 1997). I found this paradigm suitable because it is in line with the purpose of conducting this study, which is to explore how Grade 11 Physical Sciences learners' understanding developed as they constructed concept maps to deepen their understanding of concepts in electric circuits. The instructional strategy adopted in this study present is that of collaborative concept mapping. Social constructivism theory informs this strategy of learning. This study therefore made learners use collaborative concept mapping because it allows them to construct their knowledge actively by engaging in discussions about key concepts of electric circuits.

4.2. Community of practice

I adhered to the constructivist paradigm through the use of action research. Berg, Lune, and Lune (2004) define action research as “a collaborative approach to research that provides people with the means to take systematic action to resolve specific problems”. Reason and Bradbury (2001) posit that the primary purpose of action research is not just to produce new practical knowledge, but also to provide abilities to create new knowledge that is useful to people in the everyday conduct of their lives. Reason and Bradbury’s claim is attested by Cohen, Manion, and Morrison (2011), who explain that action research is a method of inquiry in which personal attempt is made to understand, improve and reform teaching and learning practices. Action research is used in real situations to address real lie needs. This method of research was relevant to this study because it allowed me to work together with my learners in an attempt to address practical problems emanating from learners’ shallow understanding of the relationships between concepts in electric circuits. It was necessary to use this method of inquiry for my professional growth and development in the field of education. McMillan and Schumacher (2014) postulate that action research can be used by educational professionals to improve aspects of their day-to-day practice. The primary goal of this study was not just to help learners learn meaningfully, but also to help professionals change practice. For teachers in the classroom, action research is a pro-active approach towards taking responsibility for their practice and seek to find ways to develop knowledge in themselves and their learners.

Action research was used because it is apt to answer the research questions as it is not limited to a specific methodology. It also allows the researcher flexibility with regard to the methods s/he uses to resolve the problem at hand (McMillan & Schumacher, 2014). It was essential to use action research in this study because answering the two research questions required a qualitative approach (i.e., a description of learners’ knowledge development and experiences as they constructed concept maps) to data presentation, analysis and interpretation. Kinchin et al. (2000) assert that teachers should not rely on quantitative analysis of concept maps to gauge learners’ understanding because that undermines their experiences and places unrealistic demands on the classroom teacher. Stuart (1985) warns that to continue to rely on numerical scores is to risk missing diagnostic data to help the learner. These authors, therefore, suggest that concept maps should be viewed as a qualitative instrument to support and promote meaningful learning in the classroom. The action research approach used in this study enabled the analysis and interpretation of learners' concept maps, followed by reflection on the results before engaging in a plan of action to impact change in the classroom. McMillan and Schumacher (2014) assert that the involvement of a practitioner throughout an action research study promotes change in the classroom and greater collaboration between a teacher and his learners. The use of action research was, therefore, essential in this study as it was aimed to understand the practice and explore the use of concept maps to deepen Grade 11 Physical Sciences learners' understanding.

4.3. Research approach

This study employed a qualitative research approach. Creswell (2014) defines a qualitative research approach as "the plans and procedures for the research that spans the steps from broad assumptions to detailed methods of qualitative data collection, analysis and interpretation" (p. 30). Mertens (2014) points out that constructivist researchers primarily utilize a qualitative research approach to collect and analyze data that explain participants' experiences from their point of view. Creswell (2014) argues that qualitative researchers play a key role in collecting data themselves through examining documents, observing behavior, or interviewing participants. The qualitative researcher tends to work with a relatively small number of cases to find details on particular matters, such as people's understanding and interactions (Silverman, 2006). I found the qualitative research approach applicable to this study because it allowed me to focus on a case of 20 Grade 11 Physical Sciences learners in order to explore their understanding of key concepts in electric circuits. The forms of qualitative data generation methods used in this study were the semi-structured interview, audio recordings from group discussions, documents, and concept maps constructed by learners. Creswell (2014) asserts that data generation methods in a qualitative research approach rely on data in the form of interviews, observations, documents, and audiovisual sources rather than depend on a single data source. The analysis of data in this study is inductive and deductive. Inductive analysis was used to look for evidence of understanding and lack thereof. The themes arose from the data and literature review and informed the theoretical framework. A deductive approach was employed when analyzing data from the concept maps constructed by learners. The themes used in the first level analysis came from the Novak analytical framework (Novak & Gowin, 1984) and the theoretical framework.

4.4. Research method

The method used in this study combined the case study approach and the action research method. The case study research is an in-depth descriptive investigation and analysis of a contemporary phenomenon within its real-life context (Creswell, 2014; Merriam, 2009). Creswell (2014) posits that a case study research is a qualitative approach in which a researcher explores a case over some time through in-depth data collection that involves various sources of information in the form of text and images. Merriam (2009) contends that a case study method shares with other forms of qualitative research the quest to search for meaning and understanding of a single or collective case by capturing the complexity of the object of study. The qualitative case study method falls within the constructivist paradigm (Creswell, 2014; Denzin & Lincoln, 2005; Hodkinson & Hodkinson, 2001). However, qualitative case studies have some limitations. According to Hodkinson and Hodkinson (2001), case studies generate so much data that it often becomes to analyze it and summarize the findings. "Further limitations involve issues of reliability, validity, and generalizability" (Merriam, 2009, p.52). Despite these limitations, Merriam maintains that the case study is best suited for qualitative research because its strengths outweigh its limitations. She argues that case study has proven useful when applied in fields such as education as it can be used to bring about an understanding that, in turn, can affect and improve practice, a concern which is in line with the purpose of this study.

The action research aspect of this study was twofold. Firstly, I created a social context by dividing my 20 Grade 11 Physical Sciences learners into four groups of five. This was done so that learners could share knowledge and their experiences during a collaborative concept mapping exercise. Secondly, I guided my learners as they constructed concept maps and teaching them electric circuits in class. Through observation and reflection, and from analyzing concept maps constructed by the groups, it was apparent that there were some learning difficulties that my learners were experiencing. I addressed these and scaffolded my teaching as I gave guidance to my learners in their ZPD.

4.5. Identifying the participants

The case for this present study was purposively selected in one of the schools in uMgungundlovu District in Pietermaritzburg. This is a school where I teach Physical Sciences and where the NSC examination results in the subject over the years have left a lot to be desired. Knowing the school and its performance, and looking at the purpose of my study, I found it appropriate to collect data from it as it has experienced challenges in achieving satisfactory performance in Physical Sciences. McMillan and Schumacher (2014) assert that it is not uncommon that a researcher may choose his sample from an area where a particular problem exists. The school and participants were chosen not only because of low achievement scores when compared to national performance but also because they were in a disadvantaged community. Another reason for selecting the school was because I could easily gain access to the participants. It was also my belief that the research findings would benefit the individuals being studied and would be meaningful to both the researcher and stakeholders of the school. I purposively chose to work with learners in grade 11 so as to gather data that could help address the identified problems in electric circuits before they progress to their final year of schooling.

This study went through several stages and followed specific procedures to identify the case. As a member of the staff at Esigodini Technical High School, I sought and was granted permission by the principal and the Department of Basic Education to access the school's NSC results for Physical Sciences from 2015 to 2017. Upon receiving permission from the school and the Department of Basic Education in the uMgungundlovu District, I took deliberate steps to generate and shape the topic on which my study would focus. I undertook an item analysis of learner performances in the NSC Physical Sciences examination, focusing on both physics (Paper 1) and chemistry (Paper 2), between 2015 and 2017. The performance of Esigodini candidates was at its worst in the Paper 1 topics of mechanics and electric circuits and magnetism, which contribute 42% and 37% respectively of the marks for the entire paper. To underscore the importance of the electric circuits topic, it was included in the Paper 1 examination for all the years covered by this study (Department of Basic Education, 2015, 2016, 2017). Some of the problems identified by NSC reports as contributing to the poor performance included Grade 11 work being poorly understood, questions pertaining to the pure recall of content being poorly answered, learners struggling with drawing and labeling free-body diagrams, and problem-solving questions involving graph interpretation being a challenge for many learners, to name but a few. Literature points to the difficulties of teaching and learning electric circuits because of its abstract nature (Anita et al., 2018; Lin, 2016; Moodley & Gaigher, 2015; Önder et al., 2017). According to the CAPS, the core concepts of electric circuits are taught in Grade 11, which, as discussed in detail in the literature review (see Section 3.6), lays the foundation for the NSC examination. Based on this analysis, I decided to work with the Grade 11 Physical Sciences learners that I teach. Choosing a case of Grade 11 learners would help provide rich data, which could help shed light on learners' understanding and address the identified problems before the learners enter Grade 12 (Denzin & Lincoln, 2005). Creswell (2014, p. 239) argues that "the idea behind qualitative research is to purposefully select participants that will best help the researcher understand the problem and the research question". Since learner-centeredness is the key to effective teaching and learning of science topics, I believed that there was something to be learned from studying the effects of learning strategies such as concept mapping on learners' holistic understanding of the topic of electric circuits.

As part of the annual teaching plan, I am required to teach electric circuits to grade 11 learners. I sent invitations to 20 learners who were hand-picked on the basis of their good conduct, satisfactory achievement in Physical Sciences, and willingness to participate. The 20 learners that participated in this study were all within the Sciences and Mathematics stream and chose Physical Sciences as their major subject. Their performance in the subject was fair, but some of them experienced difficulties in particular topics, and that has slowed their progress. The majority of the participants ranged from mid to low ability, with the exception of 2 boys whom I regarded as having high ability in the subject. Nevertheless, I regarded all of them as hard workers capable of performing very well if given a chance.

In Grade 11, learners are expected to cover the topic of electric circuits in the 3rd term of the year, but due to the time frame for data collection and presentation for this study, I moved this topic to the 1st term in order to allocate enough time for teaching and data collection. The plan was to teach the topic while collecting data so that I have enough time to sort, analyze, and present the findings for the final submission of the thesis in 2019. The rationale for choosing these participants was because I wanted the concept mapping discussions to be fruitful, and to ensure that participants conducted themselves appropriately. Van Boxtel et al. (2002) argue that a researcher may choose to work with learners who are already familiar with the terms and have an initial understanding of the concepts and their interrelationships to improve the fruitfulness of the discussions during a concept mapping exercise. Focusing on 20 learners made the sample size small and manageable for planning and budgetary purposes (Marshall, Cardon, Poddar, & Fontenot, 2013). Learners were told that the part of the study involving the construction of concept maps was to be conducted after schooling hours while other sections of the study (such as teaching activities) would be done as part of the regular teaching program, and that all learners needed to attend all the lessons. Only the concept mapping exercise, which took place after hours, was therefore reserved for selected participants.

I decided to work with my learners that I teach Physical Sciences because this was convenient for me as I could have easy access to them. According to Silverman (2006), convenient sampling may be used by researchers to select a group of participants based on their accessibility. McMillan and Schumacher (2014) contend that this type of sampling is not uncommon amongst action researchers who make use of it to focus their investigation within a particular context such as a classroom or school. Mertler (2009) argues that it makes sense for action researchers to adopt this technique because the results are not intended to be broadly applicable beyond the specific context of the study. Furthermore, I chose to focus on my school because that is where I wanted to improve the teaching and learning of Physical Sciences in order to address the problem of superficial understanding of electric circuits. Scholars such as Creswell (2014), McMillan and Schumacher (2014), and Silverman (2006) all agree that qualitative researchers tend to collect data in the field or site where participants experience the problem under study. Data was generated with 20 of my Grade 11 Physical Sciences learners. There were ten (10) males and ten (10) females between the ages of 16 and 18. Four (4) of the 20 participants played important roles in the schools. Two (2) of them, a male and a female were class representatives, and the other two (2) females were part of the Learner Representative Council (LRC). Criteria used by the school to select learners for these roles included excellent performance in all subjects, exemplary conduct, and commitment to school work. The selected learners were therefore suited for this study because they possessed qualities that I deemed to be useful for research of this nature. All 20 learners were more proficient in one vernacular language than in English.

Identifying the participants for the interview

In the research proposal for this study, I indicated that I would conduct three one-on-one semi-structured interviews at the end of each concept mapping session with one member of each group who was to be randomly selected. Unfortunately, that plan was unsuccessful due to participants' reluctance to be interviewed. Although many of them gave consent to be interviewed, none of the group members were willing to stay behind to be interviewed alone after the sessions concluded. Some highlighted fears of being interviewed because they thought of it as more of a test. Much as I explained to them the nature of the interview and assured them of confidentially, they were still not willing to participate. I then decided to change from conducting one-on-one interviews to doing a semi-structured group interview. The plan was to pose a question to the group, thus prompting a participant to provide his/her own response and others to join in the discussion thus started, thereby providing their own responses to the same question. I did this so as to achieve the requirement of my study to interview learners while respecting their reluctance to be interviewed individually. Other advantages of this improvisation were that I could save time and reduce costs. Kumar (1987) postulates that a group interview is one of the rapid, cost-effective data collection methods that allow the interviewer freedom and flexibility in conducting the interview. Kumar further argues that group interviews can help the researcher save time and provide a dynamic experience for the interviewees. However, there are weaknesses in conducting this kind of interview. Edwards and Holland (2013) point out that group interviews can unsettle participants and make them uncomfortable, which can lead to distortion of data the being collected. Other weaknesses include interviewer biases, which can undermine the validity and reliability of the information generated.

Despite acknowledged weaknesses, the idea of a group interview worked for this study by persuading reluctant participants to agree to be interviewed. Participants also said they felt comfortable being interviewed along with their fellow peers. I sent invitations to all 20 participants and managed to get four (4) participants who were willing to be interviewed on condition that they were interviewed as a group. The participants were three (3) females and one

(1) male. Each of the four participants represented the group s/he worked with during concept mapping. They were informed about the purpose of the interview and the rules of confidentiality were emphasized. The semi-structured interview was meant to be summative of all the work that had been done during the three concept mapping cycles and to give a sense of what learners understood and what they might not have been understood.

4.6. Data generation methods

The unit of analysis was Grade 11 learners collaboratively constructing concept maps to deepen their understanding of key concepts in electric circuits. In this study, data in the form of concept maps accompanied by audio recordings from the group discussions, a semi-structured interview, and document analysis was generated by following three action research cycles. The tools used were diagrams (i.e., concept maps), audio recorders (for transcripts from recordings), collected documents (such as diagnostic reports, learners' achievement marks schedules, and CAPS documents), and the interview schedule (for interview transcripts). The methods of data generation are discussed in greater detail in this section followed by the action research cycles and time frame for teaching activities and data generation.

4.6.1. Data generation during collaborative concept mapping activities

For this study, learners were first taught how to construct a concept map in a lesson that lasted a little more than an hour. The nature and length of this lesson meant that it had to be done as a standalone session after the regular schooling hours. In the lesson on how to construct a concept map, I first explained the purpose of this study and the kind of contributions participants were going to make. I made use of a PowerPoint presentation that contained descriptions, examples of concept maps, and instructions on how to construct a concept map (see Appendix A). The instructions used were adopted from the Novak and Gowin (1984) tool for drawing concept maps to learners in grade 7 through college. I found this tool clear and easy to understand for learners drawing concept maps for the first time.

After the lesson on constructing a concept map, I organized the twenty (20) participants into four (4) groups (A, B, C, and D). I then arranged the 1st of three (3) rounds of collaborative concept mapping (CCM). These sessions were arranged such that participants would collaboratively construct their concept maps at the end of a lesson on electric circuits that was part of a teaching program for the year. In the first round of CCM, in which participants were asked to collaboratively construct a concept map based on what they understood about electric circuits from the previous lesson. Participants were not given a list of expected concepts because it was assumed that they would remember them having been recently taught. The reason for this was to gauge with accuracy whether they understood the relationship between key concepts mentioned during the teaching of the topic. Also, this was intentionally done so as not to limit what learners could include in their concept maps. After each CCM round, I collected four concept maps and audio recordings for analysis and reflections.

Plans for the second lesson were informed by the first set of concept maps, and were mostly concerned with addressing identified alternative conceptions. In the second round of CCM, the four (4) groups were handed their initial concept maps with an instruction to add more information on them or redraw them if necessary. Having addressed the alternative conceptions in class, it was expected that learners would notice incorrect connections or propositions and re-work some parts of their first maps. This would have provided me with an indication of whether and to what extent their understanding had developed as well as the extent to which the activity used to address the alternative conceptions had been effective. The same process was followed for the third round of CCM. More details of what transpired during these concept mapping sessions are provided in depth in Section 4.6.4 of this study.

Justification for using concept maps collaboratively constructed by learners

Concept maps that learners collaboratively constructed were used as instruments to collect data on learners' understanding of key concepts in electric circuits. Also, the collaborative concept mapping learning strategy was employed in this study to assist learners deepen their understanding of key concepts by taking charge of their learning, reflecting on what was learned in class, and sharing ideas with their peers in the process of meaning-making. Novak and Gowin (1984) argue that the construction of a concept map can help learners retain information they have learned in class, and also help teachers diagnose any potential alternative conception that learners may hold. During the collaborative concept mapping tasks, learners were encouraged to discuss ideas they had about the topic and show how concepts such as current, voltage/potential difference, energy, power, and resistance relate. The expectation was that learners would show connections and propositions that represent the relationships between these concepts. Concept maps were accompanied by audio recordings, which contained essential data on learners' thought processes as they discussed ideas to feature on their maps. The recordings included discussions where learners collectively constructed relationships between concepts by drawing from their prior knowledge. Making use of data gathering tools such as audio recordings thus helped bring insight into learners' thoughts about concepts while sharing their ideas and negotiating meanings. In essence, the combined use of concept maps and audio recordings helped reduce some of the limitations that concept maps alone may have and also facilitated data triangulation.

4.6.2 Semi-structured interview

An interview is a qualitative method of generating data from individuals with specific characteristics to explore their attitudes, perceptions, feelings, and ideas about a topic (Dilshad & Latif, 2013). In this study, a semi-structured interview was used to obtain data from four (4) learners who were involved in the collaborative concept mapping exercises. A semi-structured interview in qualitative research involves open-ended questions to obtain data from individuals on how they view their world and make sense of the important events in their lives (McMillan & Schumacher, 2014). I opted to conduct the semi-structured interview in a group setting where learners took turns to answer the questions that were posed. According to Creswell (2014), a researcher's chosen interview approach depends on the accessibility of participants, the cost, and the amount of time available. Creswell (2014) further asserts that the interviewer has an objective in mind, asks relevant questions and records the responses of the participants. The use of a semi-structured group interview in this study was to probe learners' understanding of key concepts in electric circuits, which would help answer my first research question.

Choosing the interview questions

Questions for the semi-structured interview were adapted from (Marks, 2012) (see Appendix B). A total of four (4) questions, each containing sub-questions, were formulated using a Predict-Observe-Explain (POE) technique similar to that of Marks (2012). However, on questions where learners were supplied with apparatus to build a circuit in Marks' study, I made use of the PhET simulations as part of the POE technique to probe further into concepts. Each question focused on probing specific understanding of how an electric circuit works. The understanding are part of specific aims in the CAPS curriculum on electric circuits and have been identified as problematic in the diagnostic reports and the literature. Question 1 was about current flow in a simple circuit. This was followed by question 2, which focused on the effect of resistance in a parallel and series circuit. Question 3 looked at meanings attributed to voltmeter reading while, finally, question 4 was concerned with differentiating between current and voltage.

The following key points were adapted from Marks' (2012) study, and were prioritized for this study as I found them relevant:

- How current flow is understood – prior ideas learners have about current in a circuit and how that is linked to what they have learned in class;
- The role of the resistance and how it affects an electric circuit – whether it is just the number of resistances in the circuit which count and/or how they are connected in series and parallel;
- How current flows in the circuit when resistors are connected in series and then in parallel;
- Meanings attributed to a voltmeter reading and what sense is given to a voltmeter, leading to 'voltage' or 'potential difference';
- The distinction between electromotive force (emf) and potential difference (p.d);
- The role of a switch in a simple circuit and the meaning of the voltmeter reading when the switch is 'open' and when it is 'closed';
- How potential difference across the battery is related to the p.d. across resistors connected in series and again when they are connected in series; and
- The differentiation of current and potential difference.

Overall, the interview questions focused on probing learners' conceptual understanding of key concepts.

Justification for using semi-structured interview

This study made use of a semi-structured group interview because it allowed the researcher to do follow-ups on learners' responses to the interview questions (Denzin & Lincoln, 2005). The four (4) participants that volunteered to be interviewed were interviewed for a duration of 1 hour 30 minutes in the absence of their group members. All four (4) participants were interviewed collectively by giving each individual an opportunity to answer the question that was posed. This was done because learners had expressed unwillingness to being interviewed alone and had suggested that they all be in the same venue during the interview. Each participant was given the completed concept map constructed by his/her group and asked to reflect on their understanding of the relationships between key concepts, prior ideas about how circuits work and learning via concept mapping. The interview was audio-recorded and transcribed verbatim (Tessier, 2012). My interest was in learners' understanding of the relationship between key concepts in electric circuits, and how CCM had helped deepen their knowledge of this topic. I found a semi-structured group interview more appropriate in showing how learners perceived the relationships between concepts. However, researchers note that a semi-structured interview in qualitative research have both strengths and weaknesses (Creswell & Poth, 2018; McMillan & Schumacher, 2006; Tessier, 2012). Creswell and Poth (2018) purports that while the strength of an interview may be that it provides useful information when you cannot directly observe participants, it can only provide filtered information through the views of the interviewer (i.e., the researcher provides a summary of participants' views in the research report). McMillan and Schumacher (2014) argue that a semi-structured interview in qualitative research is a double-edged sword: while it can increase the validity and reliability of the study, allow for flexibility and adaptability, increase response rate, and may be used with just about anyone, it can also be highly taxing in terms of labor and time, does not offer anonymity (i.e., interviewee is exposed), and can be prone to subjectivity and personal bias. Having considered all these issues, a semi-structured interview was found to be the one type of interview to give me fewer problems and yet provide ample information to compare with the other sources of data.

4.6.3 Documents analysis

Documents analysis was essential in providing me with information on curriculum requirements, key problem areas on the subject, assessment criteria, and time allocation for the teaching and learning of electric circuits. Several documents, such as the Curriculum and Assessment Policy Statement (CAPS), Programme of Assessment, diagnostic reports, examination guidelines, and School-Based Assessment (SBA) mark sheets, were used to gain insight on the current issues in science education in South Africa. All the documents were obtained from the Department of Basic Education's relevant officials and online. Analyzing the CAPS document informed me of the curriculum requirements, time allocation for teaching electric circuits, teachers' guidelines for teaching this topic, and assessment criteria for teaching and learning in the physical sciences (as discussed at length in the literature review of this study). Also, the analysis of the SBA mark sheets informed me about the performance of learners in the subject in terms 1 and 2, which allowed me to choose the participants for the study while analyzing the diagnostic that reports provided me with valuable information on the critical problem areas in the subject. Table 4.1 below shows a summary of the data generation tools, methods, and the types of data collected.

Table 4.1: Data generation summary

Research question/s	**Type of data collected**	**Data source**	**Method of collecting data**
R.Q 1 What are grade 11 Physical Sciences learners' understanding of key concepts in electric circuits?	• Concept maps + Audio discussion transcripts • Interview transcript	• Concept map diagrams constructed by learners in their groups and audio recordings from the discussions. • Semi-structured interview transcript	• Learners collaboratively constructed concept maps and their discussions were audio recorded • Semi-structured interview
R.Q 2 How have grade 11 Physical Sciences learners' understanding of key concepts in electric circuits developed as they collaboratively constructed concept maps to deepen their knowledge of these concepts?	• Concept maps + Audio discussion transcripts	• Concept map diagrams constructed by learners in their groups and audio recordings from the discussions.	• Learners collaboratively constructed concept maps and their discussions were audio recorded

4.6.4. Action research cycles

As previously mentioned, this study followed an action research design. Mertler (2009) suggests that action research is the recommended approach for teachers who want to study their own classrooms, for example, their own instructional methods, their own learners, and their own assessments in order to better understand them and improve their quality. The nature of action research affords teachers an opportunity to engage in the process of finding solutions to the problems they experience in the classroom. Studies reveal that action research possesses certain characteristics that are different from other research approaches. These include methodological tools that are not rigid and can be modified to suit the demands of the research situation, cyclic research process, inquiry to social dimension, and emphasis on problem-solving (Craig, 2009; Kock, 2005; Marks, 2012). According to McMillan and Schumacher (2014), action researchers follow four phases when conducting their study: (1) selecting a focus or issue to study; (2) collecting data; (3) analyzing data; and (4) acting based on the results. However, action research has been criticized by scholars such as Kock (2005) who argue that the main problem with action research is that when results are left unchecked, they can become laden and subjective. The tendency for teacher-researchers to be over-involved to an extent of personal biases when analyzing the findings, time consumption, vulnerability to pressure, exhaustive data analysis and unclear initial research question which needs to be refined thereafter depending on initial findings, are some of the flaws inherent in the approach (Mertler, 2009). Despite such weaknesses, however, action research was still a viable design for this study as I aimed to improve my effectiveness in the classroom by helping learners understand electric circuits. This study included three cycles: planning, action, and reflection on action. To make it easy to follow the cycles which characterize the action research used in this study, I have made a brief outline of the research strategy (see Figure 4.1. in the next page) which was adapted from (No Lectures on-Campus, 2002).

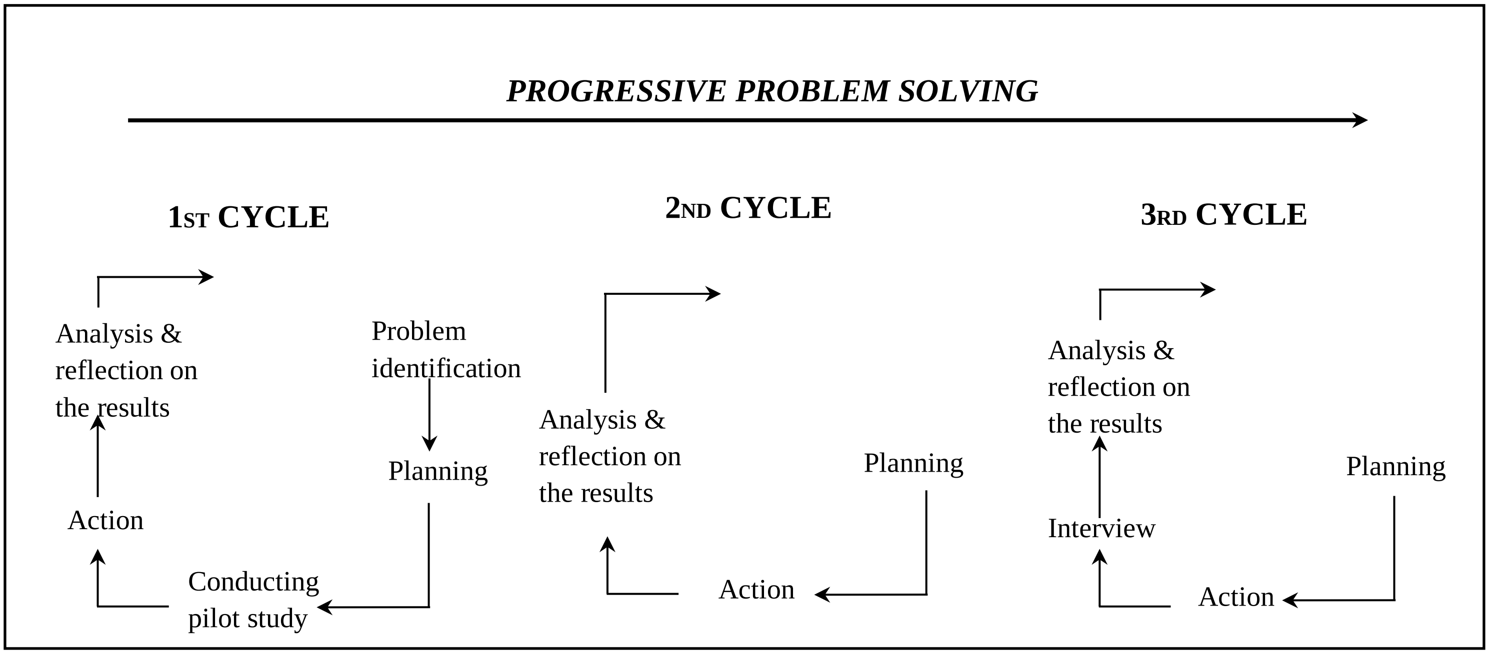

Figure 3.1.: Spiral of Action Research Cycles. Action research results from spiral research cycles, starting with a process of identifying a problem area (No Lectures on-Campus, 2002)

The first cycle:

The first cycle of the research process was guided by the literature review, diagnostic reports from the Department of Education, and my teaching experience. This helped me to identify the problem, which, in this case was learners' difficulties in understanding key concepts in electric circuits. This was followed by the formulation of the research aims before finalizing my research questions and deciding on the approach to use for this study. I also had to make plans regarding which data collection methods and instruments to use.

Determining the instruments to use in this study

To determine the instruments for this study, I first reviewed the literature and found that learner construction of concept maps was highly recommended by many scholars as a viable tool to help reveal their understanding (Govender et al., 2016; KiliÇ & ÇAkmak, 2013; Novak & Gowin, 1984). I also searched for studies on the use of concept maps in electric circuits and found that collaborative concept mapping results in meaningful learning of this topic and can be used by researchers to gather reliable data on learners' understanding or when diagnosing alternative conceptions that they may hold (van Boxtel et al., 2002). This was in line with the purpose of my study as I aimed to: examine my grade 11 Physical Sciences learners' understanding of the key concepts in electric circuits; deepen their understanding of this topic through collaborative learning and address any identified alternative conceptions that they might hold.

Literature also revealed that a combination of instruments used to collect data by researchers who conducted their studies on concept mapping included diagrams (in the form of concept maps), video recordings, audio recordings, and sometimes interviews (Govender, 2015; Govender et al., 2016; van Boxtel et al., 2002). I chose to make use of concept maps that were collaboratively constructed by learners in groups of five (5) along with audio recordings to compensate for the weaknesses of concept maps, and for economic reasons. Tessier (2012) argues that the benefit of combining audio recordings with other instruments is that it increases the effectiveness, efficiency, and economy of qualitative data management. Thus, the decision to combine the two instruments meant that I was going to analyze both the concept map diagrams and audio transcripts as I sought to answer my research questions.

The study also made use of a semi-structured interview to gather data on learners' conceptual understanding of key concepts in electric circuits. Questions set in the interview helped answer my first research question: What are grade 11 Physicals Sciences learners' understanding of the key concepts in electric circuits? The rationale for using this instrument was informed by the literature and the purpose of this study, and is explained in detail in section 4.6.2 above. Important considerations whilst finalizing the instruments before piloting were:

- The syllabus on the topic of electric circuits that learners were supposed to cover. Each concept mapping session had to be aligned with the content that learners were expected to have covered in terms of the work schedule.
- Duration of each concept mapping session. Each session was to be conducted after school for one hour, and learners were allocated this time to complete their concept map construction because many of them lived far away from the school and had to ride taxis home.
- The circuit diagram presentation in the PhET simulations for the Predict-Observe-Explain tasks. I had to make sure that the simulated diagrams for the Predict-Observe-Explain tasks were clear and consistent in their representation. The decision was thus taken to design diagrams which were similar to those that learners were already familiar with from their textbooks. However, using a simulation program also provided a ‘life-like’ representation of circuit diagrams which assisted learners to quickly grasp what was happening. This was done to reduce problems referred to by Lombard and Simayi (2019) related to interpretation of electric circuit diagrams.

My planning concluded by the drafting of lesson plans (including teaching activities), and drawing up the time frame for conducting the study, as shown in Figure 4.2. in the next page.

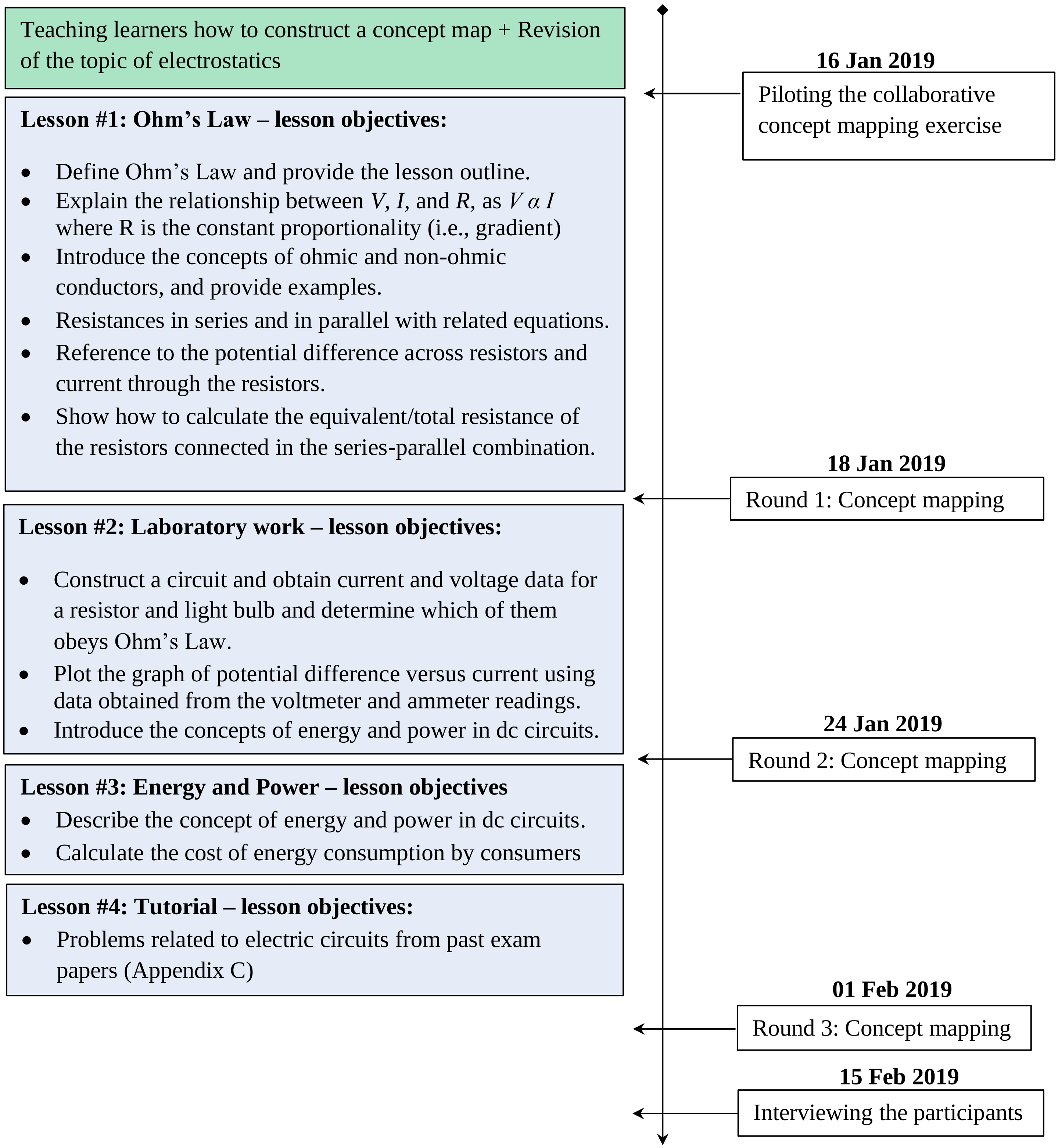

Figure 4.2.: The time frame for covering of the topic, piloting, summary of lesson objectives and data collection

Teaching learners how to construct a concept map

Before the actual concept mapping began, I taught the whole class how to construct a concept map. This was done so that learners could be introduced to the concept mapping learning strategy. I also took this opportunity to revise important concepts in the topic of electrostatics as it forms the basis for the understanding of key concepts in electric circuits. During the lesson, I gave learners a list of concepts and explained to them the basics of the concept mapping strategy as described by Novak and Gowin (1984, p. 37). We then constructed a concept map together, with everyone helping determine which concepts were related, and giving reasons. The outcome of this lesson is shown in Figure 4.3. below in the form of a concept map.

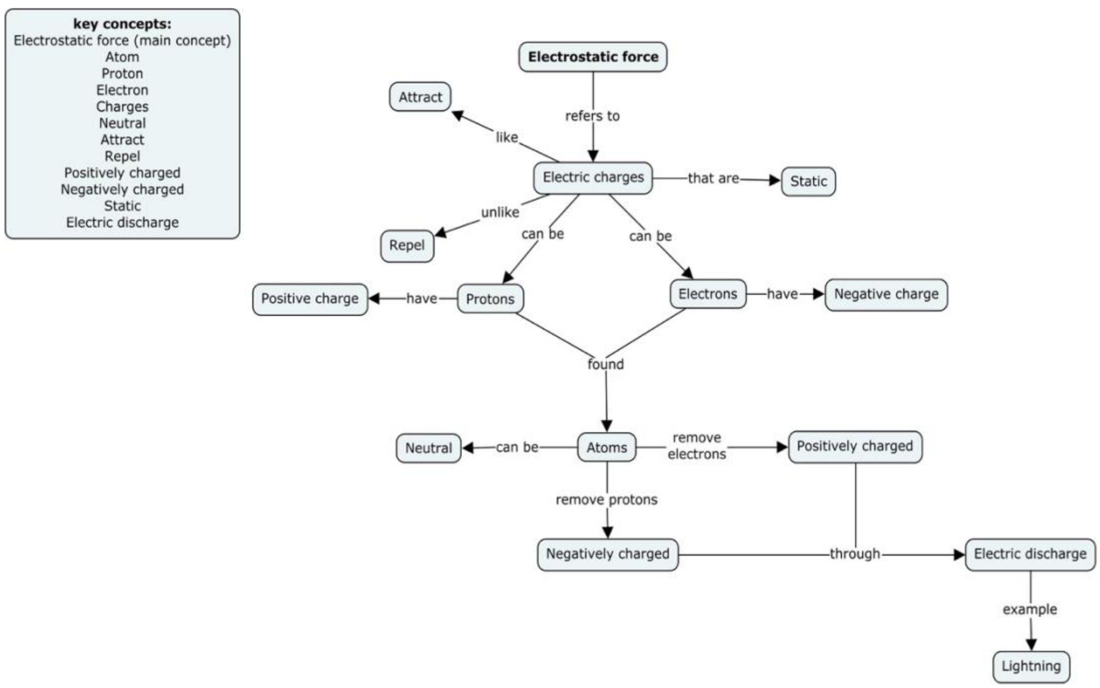

Figure 4.3.: Electrostatic force concept map constructed with learners

Piloting the collaborative concept mapping exercise

Collaborative concept mapping was field-tested with the 20 learners who had agreed to participate in the study and signed consent forms. I selected the same batch of learners for the pilot study and data collection because I wanted to familiarise them with the concept mapping strategy for learning concepts. I also needed to sort them into groups early, and check whether there were any potential problems or possible issues amongst members of each group. It was agreed that we would make time after school to meet for a lesson in preparation for concept mapping. The 20 participants were divided into 4 groups of 5. A PowerPoint presentation was prepared, based on the strategy developed by Novak and Gowin (1984) on the construction of concept maps (see Appendix A). The lesson included an activity which served as a pilot exercise for collaborative construction of a concept map. Learners were given an activity where they had to read a passage about electricity basics. They were then asked to identify key concepts, note some linking words and concepts that were most important to the storyline (and relevant to electric circuits) before constructing their concept maps in groups. Due to insufficient funds, I was unable to buy audio recorders for recording concept mapping discussions. The collaborative construction of a concept map was done to check whether the chosen instrument would be able to generate reliable data. Moreover, it was also important (for planning purposes) to check how much time learners took to construct a concept map with their peers.

At the end of the concept mapping activity, I collected four concept maps drawn by the groups for analysis. As a result of observing learners collaboratively construct a concept map and the analysis of these maps, the following was decided:

- increase the length of time for concept mapping exercise;
- use cellphones to record audio discussions;
- allow learners to come up with the concepts they deem important and relevant to the topic rather than giving them a list (this idea was important in examining whether the teaching that had taken place in class was effective and whether learners understood the key concepts discussed); and
- the concept maps would need to be redrawn using CMapTool© electronic software for clear presentation in my thesis.

Piloting the semi-structured interview questions

As explained in section 4.6.2. above, a semi-structured interview was to be conducted using the Predict-Observe-Explain (POE) technique (Marks, 2012). Four (4) interview questions (with sub-questions) related to understanding of key concepts in electric circuits were chosen from Marks' (2012) study. The set of questions was already field-tested in Marks's study but I felt it necessary to pilot it in a different context for my study to check whether they would be suitable. Before piloting, I made a few changes to the questions to ensure that they served the purpose for my study. Instead of focusing on probing learners' mental models, I paid special attention to probing learners' prior ideas in electric circuits. For instance, in an interview about the behavior of an electric circuit when a switch is closed, Marks (2012, p. 210) asked learners:

"What do you imagine is happening within the circuit? What mental model do you have as you give this answer?"

I rephrased this question and asked:

"What do you imagine is happening within the circuit? What ideas do you have as you give this answer?"

The reason for probing learners' ideas about what happens inside an electric circuit was to gauge their understanding of the operations of different components of a circuit. This was done intentionally because the assumption was that, if learners understood the functions of different components of a circuit, they would have ideas about the relationships between concepts. For example, the battery (component) is the source of energy for the charges found in every part of the circuit. This energy causes charges to flow, thus producing the electric current (key concept), which can be detected and measured by the ammeter (another component). The electric current experiences a resistance (key concept) when it flows past a resistor (a component of a circuit) and the energy they carry with them can be 'used up' or transferred in each resistor. Hence, measure of the transferred energy between two points in a circuit is known as the potential difference (key concept). Such a description would indicate understanding of key concepts in electric circuits.

The decision was to conduct the interview after all the teaching activities and concept mapping sessions. This meant that I had more time to pilot some of the key questions during my normal teaching with the whole class. I did this to check whether learners encountered difficulties in answering these questions and if there were any language barriers. The piloting of the interview questions also served as practice in conducting an interview with several learners in one time. No problems were encountered with regard the questions that were set to be administered during the interview.

The POE technique was also piloted in my teaching where the whole class was divided in groups of about eight (8) learners per group. I asked them to predict the behavior of a circuit if one of the components (e.g. resistor) was added, removed or arranged in a different way. Learners were then given a chance to discuss amongst themselves and to speak up when they have what they thought was the correct prediction. Once sufficient answers were given, I then played the simulation to reveal the correct prediction. Those who got it right clapped their hands with excitement. The POEs thus made learners engage in the learning process in a manner that was fun and playful. I piloted the POEs to check whether this study would benefit from these tasks when used during the group interview and that the simulations program was a viable tool to work with. It was observed that when learners participated in groups, they benefited from discussing and learning from each other. However, there was a disadvantage for those who were shy to speak as they could not voice their ideas and were often overlooked by those who found it easy to speak their mind. This observation was also made by Marks (2012) and was overcome by conducting POEs on one-to-one basis for his study. However, circumstances forced my study to have a group semi-structured interview instead of one-on-ones. Having noted the problems during the piloting of the POEs, I took a decision to give each learner during an interview an opportunity voice their views instead of having them discuss ideas.

The next stage of the first cycle included actions taken. I conducted an introductory lesson on electric circuits, which was followed by learners collaboratively constructing concept maps. I collected four (4) concept maps (each drawn by individual groups) for analysis and transcribed verbatim the audio recordings from the group discussions. The analysis of the first set of concept maps can be summarized as follows:

- Ohm’s Law was expressed as an equation and connected to ohmic conductors.
- Key concepts such as potential difference and current were connected and the relationship expressed was meaningful.
- Learners stated that parallel resistors divide current equally (this idea is not always true because current flow also depends on the size of a resistor’s resistance)
- Learners used the terms ‘power’ and ‘potential difference’ interchangeably in their audio discussion, thus revealing an alternative conception.
- Learners regarded the battery as a constant current source rather than a constant voltage source. This is an alternative conception documented in the literature (Nkopane et al., 2011).

Reflecting on the concept maps drawn, and the events of the first cycle, it was apparent that learners had several alternative conceptions. I then revised my lesson plan for the next cycle to include the teaching that addresses these alternative conceptions for the next cycle. In Figure 4.4 below, I have itemized everything that I did in each stage of the first cycle.

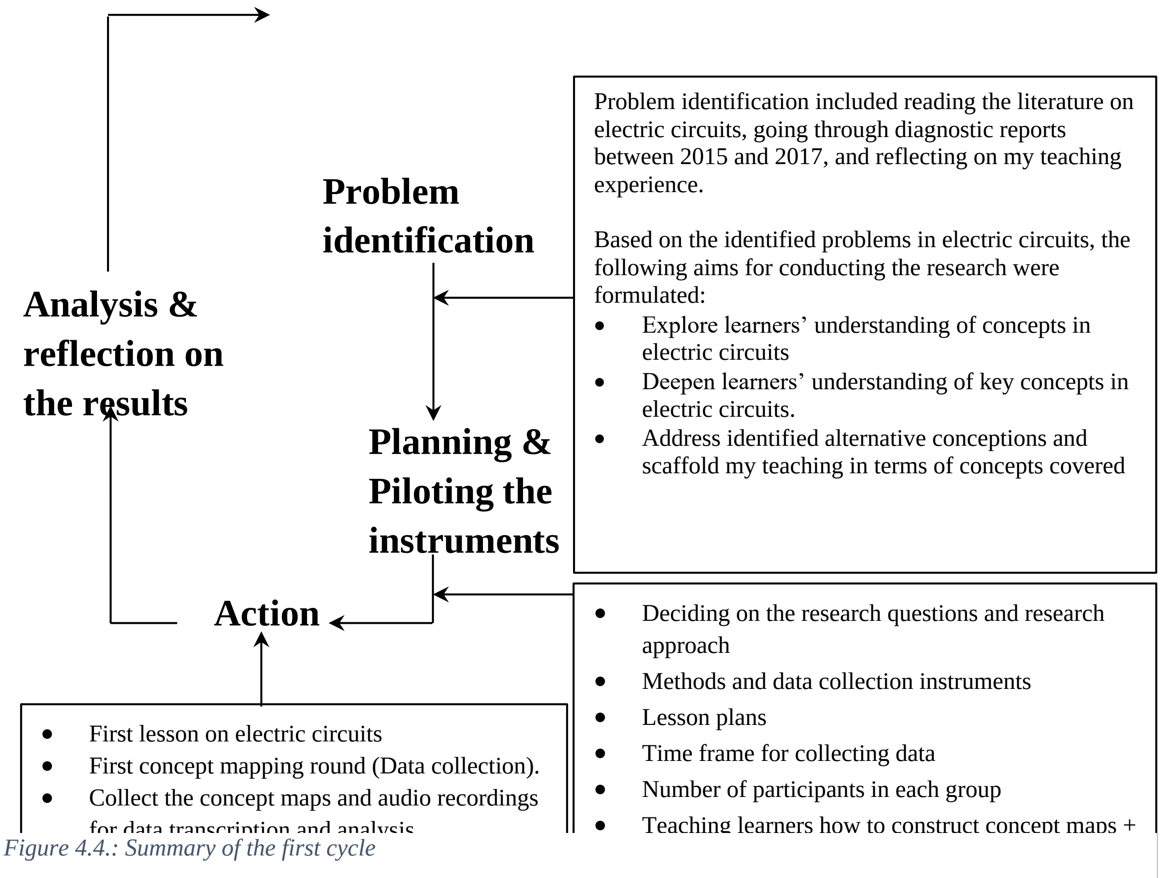

Figure 4.4.: Summary of the first cycle

The second cycle

In the second cycle, there were two participants who withdrew from the study citing personal reasons. However, there were no changes made to the groups to which they had previously belonged as this did not affect them in terms of their ability to construct a concept map. The planning in this cycle involved the teaching activities which included addressing challenges and alternative conceptions that learners may hold as identified during the previous cycle. I incorporated the PhET simulations program in my lesson as part of the intervention to show how key concepts such as current, resistance and potential difference are related to each in terms of Ohm’s Law. The use of demonstrations from the simulation program was aimed at addressing the alternative conceptions that were diagnosed in the first round of concept mapping. It also gave me an opportunity to pilot the POE technique I was going to use during the interview later on in the study.

In addition, I felt it necessary at this stage to have learners do an informal experiment. In the CAPS document, it is recommended to do an experiment on obtaining current and voltage data for a resistor and light bulb and determine which one obeys Ohm’s Law. However, looking at the evidence from their concept maps, learners did not appear to have difficulties in identifying ohmic and non-ohmic conductors as well as understanding these concepts. Therefore, I changed this experiment based on the need to further help improve my learners’ understanding of key concepts in electric circuits. The experiment was done by the whole class. Learners set up in groups and were asked to construct a simple circuit using the apparatus provided. The aim of the experiment was to determine the relationship between current going through a resistor and the potential difference (voltage) across the same resistor (see Appendix C). Upon the conclusion of the lesson, time was arranged with the 18 participants for round 2 of collaborative concept mapping.

During our second meeting, participants were given back the concept maps they had constructed in the first round. They were then asked to add, subtract or edit any information they felt was relevant in light of the learning that had taken place after the production of the first concept maps. I collected 4 concept maps, transcribed verbatim the audio recordings related to them, and analyzed both results. The following was revealed from the data:

- Alternative conceptions that were diagnosed in the first concept map were not removed.
- The use of prior knowledge was most evident from the examples learners provided in their maps, and from their audio discussions where they articulated their points on how they viewed certain relationships in the study of electricity.
- Group 3 made use of the ‘mention and define’ style to construct their concept map.
- Learners showed good understanding of how current and voltage behave in parallel and series circuits.
- Key concepts (i.e. potential difference, current, and resistance) were fairly accurately connected with each other. However, Group 3 described their relationship by merely stating Ohm’s, Group 1 showed the effect of a resistor on a current and voltage-current relationship, Group 2 showed the current-resistance relationship only, and Group 4 did not show how these concepts are related.
- In the discussion, Group 1 referred to windmills as ‘conductors’ of electricity (this is an alternative conception). Learners were also confused about the concept of hydroelectricity.

Reflecting on the results and the events of the second cycle, I noticed that learners’ overall understanding of electric circuits had slightly improved when compared to the first cycle. But participants were still unable to clearly depict the relationship between key concepts in their map. Nevertheless, participants were now more confident in articulating their points during discussions. However, the discussions often strayed away from the topic, and sometimes were not related to the topic at all. In some groups, participants spent most of their time debating one point. This affected the amount of information they could add in their map before the time was up. Nevertheless, data from this cycle showed positive improvements with fewer alternative conceptions diagnosed apart from those that remained unchanged from the first concept map. In Figure 4.5. below, I have itemized everything that I did in each stage of the second cycle.

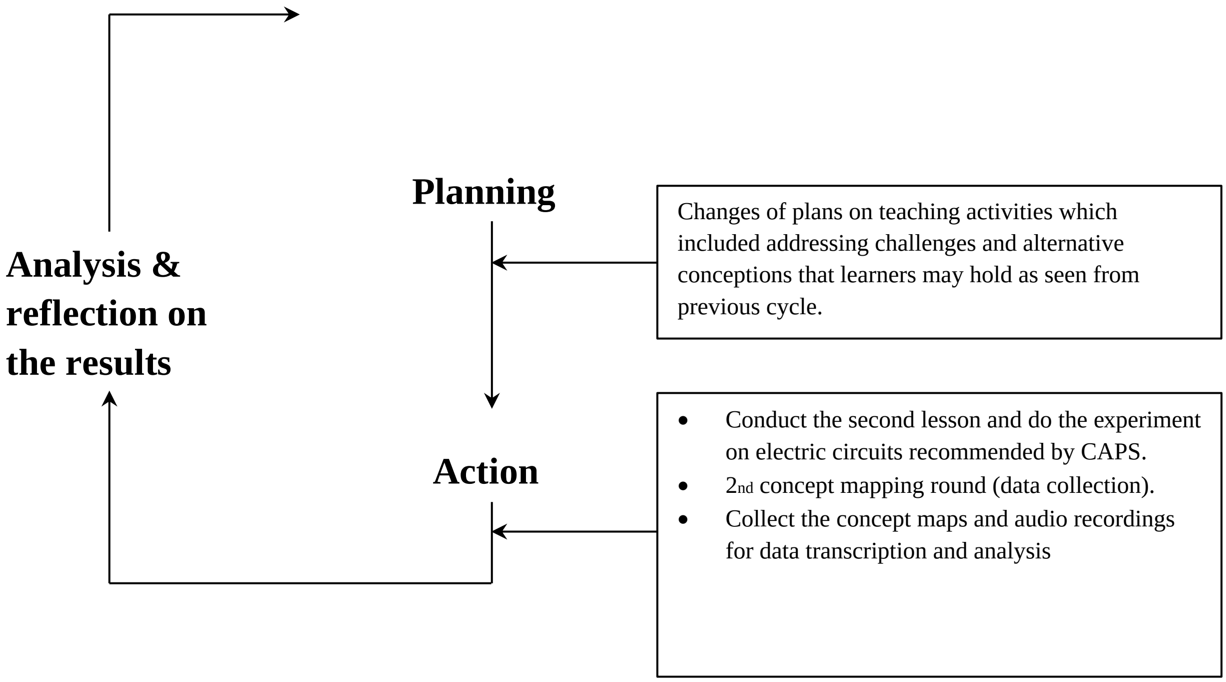

Figure 4.5.: Summary of the second cycle

The third cycle

The results from the second cycle influenced the choice of teaching activities to be used in my lesson for this cycle. For example, I made use of past exam papers to help learners understand the application of Ohm's Law (see Appendix C). The reason for this was to further deepen my learners' understanding of this topic, and to help them practice exam techniques. I also addressed the alternative conceptions that were diagnosed in the concept maps through meaningful class discussions. The confusion about windmills and hydroelectricity was addressed by showing my learners selected YouTube videos (see link 1: https://youtu.be/qSWm_nprfqE and link 2: https://youtu.be/q8HmRLCgDAI).

After timetabled teaching had concluded, and all the prescribed content in this topic had been covered, I met with the participants for the 3rd round of concept mapping. However, Group B opted not to participate in this round because they felt they had added sufficient information to their concept map. This means that three groups (B, C, and D) participated in this round of CCM.

Participants were given back their original concept maps for editing. I encouraged them to add or subtract any information where they felt necessary and hoped that they would remove the alternative conceptions that were found in the concept map drawn in the 1st and 2nd rounds since they had been addressed during timetabled teaching. There were few additions made in this round and no changes were made to the alternative conceptions. Before CCM began, learners asked me for the apparatus they had used during the laboratory work because they wanted to further verify some of the data collected when doing the experiment. I allowed this in the hope that they might help learn more about this topic as they worked with the equipment. However, this meant little time was spent on constructing concept maps. As a result, few concepts were added by Group B and D, except that Group D seemed more interested that Group B in constructing their concept map than using the apparatus.

At the conclusion of the final round, I thanked my learners for participating in the study and collected the final complete concept map that each group had constructed. I then began the process of analyzing the concept maps and transcribing the audio transcripts from the discussions. When listening to the learners' audio recordings for transcription, I noticed that there were certain issues with the sound on the cell phones I used for recording Group C. This made it difficult to hear their discussions. I therefore had to rely solely on their concept map, which, fortunately, provided me with the data I needed. The analysis of all four completed concept maps and audio recordings revealed the following:

- Alternative conceptions that were diagnosed in rounds 1 and 2 were still present in their concept maps.
- Learners used equations to represent relationships between concepts. For example, the relationship between Power, Energy, and Time was represented as P = E/t
- Little information was added by Group B and D in their final concept maps whilst Group C showed some improvement in the number of concepts and propositions incorporated into their concept map.

The next phase of this cycle consisted in conducting an interview with four (4) participants, one (1) from each of the four (4) groups. The interview was conducted in order to gauge learners' conceptual understanding of key concepts in electric circuits and would help answer my first research question. As mentioned in section 4.6.2. above, the semi-structured interview was conducted using a POE technique. There was only one session which lasted an hour and half (1h30min.) and all four (4) participants were present. The interview was guided by a set of four (4) questions. Each question had sub- questions and follow-up questions. Participants were all asked the same question, and allowed to respond individually. The interview was audio-recorded and transcribed verbatim for analysis. Findings from the interview are discussed in detail in Chapter 5 of the study. After the interview, I thanked the participants for participating in my study and wished them well. Below (Figure 4.6) I have itemized everything that I did in each stage of the third cycle.

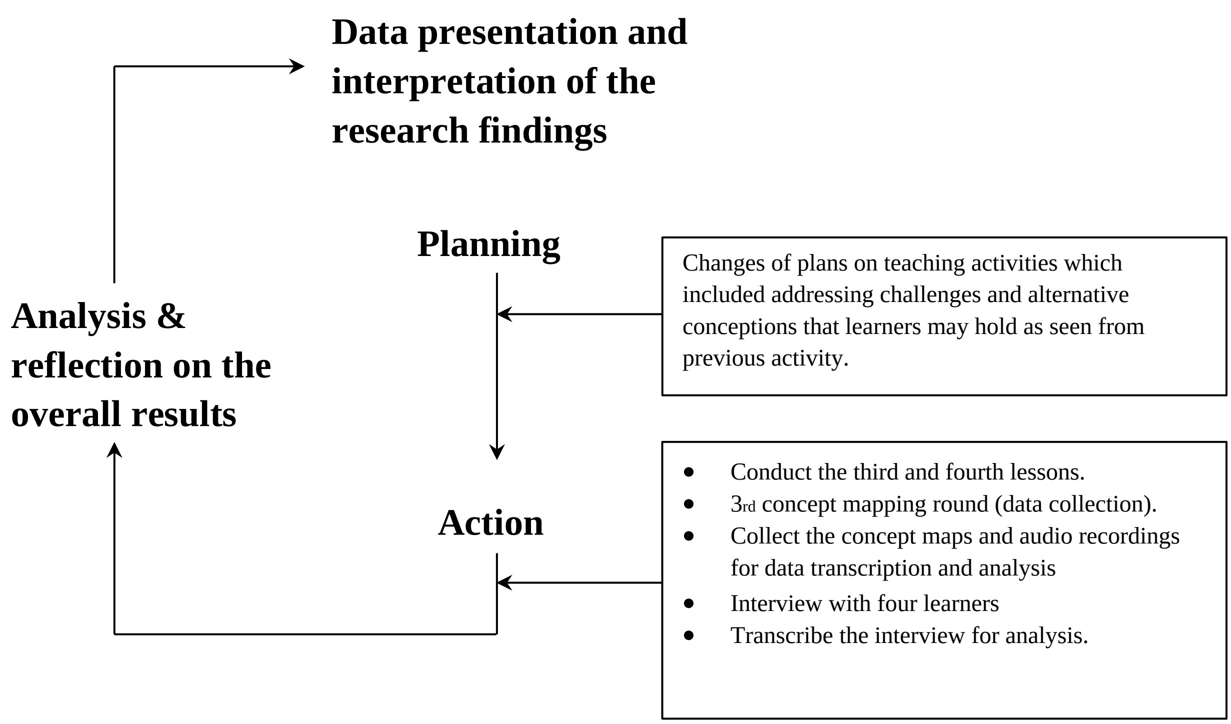

Figure 4.6.: Summary of the third cycle

4.7. Data Analysis

Data collected in this study were in the form of participants' collaboratively constructed concept maps, audio transcripts from the concept mapping discussions, and interview transcripts. For clear presentation, concept maps that were initially drawn with pen and paper by learners in their groups were redrawn by the researcher exactly as they were, this time using the CMapTool© (CMapTools, 2018) (see Appendix J). The NVIVO (NVIVO 11, 2017) was used for the coding of the semi-structured interview and transcripts from the discussions. In this section of the study, I will be presenting each data set collected and indicating how it was analyzed. First, I present the analysis of concept maps, followed by the analysis of concept mapping audio discussion transcripts, and, finally, the analysis of the semi-structured interview. I conclude the section by highlighting the ethical considerations as well as outlining how validity and reliability were ensured in this study.

4.7.1. Analysis of concept maps

The analysis of concept maps was used to find answers to both research questions:

1. What are grade 11 Physical Sciences learners' understanding of key concepts in electric circuits?
2. How have grade 11 Physical Sciences learners' understanding of key concepts in electric circuits developed as they collaboratively constructed concept maps to deepen their knowledge of these concepts?

To lay the ground for collaborative concept mapping (CCM), the participants were placed in four (4) groups of five (5) learners each. Each group was allocated an A3 paper sheet, as well as several pencils and erasers to use when constructing its concept map over three CCM rounds. Learners were expected to add information to the already existing concept map during the three rounds. For the purpose of data presentation, a concept map drawn at each stage by each group was presented. I looked for evidence of learners' understanding of the relationship between key concepts, and the evolution of their understanding as they received teaching, constructed concept maps, and received further teaching and remedial lessons, as the study progressed. The aim of this study was to gain insight into learners' understanding as they collaboratively constructed concept maps to deepen their understanding of this topic. Novak (2010) contends that concept mapping provides a learning platform from which a learner can acquire a deep, meaningful understanding of the materials being studied by constructing his/her own meaning using his/her prior experiences. Studies on concept mapping have shown that small groups working collaboratively to construct concept maps have produced more coherent maps (Govender et al., 2016; van Boxtel et al., 2002; Wanbugu, Changeiywo, & Ndiritu, 2013). These scholars argue that learners who are actively engaged through their group interaction tend to take more responsibility for their own learning and become highly motivated towards mastery, rather than performance-based learning. This study adopted a qualitative design. Data in the form of concept maps was initially constructed by participants using pen and paper, and was later captured electronically by the researcher using the CMapTool©. The software was used in an effort to present more clearly the concept maps constructed by participants. The quality of a concept map drawn using this program is far better than if produced by pen and paper, thus enhancing the validity of the data (Govender et al., 2016). Concept maps constructed by participants in their groups informed me of their understanding of the relationships between key concepts such as potential difference, resistance, and current.

The qualitative analysis of concept maps constructed by participants in their groups focused on looking for evidence of the following aspects: network of concepts and links, scientific propositions, integration of prior knowledge with new knowledge, and alternative conceptions diagnosed from the concept map. These aspects were informed by the Novak and Gowin (1984) analytical framework for concept map analysis, and were used in Chapter 5 for data presentation.

In order to mark the concept maps during the three research cycles, I compared learners' concept maps using the criterion concept maps and a table which showed related concepts that were expected after teaching and learning had occurred (see Appendix K). These tools helped me to check whether learners were doing the right thing and formulating the correct relationships in their concept maps. Bak Kibar et al. (2013) explains that the researcher's criterion map could be used to compare learners' concept maps in terms of concepts/propositions, hierarchy/connection levels, cross-linking and so on, and also to analyze whether or not they established correct relationships and wrote meaningful statements. For example, Figure 4.7. below is a concept map drawn by Group B during the 1st round and I demonstrate how it was marked and then analyzed for understanding of key concepts:

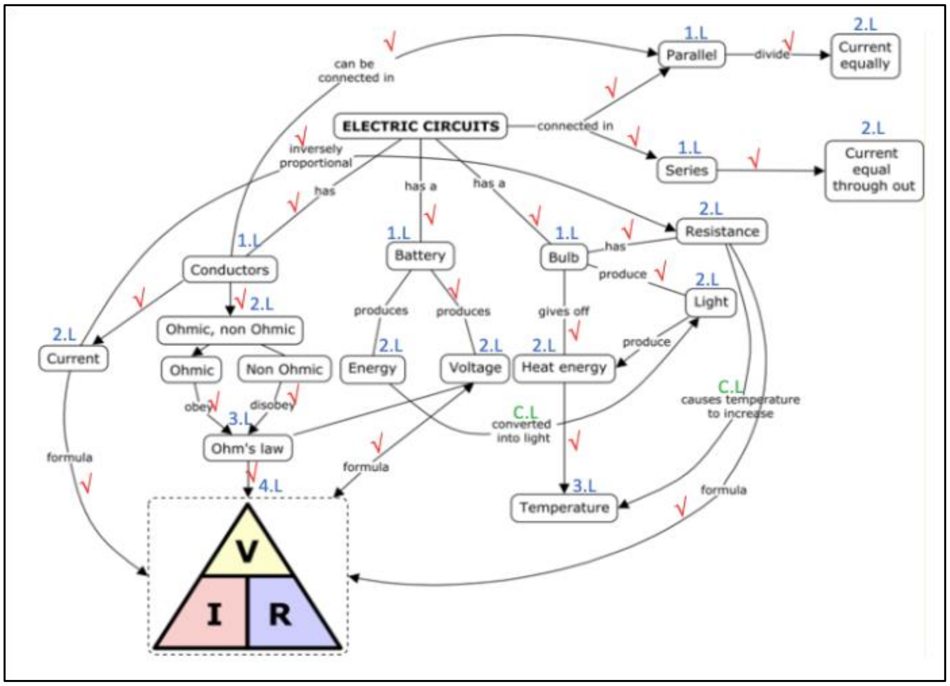

Figure 4.7.: Group B – Round 1 concept map

The analysis of this concept map began by looking at the network of concepts and links made by the participants. In their concept map, Group B chose the term ‘electric circuits’ as their main concept; and their overall concept map had three (3) connection levels. Participants related the following concepts from level 1 and 2: conductors with current/ohmic/non-ohmic, battery with energy/voltage, bulb with resistance/heat energy/light, electric circuits with parallel/series connections. They went on to relate the concepts ohmic/non-ohmic to Ohm’s Law from the third level. Heat energy was related to temperature, the resistance key concept was also related to temperature, parallel/series connections were related to the current key concept from level 2, and current was also related to resistance from level 2. Group B also made two cross-links between energy and light, as well as resistance and temperature. This revealed creative thinking and understanding of concepts in different domains (Novak & Cañas, 2006b). Most of the connections made in this concept map were also present in the criterion concept map. However, participants in this group did not provide all the concepts expected in their initial map. For instance, they failed to mention the voltmeter (showing how it relates the voltage/potential difference), a switch, charges (how they relate to current, ammeter, and electrical energy), and examples of conductors (such as copper, aluminum, etc., and how they relate to resistance and current).

The second unit of qualitative analysis of participants' collaborative concept map involved looking at the scientific validity of the propositions made by participants. The analysis focused on whether learners had made correct or incorrect propositions in the concept maps. To check the correctness of the propositions, I used a criterion concept map that was created for comparison. The above concept map constructed by Group B (Figure 4.7.), shows that learners made the following correct scientific propositions:

- parallel-connected resistors split the electric current;
- the electric current remains the same in the series-connected resistors;
- ohmic conductors obey Ohm's Law;
- non-ohmic conductors do not obey Ohm's Law;
- the battery produces energy or voltage;
- the Ohm's Law equation is given as V = I.R.;
- the bulb produces heat energy;
- heat energy is converted into light;
- the bulb has resistance;
- the bulb produces light;
- resistance causes heat to increase; and
- current is inversely proportional to resistance.

The following concepts were also connected but without any linking words:

- heat energy and temperature; and
- conductors and current.

In such cases, the analysis of concept maps was assisted by the audio recordings from the discussions, which revealed ideas that learners discussed but did not incorporate into their concept map. For example, two learners had the following discussion:

Ntando: Yabo la kwi conductor asiqale sithi i-conductor angithi ihambisa i-current. Shuthi mesithi conductor its where current flows angithi? [*You see here in the conductor, we can start by saying, the conductor allows current to flow. It means a conductor is where current flows right?*]

Melusi: Ay it gives way to current baba, ngaphandle kwe-conductor ngeke ihambe i-current ayikho i-current meyingekho i-conductor. [*Without the conductor there can be no current (flow)*]

Thabani: Ayikho i-current meyingekho i-conductor. [*There is no current if there is no conductor*]

The above excerpt shows learners discussing and important scientific proposition about the relationship between the current flow and a conductor, despite the fact that there were no linking words between these two concepts in their concept map. The propositions that learners in Group B made were correct and showed that they understood the relationships between concepts in the topic of electric circuits. However, there were a few missing propositions that learners were expected to note at this stage of the study, and these are: charges are electrons in the circuit; the electric current is the flow of charges; a switch opens and closes to control the movement of charges in a circuit; electric energy causes charges to move; and the potential difference is directly proportional to the electric current at constant temperature. Omission of these propositions did not indicate shallow understanding of the relationship between key concepts. On the contrary, it indicated that learners understood *some* concepts well enough to mention them in their concept map. It was therefore expected that they show the missing relationships in the next round of concept mapping, as they built on their existing concept map.

The third unit of qualitative analysis of Group B's initial concept map focused on looking for evidence of how learners integrated their prior knowledge with new knowledge as they constructed their map. Information related to this category was found in the audio transcripts from the discussions. The coding of the audio transcripts is discussed in detail in section 4.7.2. below.

The fourth and final qualitative analysis focused on diagnosing alternative conceptions that learners may hold. The idea that concept maps help reveal alternative conceptions is supported by numerous scholars who have used concept maps in their studies (Govender, 2015; Govender et al., 2016; Misfades, 2009). It was therefore important to look for alternative conceptions in the learners' concept maps as they helped reveal important evidence of the extent of their understanding. Group B's concept map used as an example in this section did not contain any notable alternative conceptions.

4.7.2. Analysis of audio discussion transcripts

The analysis of audio discussion transcripts was used to find answers to the first research questions:

1. What are grade 11 Physical Sciences learners' understanding of key concepts in electric circuits?

Data in the form of audio recordings transcripts was captured electronically, transcribed verbatim and then coded into the NVIVO software (NVIVO 11, 2017). Since audio discussion transcripts and concept maps were analyzed concurrently, I made use of the same themes from the concept maps for coding of this data. However, I excluded the network of concepts and links theme because that theme could only be observed from the concept maps. For example, under the category of scientific propositions, learners had numerous discussions about important relationships between key concepts in electric circuits. An excerpt below is a good example of a scientific proposition made by learners in Group A in their discussion in the first round:

Lungile: Sofike sithi ilo icurrent mesesifaka ilink sithi directly proportional kuleyonto le..[*We will start by saying "current" and then a link that says directly proportional to this…*]

Amanda: I-directly proportional kwini? [*It is directly proportional to what?*]

Lungile: Potential different is directly proportional kwi current e-flow(ayo) through i-conductor while i-temperature i-remainer constant angani? [*Potential difference is directly proportional to current through a conductor while temperature remains constant right?*]

Amanda: Shuthi sesizokwazi ukuthi sisho ukuthi itemperature ine affect kanjani kwi circuit [*that means we will be able to say what kind of effect a temperature has on a circuit*]

Lungile: Shuthi mawukuthi i-temperature iyashintshashintsha ayi obey ilentunjana i Law ye Ohms [*that means if the temperature changes, it (conductor) does not obey Ohm's Law*] [Group A: 1st Round]

The above discussion revealed crucial evidence of learners' understanding of the relationship potential difference and the electric current, and this helped answer my first research question.

4.7.3. Analysis of the semi-structured interview transcript

The key aspects taken from the interview schedule provided me with conceptual categories which I used to find answers to the 1st research question:

1. What are grade 11 Physical Sciences learners' understanding of key concepts in electric circuits?

The data from the semi-structured interview was analyzed and inductive reasoning was used to code participants' responses according to the categories which emerged from the available data. These were in relation to the interview protocol on learners' understanding of key concepts in electric circuits (see Appendix B). The interview transcript was analyzed for individual learners' perspective about key concepts in the electric circuits topic, which they had already covered. The key aspects of conceptual understanding I was looking for were found to comprise of ideas about current in a simple circuit, resistance in parallel and series circuit, meanings attributed to voltmeter readings, and differences between current and voltage in an electric circuit. At the end of the NVIVO coding, I had an indication of each learner's perspectives regarding their understanding of key concepts in electric circuits topic they had learned. The coding here informed my first research question.

4.8. Ethical considerations

Participants were informed that their involvement in the study was voluntary and that they had a right to withdraw from the study at any given time. However, they were encouraged to take part in the study as they would benefit from being equipped with learning strategies to help them perform better in the subject. Silverman (2006) stresses that before the research takes off, great attention ought to be paid to the ethical issues involved. In an effort to obtain informed permission for the research, I wrote and sent letters to the school principals (see Appendix G), parents of all participants (see Appendix E) and to participants themselves asking for permission from each of them (see Appendix F). I then requested permission from the Department of Basic Education in Pietermaritzburg to conduct a study in one of their institutions in the district.

Permission was granted and accompanied by reference a number (2/4/8/1648) (see Appendix H). I also applied for ethical clearance at the University of KwaZulu-Natal (Appendix I), which was granted to me with a reference number: HSS/2096/018M. Moreover, only a school and participants with duly signed response letters was allowed to participate in the study. To ensure anonymity, I used pseudonyms for the school and for each of the participants involved in the study I made sure that all the data collected was made available to other parties, including teachers of the participating school. I did not discuss anything regarding the participants, whether positive or negative, with the school authorities. Moreover, all data that I collected was stored by my supervisor at UKZN and after 5 years, all data will be shredded or incinerated.

4.9. Trustworthiness

To ensure validity and reliability of the findings, this study employed the triangulation strategy by making use of multiple data collection instruments, namely, concept maps, audio recordings, and a semi-structured interview. McMillan and Schumacher (2006) define triangulation as a cross-validation among data sources, data collection strategies and periods of time in order to determine the credibility of the research. Golafshani (2003) advocates the use of triangulation by stating that, combining multiple methods of data collection leads to more valid, reliable and diverse construction of realities in a qualitative research study. In this present study, each instrument was specially selected to compensate for the shortfalls and the limitations of the other (Shenton, 2004). The information that was not captured in the concept maps was found in the audio transcripts and the interview; this ensured that I obtained credible and reliable data to answer my two research questions. Moreover, I found it necessary to use different instruments to collect data in order to ensure the trustworthiness of the findings; for example, data which sort to explain the learners' understanding of concepts was captured from concept maps (visual data), audio transcripts (verbal data), and the semi-structured interview (verbal data). This approach provided me with a chance to have multiple perspectives of the same data for comparison of facts.

However, the triangulation strategy had its shortcomings due to the vast amount of data collected which needed to be sorted and analyzed (Flick, Kardorff, Steinke, Kardorff, & Steinke, 2004). I also had difficulties in coding data from the concept maps using the same codes from the audio transcripts because some of the important data could only be found in one source (either in the concept map or audio discussion) but never on both. This meant that I could not clearly match all the patterns for cross-validation all my findings.

In order to check the consistency of the findings and to eliminate any blind spots, I sought the help of my supervisor to review my findings. I also sought the help from my colleagues who have knowledge of research to scrutinize some of the aspects of my research methods to bring in new ideas and point out any weaknesses that might exist. Shenton (2004) recommends asking colleagues and peers with knowledge of research to review your findings as this may provide fresh perspective that enables the researcher to refine his/her work.

CHAPTER FIVE – PRESENTING THE GRADE 11 CASE

In the previous chapter, I discussed the type of data generated and how it was analyzed. In this chapter the data is presented. The four (4) groups of five (5) learners (A, B, C, and D) collaboratively constructed one (1) concept map each over three (3) consecutive 'rounds'. I start this chapter by describing the context of the case study, paying particular attention to the school and the learners involved. Secondly, I present the concept maps of the four (4) groups, showing how they developed and evolved over the said three (3) rounds. I describe how learners indicated concept relationships within their concept maps, using the categories informed by the chosen theoretical framework of social constructivism and concept mapping, which comprises a network of concepts and links found in the concept maps, scientific propositions found in the concept maps, integration of prior knowledge with new knowledge, and alternative conceptions diagnosed in the concept maps. The discussions from the concept mapping process are presented in the second analysis in chapter 6. Finally, I present data from the semi-structured interview using the themes that came from the available data.

5.1. Concept maps collaboratively constructed in each of the three rounds

1st round: Concept maps constructed by the 4 groups

The start of the first round of CCM preceded the teaching of electric circuits, which included the following aspects: the description and explanation of the Ohm's Law and its application in electric circuits (i.e., *V* = *I.R.*), the relationship between the potential difference, electric current and resistance as key concepts, the concepts of Ohmic and non-Ohmic conductors (as well as real world examples), the effect of resistances in series and parallel on the potential difference and electric current in a circuit, and the calculations involving the equivalent resistance of the series-parallel combinations (i.e., $R_{equiv.} = R_{series} + R_{parallel}$). Based on their knowledge of the related concepts in electric circuits, learners collaboratively constructed the following concept maps in the first round.

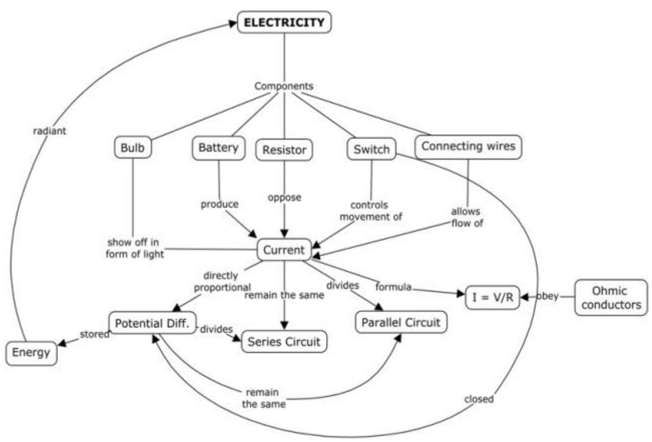

Figure 5.1.: Group A – Round 1 concept map

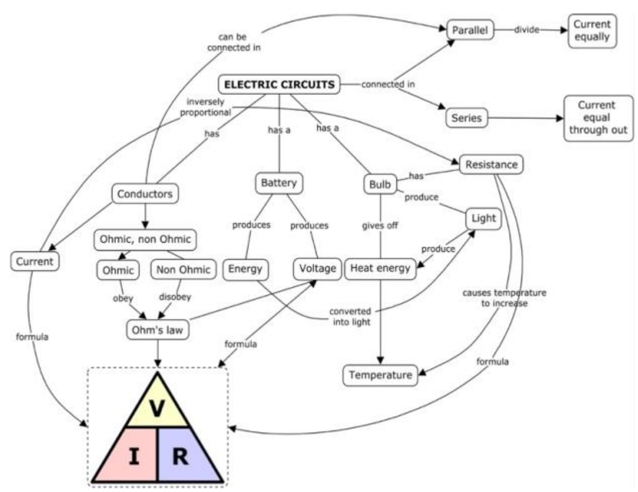

Figure 5.2.: Group B – Round 1 concept map

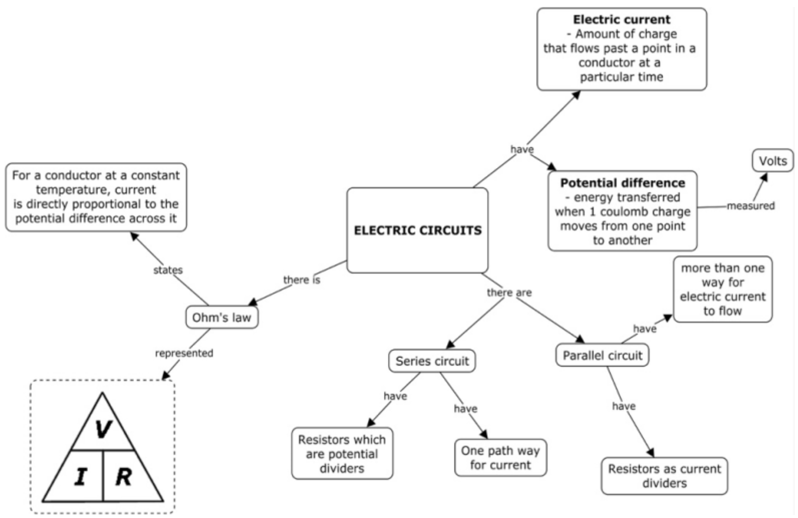

Figure 5.3.: Group C – Round 1 concept map

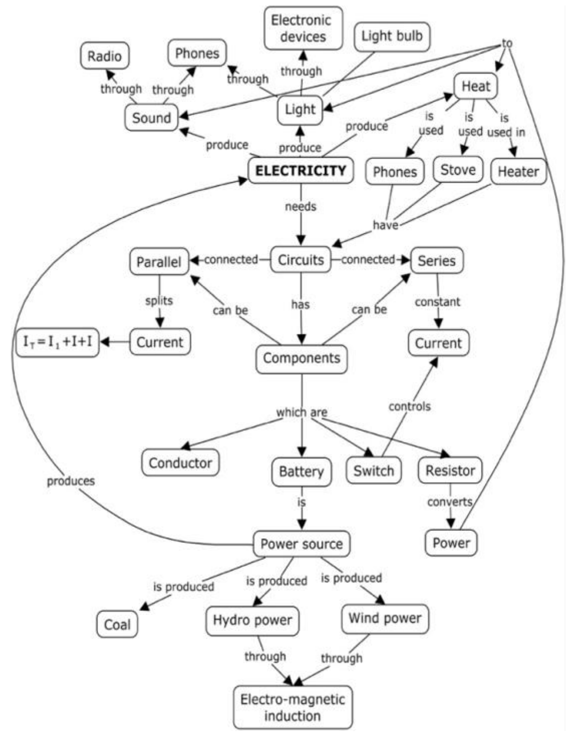

Figure 5.4.: Group D – Round 1 concept map

Looking at the above concept maps constructed by the four (4) groups in the first round, the following scientific propositions (in Table 5.1.) were expressed by learners based on the instruction that they had received.

Table 5.1: Scientific propositions learners expressed in round 1 concept maps

Group A	Group B	Group C	Group D
• Components of electricity are: bulb, battery, resistor, switch, and connecting wires. • Switch controls the movement of current • Connecting wires allow current to flow • Resistor opposes current • Battery produces current • Current shows off in the form of light from the bulb	• An electric circuit has a: conductor, battery, and bulb. • Electric circuits can be connected in parallel and series. • Parallel circuits divide current equally. • In series circuits, current is equal throughout. • Ohmic cond. Obey Ohm's Law	• Electric circuits have an electric current (amount of charge that flows past a point in a conductor at a particular time). • Electric circuits have potential difference (energy transferred when 1 coulomb charge moves from one point to another). • P.d. is measured in volts	• Electricity needs circuits. • Circuits are connected in parallel and series. • Circuits have components which are: conductor, battery, switch, and resistor. • Battery is a power source. • Power source is produced by coal, hydropower, and wind power through electromagnetic induction.

• Current is directly proportional to the potential difference (P.d) • Current remains the same in a series circuit • Current divides in a parallel circuit • Formula for calculating current is I = V/R • P.d. divides in a series circuit • P.d. remain the same in a parallel circuit • Closed switch shows P.d. • P.d. is a stored energy • Ohmic conductors obey I = V/R	• Non-ohmic conductors disobey Ohm's Law. • Battery produces energy & voltage • Formula for voltage, current, and resistance is V = IR • Bulb gives off heat energy. • Bulb has resistance • Current is inversely proportional to resistance. • Bulb produces light • Energy is converted into light • Resistance causes temperature to increase. • Light produces heat energy	• There are series and parallel circuits. • Series circuits have resistors which are potential dividers, and have one path way for current. • Parallel circuits have more than one way for electric current to flow, and have resistors as current dividers. • Ohm's Law states: for a conductor at a constant temperature, current is directly proportional to the potential difference across it. • Ohm's Law is represented by V=IR	• Power source produce electricity • Switch controls current. • Resistor converts power to sound, light, and heat. • Phone, stove, and heater have circuits • Electricity produce light through electronic devices, light bulbs, and phones. • Electricity produce sound through radio and phones. • Electricity produce heat. • Parallel circ. split current ($I_T = I_1 + I_2 + I_3$) • Series circ. have constant current.

2nd round: Concept maps constructed by the four (4) groups

Round 2 of CCM followed a lesson involving laboratory work, where learners constructed a simple circuit to obtain current and voltage data for a resistor and light bulb and determined which one obeys Ohm's Law. The experiment also required learners to determine the relationship between the electric current flowing through a resistor and the potential difference (voltage) across the same resistor and plot a graph using the data obtained from the voltmeter and ammeter readings. This lesson concluded with an outline of the following lesson and a brief introduction to the concepts of energy and power in direct current (dc) electric circuits. The 2nd round of CCM then followed, and the new concepts that were added in this round were color coded with blue.

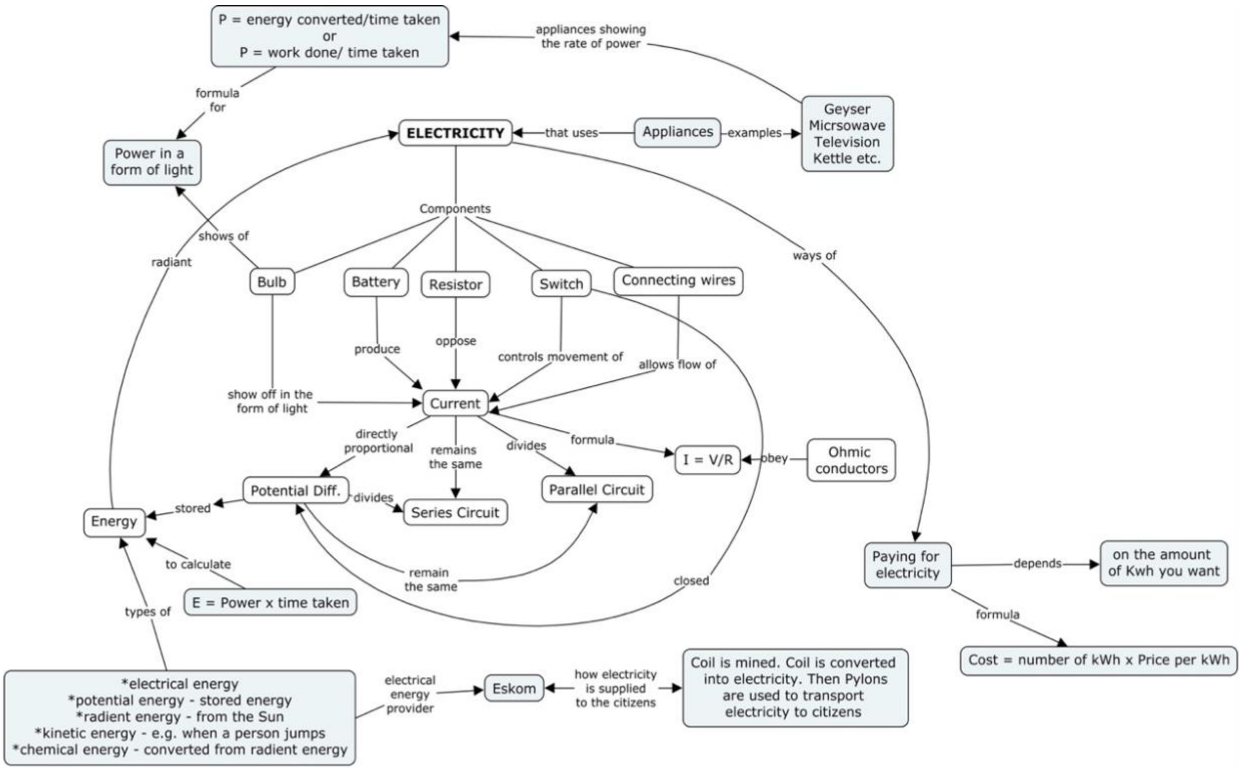

Figure 5.5.: Group A – Round 2 concept map

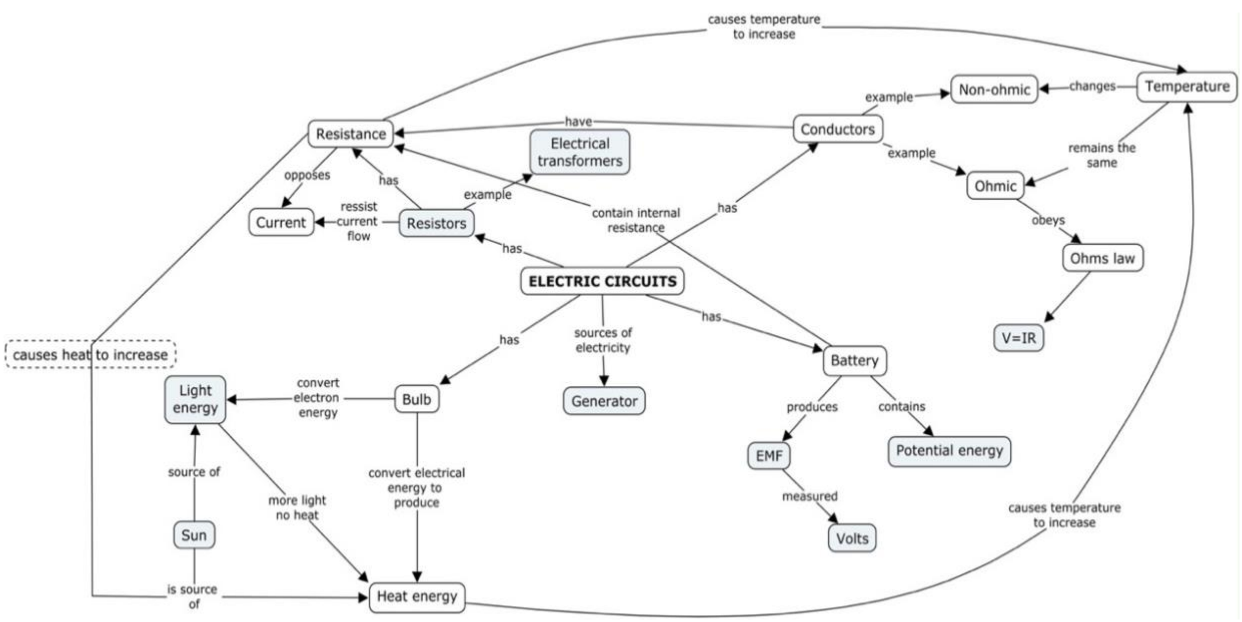

Figure 5.6.: Group B – Round 2 concept map

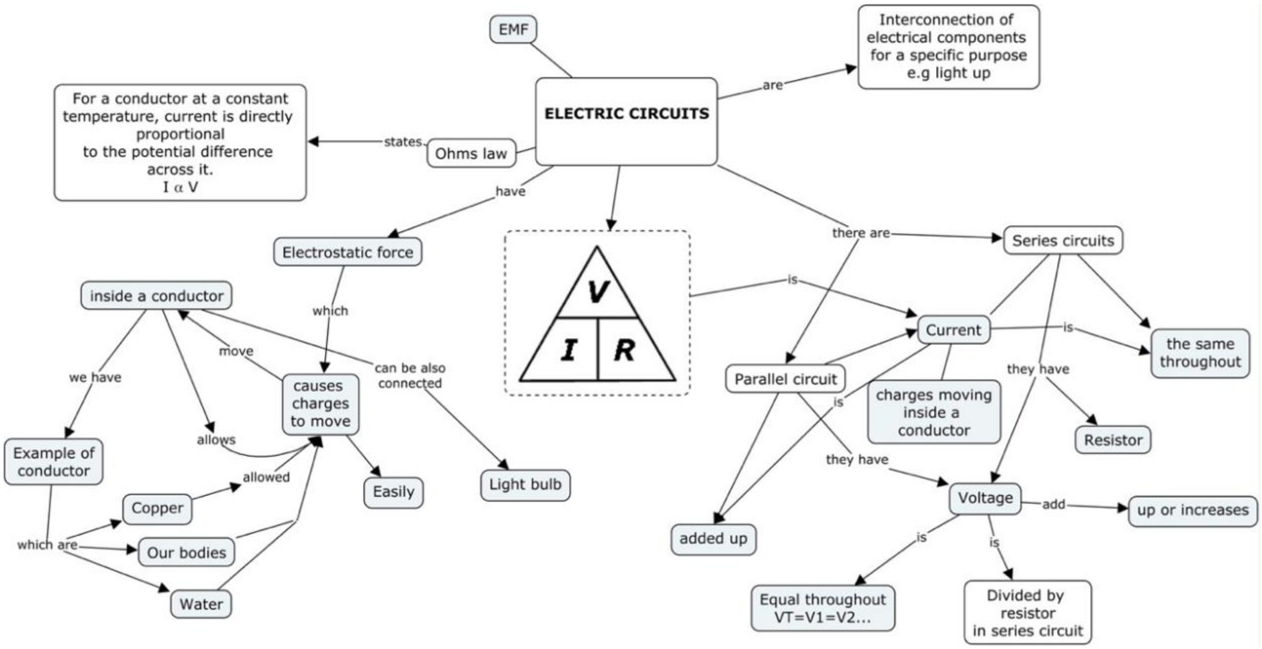

Figure 5.7.: Group C – Round 2 concept map

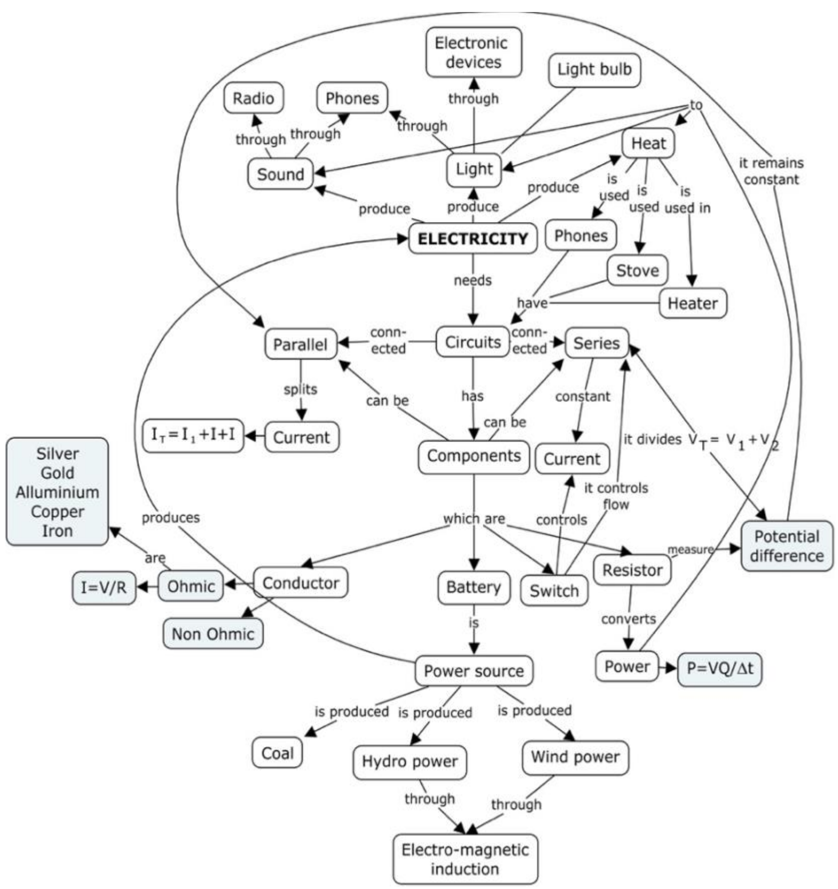

Figure 5.8.: Group D – Round 2 concept map

Fewer scientific propositions were expressed in this round of CCM when compared to the first round. Some of the notable changes present in this round include relationships between concepts that learners expressed in the form of equations. This was an indication that learners were now aware of the application of these concepts in problem-solving situations. Table 5.2. below shows some of the new propositions learners expressed.

Table 5.2: Scientific propositions learners expressed in round 2 concept maps

Group A	Group B	Group C	Group D
• Appliances that use electricity are: geyser, microwave, television, kettle etc. • Bulb shows power in the form of light • Formula for power is: Power = energy converted/time or P = work done/time • Energy = Power × time is used to calculate energy. • Types of energy are: electrical energy, potential energy (stored energy), radiant energy (from Sun), kinetic energy (e.g. when a person jumps), chemical energy (converted from radiant energy). • Eskom is the electrical energy provider • How electricity is supplied to the citizens: Coal is mined and converted into electricity, then transported to citizens by pylons. • Paying for electricity depends on the amount of kWh you want Formula for paying for electricity is: Cost = no. of kWh × Price per kWh	• Source of electricity is a generator. • Resistors have resistance. • Resistors resist current flow. • Resistance opposes current. • Example of a resistor is an electrical transformer. • Battery produces EMF • EMF is measured in volts • Battery contains potential energy • Sun is a source of light/heat energy. • Temperature changes in non-ohmic conductors. • Temperature remains the same in ohmic conductors.	• Electric circuits are interconnection of electrical components for a specific purpose e.g. light up. • Electrostatic force causes charges to move inside a conductor. • Examples of conductors are: copper, our bodies, and water. • Conductors can also be connected in a light bulb. • Current refers to charges moving inside a conductor.	• Series circuit divides potential difference ($V_T = V_1 + V_2 + V_3$). • Potential difference remains the same in parallel circuit. • Power is P = VQ/t • Ohmic conductors are silver, gold, aluminum, copper and iron.

3rd round: Concept maps constructed by the three (3) groups

Round 3 of CCM featured only three (3) groups since members of Group A asked to be excused from the study. This round came shortly after the third and fourth lessons had been conducted. These lessons were based on the relationship between energy and power in direct current electric circuits, calculating the cost of energy consumption by the consumers, and a tutorial of problems related to electric circuits from past exam papers. Three of the four groups sat for the third and final round of CCM. This time, learners had asked for the apparatus to further verify the findings from the experiment they performed during laboratory work. Groups B and D added only a few concepts in their concept map as they spent most of their time manipulating the apparatus and building new circuits. However, Group C spent most of this session constructing their concept map. Consequently, they were the only ones who added a significant number of propositions during this round of CCM (see Table 5.3.). Below, I show concept maps that the three (3) groups constructed in round 3 with changes in these maps indicated by an orange color.

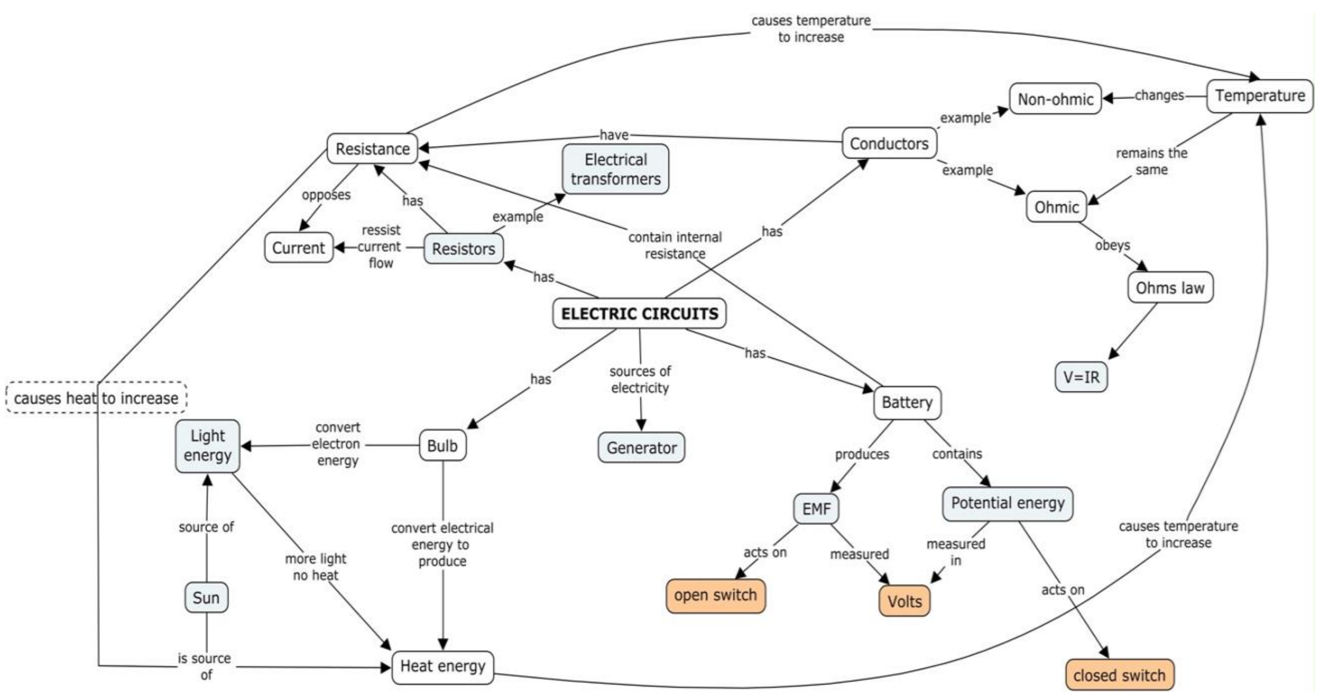

Figure 5.9.: Group B – Round 3 concept map

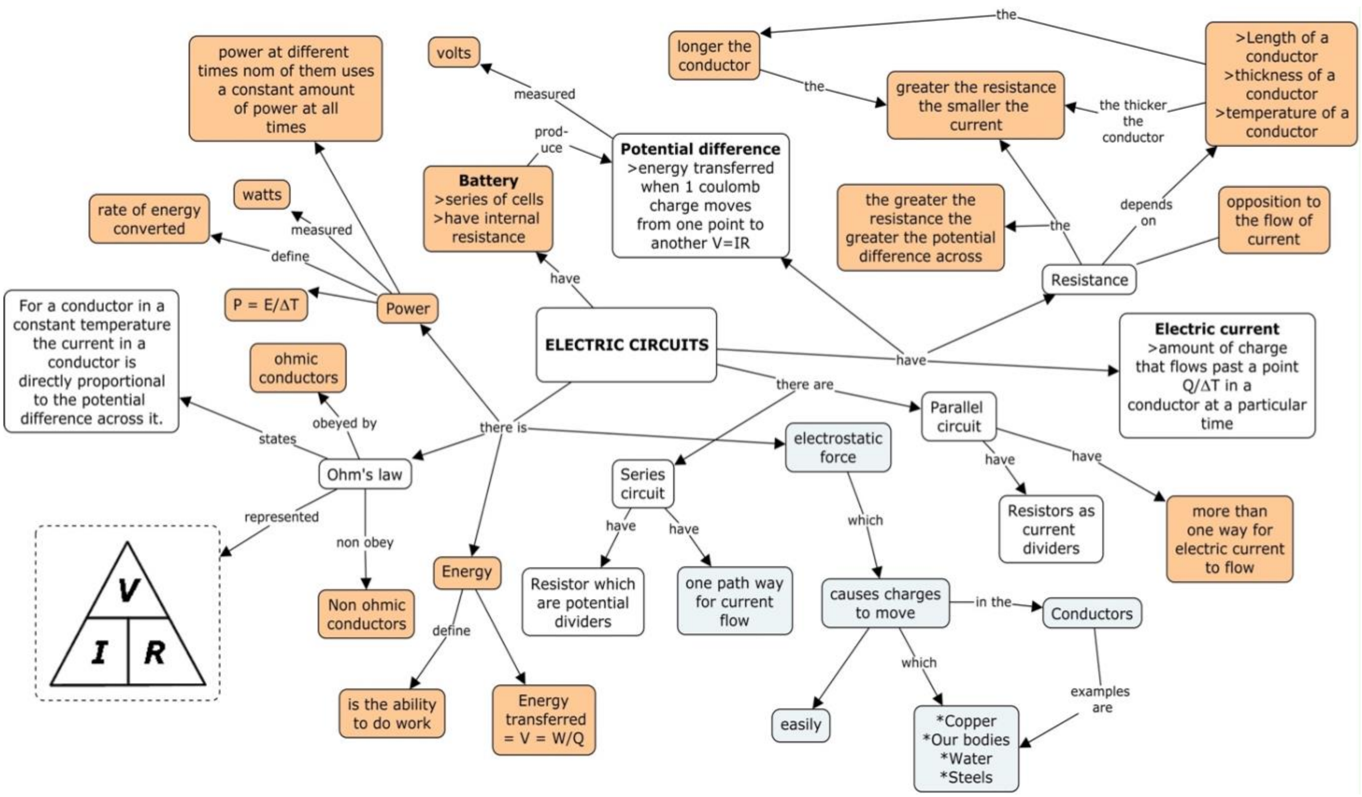

Figure 5.10.: Group C – Round 3 concept map

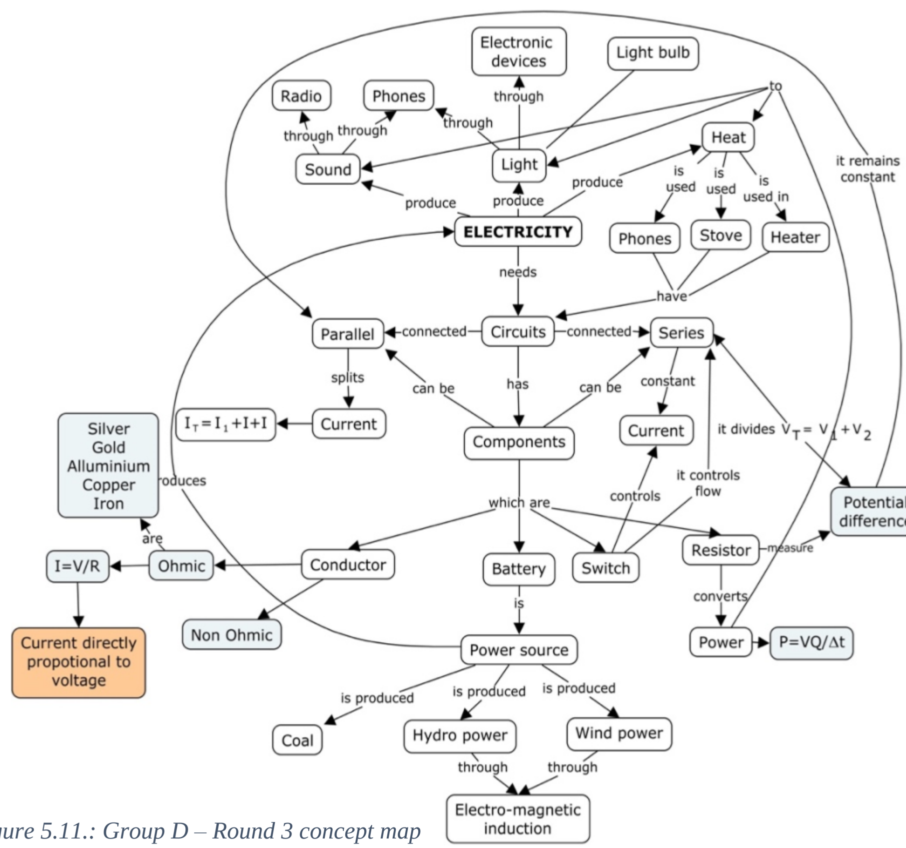

Figure 5.11.: Group D – Round 3 concept map

Table 5.3: Scientific propositions learners expressed in round 3 concept maps

Group B	Group C	Group D
• Potential energy is measured in volts. • Potential energy "acts on" a closed switch. • EMF "acts on" an open switch	• Electric circuits have resistance. • Resistance depends on: length of conductor, thickness of a conductor, and temperature of a conductor. • The greater the resistance the smaller the current. • The greater the resistance the greater the potential difference across. • Resistance is the opposition of the flow of current. • Energy is the ability to do work. • Energy transferred is V = W/Q. • Power is defined as the rate of energy converted, P = E/t. • Power is measured in watts. • Battery (series of cells, have internal resistance) produce potential difference. • P.d. is measured in volts.	• Current is directly proportional to voltage.

5.1.1. Network of concepts and links found in the concept maps

The qualitative assessment of participants' collaborative concept maps included the analysis of the network of concepts and links. Learners related various concepts across three (3) concept mapping rounds in the topic of electric circuits. The four (3) groups constructed their concept maps in a similar fashion, by first writing the main concept, and then showing how different concepts are related in a hierarchical form. Groups A and D used the term 'electricity' as their main concept whilst Groups B and C chose the term 'electric circuits'. The main concept was related to the components (i.e. bulb, battery, resistor, switch, and conductors) of an electric circuit in the first level by two groups. Interestingly, none of the groups mentioned voltmeter and ammeter as part of the components. Group B related the components to current, voltage, and resistance to indicate their function in a circuit. Group A related the components to current which they showed as the central term.

All four groups related the main concept with series and parallel circuit concepts. Three groups related the series/parallel circuits with current and potential difference, meaning that learners established the connection between the effect that a series and a parallel connection has on the potential difference and current in a circuit. This provided an initial understanding of learners' thoughts regarding these key concepts. The four groups went on to relate the term ohmic conductor with Ohm's Law, which is a key concept. Groups A and C made this connection in level 2, Group B made it in level 3, and Group D made it in level 4, meaning that Ohm's Law was less general than specific for most of the learners. Two groups related current and potential difference, while one group related current to resistance in the second level. The symbolic relationship between potential difference, resistance, and current was popular amongst the learners, with Groups B and C expressing this relationship in terms of a triangle (V, I, and R), and Groups A and D expressing it as an equation $I = V/R$.

Two (2) of the four (4) groups related the battery concept to energy or power source from the first level. In this connection, learners perceived the battery as a source of voltage in an electric circuit. Two groups related power to a resistor and one (1) group expressed the relationship between power and energy in terms of an equation, energy = power × time. Group C showed the relationship between the electrostatic force concept and charges, which are less general concepts, according to them. And these two concepts were related to a conductor and current from the first level. The sharp rise of clear connections such as this was an indication of the development of learners' understanding of this topic.

Table 5.4. below shows a summary of relevant concepts and how they are linked in the concept maps the four (4) groups constructed in rounds 1, 2, and 3 of concept mapping. The columns in the table are colored coded with white (for round 1 concepts), blue (for round 2 new concepts), and orange (for round 3 new concepts). The summary table shows the main concept (MC) that learners presented. This is followed by related concepts. In cases where a concept has been linked with two or more other concepts, a stroke (/) is used.

Table 5.4: Summary of related concepts found in the concept maps

Group	Round 1	Round 2	Round 3
A	• Electricity (MC) • Ohm's Law – Ohmic conductor • Electricity – Energy • Resistor – Current • Potential difference (P.d) – Current • Switch – Current • P.d – Energy • P.d – Series/Parallel circ. • P.d – Switch • Bulb – Current • Battery – Current	• Electricity – Appliances • Bulb – Light • Eskom – Electrical energy	
B	• Electric circuits (MC) • Ohm's Law – Ohmic cond. • Conductors – Ohmic/non-ohmic • Conductors – Current • Current – Resistance • Battery – Energy/Voltage • Bulb – Heat energy/Light/Resistance • Heat energy – Temperature • Energy – Light • Resistance – Temperature • Current – Series/Parallel circuit	• Electric circuits – Generator • Battery – EMF • Sun – Light energy • Resistor – Electrical transformer/Resistance	• EMF – Open switch • Potential energy – Closed switch
C	• Electric circuits (MC) • Resistor – Current/P. d • Current – Parallel/Series circuit • P.d. – Parallel/Series circuit • P.d. – Current	• Electrostatic force – Charges • Conductors – Charges • Current – Charges	• Power – Energy/Rate • Battery – P.d. • Resistance – Current • Energy – Work done • Ohmic/non-ohmic cond. – Ohm's Law
D	• Electricity (MC) • Current – Series/Parallel circuit • Battery – Power source • Resistor – Power • Power – Light/Sound/Heat • Electromagnetic induction – Wind power/Hydropower.	• Conductors – Ohmic/non-ohmic • Ohmic cond. – Ohm's Law • P.d – Series/Parallel circuits • Switch – Current • Resistor – P. d	• P.d – Current

5.1.2. Scientific propositions found on the concept maps

The second unit of qualitative analysis of participants' concept maps focused on looking at the scientific propositions. The propositions made in the 1st round were the following:

- Electricity is used in appliances and electronic devices.
- The components of electric circuits include a light bulb, a battery, a switch, resistors, and connecting wires.
- A switch controls the movement of the current.
- A resistor opposes the current flow.
- A battery is a power source.
- Current is directly proportional to the potential difference.
- Current is inversely proportional to resistance.
- Current remains the same in a series circuit, but splits in a parallel circuit.
- Formulae for calculating voltage, current, and resistance is $V = IR$.
- Ohmic conductors obey Ohm's Law.
- Non-Ohmic conductors disobey Ohm's Law.
- A light bulb has resistance.
- A light bulb gives off light.
- Potential difference is measured in volts.

Building up to this, the propositions made in the 2nd and 3rd round were the following:

- Electrostatic force causes charges to move inside the conductor.
- Current refers to the movement of charges inside a conductor.
- The formulae for calculating Power is P = Energy converted | Time taken.
- The formulae for calculating Energy is E = Power × Time taken.
- Types of energy are: electrical energy, potential energy (stored energy), radiant energy (from the sun), kinetic energy (e.g. when a person jumps), and chemical energy.
- Eskom produces electricity and supplies it to the citizens.
- The formulae for calculating cost of electricity is Cost = no. of KWh × Price per KWh.

- Source of electricity is a generator.
- Resistors have resistance.
- Resistance depends on the length of the conductor, thickness of the conductor, and temperature of a conductor.
- A battery produces an EMF.
- Potential energy ‘acts on’ a closed switch.
- EMF ‘acts on’ an open switch.
- A sun is a source of light/heat energy.
- Temperature remains the same in Ohmic conductors.

There were a few propositions which were common to all four (4) groups. First, was the effect of the series/parallel circuits on the current and potential difference in an electric circuit. Learners expressed that the current remains the same if the resistors are connected in series, and it divides if the resistors are connected in parallel. Also, the potential difference was said to divide if the resistors are connected in series and remains unchanged if they are connected in parallel. Group B said that current is divided equally in parallel resistors. This showed learners’ partial understanding of current behavior in parallel circuits because learners did not consider a scenario where there are resistors with different amounts of resistance. In such cases, the current will split unequally, depending on the amount of resistance.

The second proposition that all groups made was the idea that ohmic conductors obey Ohm’s Law, and non-ohmic conductors disobey this law. Group B went further to state that temperature changes in non-Ohmic, while it remains the same in ohmic conductors, meaning that some learners understood the significant condition for Ohm’s Law (i.e., temperature ought to remain constant). This idea was further expressed in a discussion between learners during the first concept mapping round:

Melusi:	Types of conductors?
Sthe:	Khona ama conductors lawa a..a..a..ane resistance kodwa ay ay asingakufakini lokho [*there are conductors with resistance but no let us not add that*]
Melusi:	Resi..iconductor with high resistance uyayazi leyo? [*do you know a conductor with high resistance?*]

Sthe: Iyona le ukuthi ine resistance le [this is the one with resistance (says: non-ohmic conductor)]

Melusi: Ayingeni kwi ohmic ne non ohmic le? [*will that not be part of Ohmic?*]

Sthe: Ey mina angyaz leyonto uSthe oyaziyo [*ey I do not know what you are talking about*]

Ntando: If into meyi ohmic conductor..meyi ohmic isuke i obey Ohm's Law shuthi leyo conductor leyo akusiyona ekuhamba kuhambe kushise, meke kwashintsha i-temperature kwakhuphuka itemperature kukhuphuka iresistance [*if something is ohmic, it obeys Ohms Law, which means that conductor does not overheat, when temperature changes by increasing temperature, resistance increases*] [Group B: 1st Round]

Group C also said in their discussion that the unit measure for temperature is kelvin:

Vusi: Ok yini enye esiyaziyo nge Ohm's Law? [*what else do we know about Ohm's Law?*] Oh! one more thing Ohm's Law works if i-temperature is kept constant…

Bathandwa: And i-temperature siyi-measure in kelvin [*And we measure temperature using kelvin*] [Group C: 1st Round]

Three (3) of the four (4) groups stated that the current is directly proportional to the potential difference while two (2) groups noted that current is inversely proportional to the resistance in a circuit. Group B related resistor and current to form a proposition that a resistor opposes current in an electric circuit. This proposition was also expressed by Group C who stated that "*the greater the resistance, the smaller the current and vice versa*" [Group C: 3rd Round]. Three (3) groups (B, C, and D) expressed the idea that a battery is a source of energy/voltage/potential difference in a circuit. Group C defined energy as the ability to do work; they went further to state that energy transferred by a resistor can be calculated using the equation $V = W/Q$. Group A, C, and D referred to power as the rate at which work is done (i.e., $P = E/\Delta t$). Group D mentioned that resistors convert power to sound, light, and heat. Understanding of the relationship between power and energy was further revealed in a discussion between learners in the 2nd round of concept mapping process:

Melusi: Power is the rate at which work is done…

Ntando: ini into ekhipha i-power [*what produces power?*]

Melusi: into ekhipha i-power i-power station i-coal is a power source [*what produces is a power station; coal is a power source*]

Ntando: I-generator is a power source [Group B: 2nd Round]

This excerpt shows learners' understanding of this relationship. Only Group B did not include it in its concept map.

Group A and B proposed that a bulb has resistance and produces light, which in turn produces heat energy. An exciting proposition was highlighted by Group C who related the electrostatic force and charges concepts to form a proposition that an electrostatic force causes charges to move in a conductor, which can then be connected to a bulb to produce light. Furthermore, this movement of charges inside a conductor was said to produce current. Group B also included a vital proposition regarding the connection between potential energy (or potential difference) and a switch from the first level. They mentioned that a potential difference could be found in a circuit when a switch is closed; meaning, when there is a current flow. Furthermore, this group also expressed that if a switch is open, the reading on the voltmeter will show the electromotive force (EMF); and that batteries have internal resistance.

The propositions expressed in the three rounds of CCM are summarized in the Table 5.5. below.

Table 5.5.: Summary of scientific propositions found in the concept maps in 3 rounds

Group	Round 1	Round 2	Round 3
A	• Components of electricity are: bulb, battery, resistor, switch, and connecting wires. • Switch controls the movement of current • Connecting wires allow current to flow • Resistor opposes current • Battery produces current • Current shows off in the form of light from the bulb • Current is directly proportional to the potential difference (P.d) • Current remains the same in a series circuit • Current divides in a parallel circuit • Formula for calculating current is I = V/R	• Appliances that use electricity are: geyser, microwave, television, kettle etc. • Bulb shows power in the form of light • Formula for power is: P = energy converted/time taken or P = work done/time taken • Energy = Power × time taken is used to calculate energy. • Types of energy are: electrical energy, potential energy (stored energy), radiant energy (from Sun), kinetic energy (e.g. when a person jumps), chemical energy (converted from radiant energy). • Eskom is the electrical energy provider • How electricity is supplied to the citizens: Coal is mined and converted	

	• P.d. divides in a series circuit • P.d. remain the same in a parallel circuit • Closed switch shows P.d. • P.d. is a stored energy • Ohmic conductors obey I = V/R	into electricity, then transported to citizens by pylons. • Paying for electricity depends on the amount of Kwh you want • Formula for paying for electricity is: Cost = no. of Kwh × Price per Kwh	
B	• An electric circuit has a: conductor, battery, and bulb. • Electric circuits can be connected in parallel and series. • Parallel circuits divide current equally. • In series circuits, current is equal throughout. • Ohmic cond. Obey Ohm's Law • Non-ohmic conductors disobey Ohm's Law. • Battery produces energy & voltage • Formula for voltage, current, and resistance is V = IR • Bulb gives off heat energy. • Bulb has resistance • Current is inversely proportional to resistance. • Bulb produces light • Energy is converted into light • Resistance causes temperature to increase. • Light produces heat energy	• Source of electricity is a generator. • Resistors have resistance. • Resistors resist current flow. • Resistance opposes current. • Example of a resistor is an electrical transformer. • Battery produces EMF • EMF is measured in volts • Battery contains potential energy • Sun is a source of light/heat energy. • Temperature changes in non-ohmic conductors. • Temperature remains the same in ohmic conductors.	• Potential energy is measured in volts. • Potential energy "acts on" a closed switch. • EMF "acts on" an open switch
C	• Electric circuits have an electric current (amount of charge that flows past a point in a conductor at a particular time). • Electric circuits have potential difference (energy transferred when 1 coulomb charge moves from one point to another). • P.d is measured in volts • There are series and parallel circuits.	• Electric circuits are interconnection of electrical components for a specific purpose e.g. light up. • Electrostatic force causes charges to move inside a conductor. • Examples of conductors are: copper, our bodies, and water. • Conductors can also be connected in a light bulb. • Current refers to charges moving inside a conductor.	• Electric circuits have resistance. • Resistance depends on: length of conductor, thickness of a conductor, and temperature of a conductor. • The greater the resistance the smaller the current. • The greater the resistance the greater the potential difference across. • Resistance is the opposition of the flow of current. • Energy is the ability to do work.

	• Series circuits have resistors which are potential dividers, and have one path way for current. • Parallel circuits have more than one way for electric current to flow, and have resistors as current dividers. • Ohm's Law states: for a conductor at a constant temperature, current is directly proportional to the potential difference across it. • Ohm's Law is represented by *V=IR*		• Energy transferred is V = W/Q. • Power is defined as the rate of energy converted, P = E/t. • Power is measured in watts. • Battery (series of cells, have internal resistance) produce potential difference. • P.d. is measured in volts.
D	• Electricity needs circuits. • Circuits are connected in parallel and series. • Circuits have components which are: conductor, battery, switch, and resistor. • Battery is a power source. • Power source is produced by coal, hydropower, and wind power through electromagnetic induction. • Power source produce electricity • Switch controls current. • Resistor converts power to sound, light, and heat. • Phone, stove, and heater have circuits • Electricity produce light through electronic devices, light bulbs, and phones. • Electricity produce sound through radio and phones. • Electricity produce heat. • Parallel circ. split current ($I_T = I_1 + I_2 + I_3$) • Series circ. have constant current.	• Series circuit divides potential difference ($V_T = V_1 + V_2 + V_3$). • Potential difference remains the same in parallel circuit. • Power is P = VQ/t • Ohmic conductors are silver, gold, aluminum, copper and iron.	• Current is directly proportional to voltage.

5.1.3 Integration of prior knowledge with new knowledge

The third unit of qualitative analysis of participants' concept maps focused on evaluating statements that show the link between prior knowledge and new knowledge. These statements were only found in the concept maps from rounds 1 and 2. Most of the statements related to prior knowledge came from learners' prior learning experiences. The relationship between four concepts (i.e. light bulb, light, energy, and current) was most popular amongst the four groups. The concept light bulb (from their everyday world) was related to current key concept to form a proposition that "current shows off in the form of light from a bulb". Meaning that if there is current flow in a circuit, a bulb will light up. Group B further expressed that light bulbs have resistance, and give off heat energy. Group D mentioned that light bulbs can be connected to conductors. Additionally, Groups A and D related the main concept electricity to various household appliances such as geyser, microwave, television, kettle, radio, phones, stove, heater etc. Also, group D expressed that electronic devices such as phones, stoves, and heaters have electric circuits.

Learners also made use of their prior knowledge when discussing points to include in their concept map in the 1st round of concept mapping process, for example, Group A discussed;

Lungile:	Angani uyazi ukuthi kwi-photosynthesis iproduct ilo i-glucose ne-oxygen ilento engiyishoyoke nami ukuthi i-battery ne connecting wire i-product yakhona i-electricity ephuma kuphi kwi-bulb...iyezwakala lento engiyishoyo? [*you know that in photosynthesis the product is glucose and oxygen…that is what I mean when I say the battery and connecting wires produce electricity which shows up in a bulb, do you get what I am trying to say?*]
Amanda:	Ehhe!
Sthandiwe:	I-bulb it shows off i-current in a form of light...[Group A: 1st Round]

This excerpt demonstrates learners comparing the process of photosynthesis with how electricity is shown through a light bulb. They compared photosynthesis and electricity in a sense that both processes show byproducts. For photosynthesis, it is glucose and oxygen; and for electricity, it is light being produced by the light bulb. This idea stems from learners' prior learning experience, and reveals how learners use what they already know, to try and understand new information presented to them. Furthermore, Group D also incorporated their prior knowledge when discussing sources of electricity. In their discussion, learners Group D mentioned the concept of electromagnetic induction, also known as Faraday's Principle. In the 1st round of concept mapping process, learners discussed that technology such as wind-power and hydro-power make use of electromagnetic induction to generate electricity for the consumers;

Nolwazi:	unini u Faraday mfethu? ha ha ha [when is Faraday my brother? Ha ha ha]
Khule:	la khona (points) ne campus la yah [*here (points) there is even a campus here yeah ha ha ha*]
Nolwazi:	power source sithe yini, sithe icoal? [*what did we say is the power source, did we say it's coal?*] Kube yini kube ihydro [*and hydro?*]
Khule:	lana ayingeni i-electromagnetic induction? [*does electromagnetic induction feature here?*]
Nolwazi:	sithe i-wind… [*we said wind…*]
Khule:	and wonke a-link(a) to one thing [*and all link to one thing*], electromagnetic induction
Nolwazi:	wind banike? [*wind what then?*] Wind power?
Snakho:	I-wind power yah [*yes, wind power*]
Nolwazi:	and i-hydro i-hydropower
Khule:	Is produced through electromagnetic induction [Group D: 1st Round]

The principle of Faraday was taught to learners prior to the topic of electricity, meaning learners were well aware of it and used their understanding of it to learn about and understand electric circuits. Two groups (B and D) highlighted alternative sources of power, such as, hydropower, wind power, generator, and solar energy. Group A indicated that Eskom is the electrical energy provider; and electricity can be produced from mined coal, then transported to citizens by pylons. Furthermore, group A also related potential difference key concept with energy; and listed various other forms of energy and their sources, namely: electrical energy, potential energy (stored energy), radiant energy (from Sun), kinetic energy (e.g. when a person jumps), chemical energy (converted from radiant energy). Meaning that learners' understanding is that energy comes from various sources, but the one found in an electrical circuit is regarded as electrical energy. These ideas come from their everyday life and also from prior learning experiences, for example, in a discussion that took place during the 2nd round of concept mapping process learners said;

Sindiswa:	Ehhe! singasho njalo..eh eh hhay kuthi i-radiant hlambe e-convert(we) kwilo?...[*can we say that radiant energy is converted from the…?*]
Sthandiwe:	I don't know...
Sindisiswa:	Usaykhumbula ka..ka..ka Life Sciences? [*do you remember in Life Sciences lesson?*]

Lungile: Ehhe! i-radiant energy e-convert(wa) angani idonswa kwi langa? mese iya-convert(wa) as a source of energy…[*yes that radiant energy is drawn from the Sun? and then converted as a source of energy*] [Group A: 2nd Round]

Learners linked the concept of energy that they learned from Life Sciences to the topic of electricity, in terms of listing various sources of energy.

Table 5.6.: Summary of statements showing integration of prior knowledge with new knowledge

Group	Round 1	Round 2
A	• Current shows off in the form of light from the bulb.	• Appliances that use electricity are: geyser, microwave, television, kettle etc. • Bulb shows power in the form of light • Types of energy are: electrical energy, potential energy (stored energy), radiant energy (from Sun), kinetic energy (e.g. when a person jumps), chemical energy (converted from radiant energy). • Eskom is the electrical energy provider • How electricity is supplied to the citizens: Coal is mined and converted into electricity, then transported to citizens by pylons.
B	• Source of electricity is a generator. • Example of a resistor is an electrical transformer. • Sun is a source of light/heat energy. • Bulb has resistance • Bulb gives off heat energy	• Source of electricity is a generator. • Example of a resistor is an electrical transformer. • Sun is a source of light/heat energy.
C		• Examples of conductors are: copper, our bodies, and water. • Conductors can also be connected in a light bulb.
D	• Power source is produced by coal, hydropower, and wind power through electromagnetic induction. • Phone, stove, and heater have circuits • Electricity produce light through electronic devices, light bulbs, and phones. • Electricity produce sound through radio and phones. • Electricity produce heat.	

5.2.4 Alternative conceptions that were diagnosed during the CCM tasks

The fourth unit of qualitative analysis of participants' concept maps focused on diagnosing alternative conceptions that learners had about electric circuits. Evaluating alternative conceptions in participants' concept maps and audio discussions helped in the planning of my lessons and class activities by revealing aspects on electric circuits that learners found challenging or confusing. Alternative conceptions that were diagnosed in the 1st concept map remained unchanged throughout the study. Other alternative conceptions were diagnosed in the audio discussion. Due to the fact that only a few alternative conceptions were found in the concept maps, a summary table was not made in this section.

In their round 1 concept map, Group A expressed the notion that a battery produces current. A similar alternative conception was diagnosed in a discussion by Group D in the first round when learners said:

Nolwazi:	Battery is...
Khule:	is a..mese ubhala u-power source…mese uthi power source produces electric current [*is a…and then write 'power source'…and say the power source produces current*]

This is a power supply alternative conception and has been documented in the literature (Dupin & Joshua, 1987; Pesman & Eryilmaz, 2010; Shipstone, 1984). This alternative conception was addressed in the lesson that followed by using illustrations from the PowerPoint, PhET simulations, and an explanation that a battery produces potential energy which is given to the charges, thus allowing them to move. This movement of electric charges in a conductor is called an electric current. Attempts to address this alternative conception appeared to be futile as it still remained in the learners' concept maps throughout the study.

An alternative conception about the means used to transport electricity to consumers was found in a Group A audio discussion:

Lungile:	Uke ubone kwezinye iyndawo kunalezizinto nike niybone lezonto ezingathi ziyi-fan? [*Have you noticed that some areas have things that look like fans?*]
Sthandiwe:	Oh yah...
Sindiswa:	Ama water mi....ama water mill noma? ama wind mills? [*you mean water mill or? Wind mills?*]

Lungile: Abanyeke basebenzisa wona ziningi iyndlela akuwona ama pylons kuphela... [*some people use that, there are many ways (to transport electricity) it's not just pylons only*] [Group A: 2nd Round]

Learners seem to have shallow understanding of windmill technology. The idea of windmills stems from learners' everyday life. In this case, learners appeared confused as to how this technology is used in the real world. I addressed this alternative conception by showing learners a YouTube video explaining the windmill technology (link 1: https://youtu.be/qSWm_nprfqE and link 2: https://youtu.be/q8HmRLCgDAI). This alternative conception had been found only in the audio transcripts and was not included in the concept map. It was, therefore, unclear whether this alternative conception had been addressed as there was no tangible evidence of how the learners might have dealt with it, if at all.

Overall summary of CCM

While the overall concept maps drawn by the four (4) groups were adequate, there were a few signs of learners struggling to construct clear and straightforward concept maps. The bulk of the concepts were incorporated into the concept maps in the first round of concept mapping. In the 2nd and 3rd rounds, the number of new concepts significantly decreased, with the exception to Group C, whose conceptualization ability appeared to grow stronger with each concept mapping round. Overall, the result seems to suggest that learners have expected understanding of the relationship between concepts in this topic for Grade 11 level. This was shown by the incorporation of several well-articulated key concepts (viz. potential difference, current, resistance, energy, power, and Ohm's Law) into their diagrams.

The propositions expressed in the concept maps showed learners' understanding of key concepts in electric circuits. However, several alternative conceptions were diagnosed, all of them stemming from everyday language use of electricity, misinterpretation of concepts taught in class, and/or misunderstanding of meanings attributed to some concepts. Literature supports a common view among science teachers that learners often find it difficult to understand much of the material being presented to them (Taber, 2001). Although these alternative conceptions were addressed during teaching activities in the classroom, they were still evident in the learners' concept maps throughout the study.

5.3. Semi-structured interview

While the first level analysis of the concept maps in the previous section indicated learners' understanding of the relationships between key concepts, this was complemented by more in-depth information from the interview. This section of the study presents the semi-structured interview conducted with one (1) learner per group from each of the four (4) groups. Pseudonyms are used to identify the learners. The interview was conducted after completing all teaching activities and concept mapping exercises. While the interview schedule is provided in Appendix B, the questions asked and the diagrams produced by the learners are included in this section for ease of reference. The themes used in the interview first level analysis came from the data itself.

The first interview question probed learners' view on the ammeter readings, their ideas about what happens in the circuit, and predictions of the reading on the ammeter when its position is changed. The 2nd interview question looked into learners' understanding of resistance in series and parallel circuits as well as how current is affected by different ways of connecting resistances. The 3rd interview question probed learners' views about meanings attributed to voltmeter readings as a means to determine perceptions of the potential difference. The 4th and last interview questions focused on differentiating between the potential difference (p.d.) and the current. All interview questions were based on the understanding that learners were expected to have after teaching activities as well concepts that the learners had appeared to find difficult during the concept mapping exercise.

The 1st interview question – Current in a simple circuit

I. The aim of the first interview question:

The first interview question contained a series of sub-questions of significant importance and was aimed at probing learners' ideas about how a simple electric circuit works. It was essential to find out how learners use their prior knowledge to visualize what is happening within the circuit, and how circuit components such as the ammeter and a switch affect the current in that circuit. During the interview, one of the primary goals was to get a clear picture of learners' ideas and understanding, having used concept maps to deepen their understanding of electric circuits.

In an era where learners are too used to routine problem tasks and having what they say or do categorized as 'correct' or 'incorrect', it was felt that the interview and the setting should be arranged in a relaxed manner so that learners feel comfortable enough to explain their ideas without fear of being judged as 'right' or 'wrong'. Ideas that were probed during the interview dealt with issues that were covered during the teaching activities.

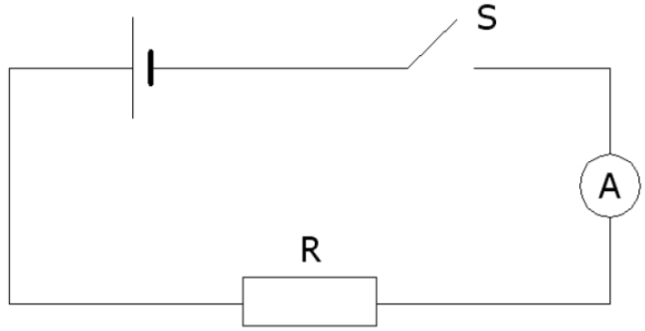

Figure 5.12.: A simple circuit diagram

The circuit diagram shown in Figure 5.12, together with the simulation circuit in the PhET simulations program, were shown to all four (4) learners at the same time. The learners were then asked:

- Based on your own understanding of electricity, describe your mental picture of what is happening in this electric circuit when S is switched on.
- What do you imagine is happening within the circuit? What ideas do you have as you give this answer?
- What affects the ammeter reading? Why?

-

Also, learners were asked to predict what will happen when the circuit is switched on, giving reasons for the prediction. The following questions were asked:

- If you switch S on, what would you notice? Why?
- Will it make a difference to the ammeter reading if the position of the ammeter is changed and it is placed on the other side of the resistance? Why?

II. Ideas about current

Current as something flowing when a switch is closed:

When learners were asked to say what they imagine happens in a circuit when a switch is turned on, their response showed that they knew current as something flowing inside a circuit. However, none of them mentioned ‘electron flow’. One of them (Sthandiwe) was specific in her indication of the direction of flow, saying, “Current flows from the positive part of the battery to the negative part”. Rethabile and Sthandiwe said that when current flows, the ammeter will “start to calculate” how much current is flowing inside the circuit.

Although the interview began with learners describing the flow of current, some went as far as verbally explaining how current and resistance are related. The following extract is an example of how Sthandiwe and Lungile described this relationship.

Sthandiwe: Yebo thisha nami ngicabanga kanjalo, ukuthi mhlampe, ok thisha njengoba sibona ukuthi icurrent iyaflow(a) laphaya, ngcabanga ukuthi enye into eyenza ukuthi icurrent ibe u 0.90 Amps, mhlampe [*yes teacher I also think that maybe…ok teacher as we can see the current flowing there, I think one of the reason why it 0.9 amps is because*] resistance has something to do with current esiyibona laphayana kwi [that we see in the] ammeter… maybe if i-resistance iningi icurrent izobancane icurrent ezoflow(a) mhlampe I assume ukuth i-resistance kule circuit iningi njengoba icurrent incane nalapha kwi ammeter [*maybe if the resistance was big, the current flowing would be small, my assumption is that the resistance in this circuit is small as shown in the ammeter*]

The above extract describes why we see a smaller reading on the ammeter. Sthandiwe bases her assumption on the circuit having more resistance. This notion comes from the idea that the smaller the current, the more the resistance. Lungile reiterates this relationship, but in more scientific language.

Lungile: Shuthi laphaya uSthandiwe mechaza shuthi minangibona ukuthi iresistance ne-current ba inversely proportional shuthi okunye maku…iresistance mayinkulu, icurrent izobancane, shuthi icurrent mayincane iresistance izobankulu. [*it means that there (points) as Sthandiwe was explaining that resistance and current are inversely proportional… if there is a big resistance, the current will be small, and if the current is small, the resistance must be big*]

Current as a result of energy from the battery

Some of the learners – Lungile, Sthandiwe, and Ntando, for example – saw current as being caused by energy given to the charges from the battery, resulting in a flow.

Interviewer: What affects the ammeter reading, and why?

Lungile: Thisha ngicabanga ukuthi ehh engine ebonile ekuqaleni ukuthi ibisavulekile? mese usuyivala ehh ilo..ilo..i-energy esuka kwi battery isiyakwazike manje ukwenza iflow(a) njengoba kade eseshilo Sthandiwe ukuthi izoqala from the positive side shuthi ngeskhathi isiflow(a) laphoke sekuzo determine(ka) i-current esi-flow. Shuthi icurrent eflow(ayo) idluliswa ibattery yah mese uyatholake laphaya ukuthi icurrent iwubanike. *[Teacher I think that as you saw previously that it (switch) was open? If you close it, the energy from the battery is able (to cause) the flow, as Sthandiwe said (earlier) that the current will flow past the battery from the positive side, it means (that at) the time it flows we can determine the current that is flowing. It means the reason current flows is because of the battery…yeah, then you can get there (points at the ammeter) the value of a current.*]

In Group A's first concept map, Lungile and her fellow members suggested that "the battery was a source of current". This idea remained unchanged throughout their concept mapping activities and was listed as an alternative conception. However, at this stage, it appeared that this idea had now changed, and that learners now have a scientifically correct understanding of the battery "as a source of energy" for the charges which obtain this energy and result in a current flow as shown in the extract below.

Interviewer: What do you imagine is happening in the circuit, in other words what prior ideas do you have?

Sthandiwe: I think mina thina ok siyabona ukuthi icurrent iya flow shuthi somewhere khona ivoltage le [*I think we will see current flow which indicates voltage somewhere*] … somehow it pushes current to flow…yeah.

Ntando: Ngivumelana noSthandiwe kodwa mina ngizothi ukushintsha kancane… I think iyakhombisa ukuthi kule circuit sine [*I agree with Sthandiwe but I will change a bit… I think it shows that this circuit has an*] energy provider causing ama-charges to move. [*Energy provider causing charges to move*]

The above extract provides more evidence of learners' understanding of the idea that a battery is a source of energy for the charges flowing through an electric circuit.

The 2nd interview question – Resistance in series and parallel circuit

I. Aims of the 2nd interview question

The main aim of this interview question was to see how learners understand the relationship between current and resistance, as well as how parallel and series connections of resistors affect current in an electric circuit. Is it the way resistors are connected that affects the current or must the size of these resistors also be considered? The learners were first shown the circuit diagram in figure 5.13. (see below) and told that R_1 and R_2 are two equal resistors connected in series.

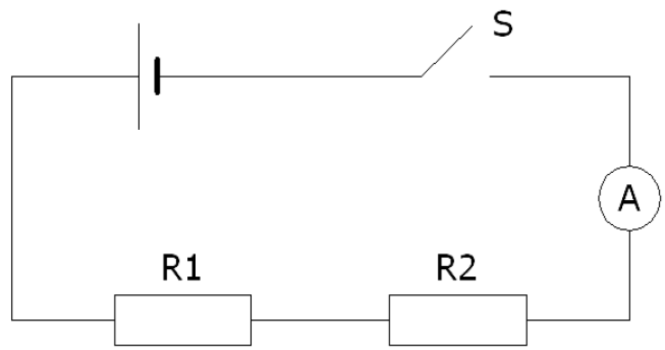

Figure 5.13.: A circuit with resistors connected in series

The following questions were asked, before switching S on:

- In this circuit using two equal resistances, what happens when S is switched on? Why?
- In the same circuit, if we increase one of the resistors, what will happen to the reading on the ammeter and why?

After predictions were made, the learners were allowed to observe the simulation program and also refer to their constructed concept maps to comment on the relationship between the current and resistance, giving reasons why the circuit works that way.

Learners were then shown figure 5.14. (see below) and asked the questions beneath it before switch S was switched on:

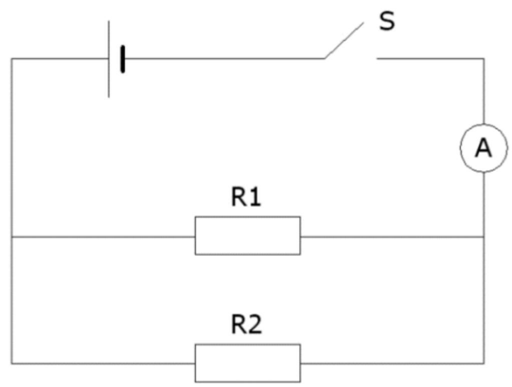

Figure 5.14.: A circuit with resistors connected in parallel

Questions: What happens to the ammeter reading, when S is on (when comparing it to when the resistances were connected in series)? Does it increase, remain the same or decrease? Why?

<u>The relationship between current and resistance</u>

Learners made it evident that after the first interview, they had a clear understanding of current in an electric circuit, and that they had an idea of how current and resistance are related. They opined that, as the current moves through the conductors, it experiences some degree of friction or opposition to the motion. This opposition to the motion is brought about by resistors and is called resistance. Thus, the learners said, *the relationship between the electric current and resistance is inversely proportional*. Furthermore, the learners found it natural to predict how the current would behave if resistors were connected in series or parallel, and that when more resistors are added in series, the ammeter reading would be reduced. However, some could not explain why the circuit behaves this way.

Predictions with reasons

When learners were asked how the current would behave if the resistors were connected in series, they all commented that it would remain the same, but when resistors are connected in parallel, the current would be split to each resistor. In comparatively predicting ammeter readings in series and parallel circuits, the learners said,

Interviewer:	If the same resistors were connected in parallel, what would happen to the reading in the ammeter?
Ntando:	I think thisha izokhuphuka [*I think teacher it will increase*]
Interviewer:	Why do you think that is going to happen?
Ntando:	kodwa thisha mina ngizoyichaza in terms of ama calculations ukuthi njengoba sino 10 resistor ngenhla no 10 resistor ngezansi shuthi icurrent Izo splitter ilingane kule resistor engenhla nalengezansi shuthi since lama resistor e-parallel... I think ukuthi itotal resistance azoyi adder njengoba eparallel i-total resistance yawo isizobancane ngeke isaba… ngeke ize ifike ku 10…[*but teacher I will explain it in terms of calculations that we have a 10 (ohm) resistor at the top and another 10 (ohm) resistor below it means the current will split equally to the top and bottom since the resistors are connected in parallel, I think their total resistance will be small, it won't reach 10 (ohms*]
Lungile:	Nami ngivumelana noNtando ngoba kwi parallel circuit ilo ilo icurrent iya-divideka so lokhu okushiwo uNtando i think kuyikona. [*I also agree with Ntando because in parallel circuit it is where current will be divided, I think what Ntando is saying is correct*]
Rethabile:	Thisha ngivumelana nabo. [*I also agree with them*]
Sthandiwe:	Nami ngivumelana nabo ukuthi kule connection le icurrent izokhuphuka kodwake…nokuthi itotal resistance izoba…(paused) ok…ngifuna ukuthini?..ehh ngifuna ukuthi thisha i..i..i-current i..ngicabanga ukuthi izofana kuleli point leli lokuqala naleli lesibili (points at a sim) ngoba i-resistance iyalingana [*I also agree that this (parallel) connection current will increase but, total resistance will (paused) ok what do I want to say? Uhm I want to say that (teacher) the current will…I think it will be the same at this point at the start (points to the simulation where the current has splits) because the resistances are equal*]
Interviewer:	Why do you think izofana [*will be the same*] between those two?
Sthandiwe:	Because thisha iresistance iyalangana kulama resistor lawa … [*because the resistance is the same between these resistors*]
Interviewer:	But what if iresistance ibingalingani what do you think would've happened?
Sthandiwe:	I think icurrent Ibizo splitter..yes.. [*I think current would split*]

Learners seemed to agree that the reading in the ammeter would be reduced because total resistance of a parallel circuit is less than that of a series circuit (i.e. if the resistors are the same on both circuits). However, Sthandiwe's response about current going to each resistor being the same due to identical resistors led to a follow up question which probed what the reading on the ammeter would be if the resistors were not identical, first in a series circuit then in a parallel circuit. I then changed one of the resistors to 15 ohms and the other remained at 10 ohms in a series circuit. In prediction, Ntando, Lungile, and Sthandiwe said,

Ntando: I think thisha I ammeter izo reader icurrent encane because mawukhuphula ilo i-resistance icurrent iya decrease… [*I think it will read a lesser current because when you increase the resistance, current will decrease*]

Lungile: thisha… uthi uNtando…cela ungiphindela Ntando uthi mawukhuphula i..i-current…thisha ngicabanga ukuthi ehhene angithi amalontuzana ama resistor asenelentuzana angafani shuthi la kulentuzana kule esishintshile sekuzodingeka icurrent eningini ukuze ipass(e) through kule lentuzana esikhuphuliwe shuthi icurrent laphaya ngivumelana noNtando ukuthi isizoncipha….yah isizoncipha ngoba sesidinge icurrent eningi ukuthi ipass(e) through laphaya mesesifika laphaya kwi ammeter reading ngicabanga ukuthi izoncipha yah..yah.. [Teacher*…Ntando says?... can you please repeat Ntando, do you mean when you increase current? Teacher I think that when resistors are unidentical, in the one that has changed (15-ohm resistor) we will need more current to pass through there because (resistance) is increased, therefore I agree with Ntando that the current will decrease…yeah, it will decrease because we need more current to pass through the ammeter*]

Sthandiwe: Shuthi thisha into eyenzeka laphaya (*points at the simulation*) noma i-resistance kuma resistors engafani as long as i-circuit i-connected in series, i-current will be the same throughout. [*it means Teacher what is happening there is that even if the resistance is not the same in the resistor, as long as the circuit is connected in series, the current will be the same throughout*.]

Ntando and Sthandiwe correctly predicted that when more resistance is added to one of the resistors in series, it leads to an increase in the total resistance of the circuit, and, consequently, the reading on the ammeter will be decreased. Although Lungile appears to agree with what Ntando is saying, her reasoning reveals an alternative conception that the cause of a decrease in the ammeter reading as a result of 'a bigger resistance means that more current is needed to pass through'. The correct reasoning should be that a bigger resistor indicates that current flowing in a circuit will experience more resistance and, therefore, the reading on the ammeter will show a reduced current flow. Lungile's alternative conception was previously diagnosed in her audio discussion transcript during concept mapping and appears to persist despite being addressed during teaching activities through the use of the PhET simulations program (Marks, 2012) and a water pipe analogy (Breithaupt, 2000). Scholars such as Küçüközer and Kocakülah (2007); Pesman and Eryilmaz (2010); Shipstone (1984) point out that some alternative conceptions that are rooted in the learner's cognitive structure can be difficult to root out even after teaching and learning.

The interview then moved on to resistors in a parallel circuit.

> Interviewer: Would the current be split equally in the 15- and 10-ohm resistors?
>
> Sthandiwe: Thisha I think icurrent ebizohamba ku 15-ohm ibizobancane compared to i-current ebiya ku 10-ohm ngenxa yokuthi laphaya ku 15-ohm iresistance iningi compared to iresistance eku 10-ohm. [*(teacher) I think the current that will go through the 15 ohm (resistor) will be less compared to the one that flows in the 10 ohm (resistor) because at 15 ohms there is more resistance compared to the resistance at 10-ohm*]

The 3rd interview question - meanings attributed to voltmeter reading

I. The aim of the 3rd interview question

Diagnostic reports show that learners often find it difficult to explain and distinguish between potential difference and electromotive force (EMF; which is the energy provided by the cell) as well as the relationship between potential difference and resistance (Department of Basic Education, 2016, 2017). Since the curriculum does not include the concept of EMF in the Grade 11 syllabus, it was prudent to focus on the concept of potential difference at this stage. Merely giving learners definitions of terms has limited effect, and would not have shown understanding. It was thought, therefore, that if learners could account for the reading of the voltmeter, saying what it meant to them, probing into ideas of potential difference and supply voltage could be sufficient. Rosenthal and Henderson (2006) stress that an instructional approach of teaching the potential difference in electric circuits should put more emphasis on voltmeter readings.

This interview question was also aimed at exploring learners' conceptual understanding of the fact that the sum of the potential differences across two series resistors is equal to the total voltage. It was also deemed essential to find out whether learners understood that the potential difference across resistors in parallel is equal to the total voltage in an ideal circuit, regardless of whether resistances are equal or not. All of these aims can be summed up as exploring learners' understanding of the relationship between resistance and potential difference. Once again, I used the POE technique in administering this interview question.

Learners were shown the circuit diagram in Figure 5.15. (see below) and asked to observe the simulation program, and refer to their concept map for the relationship between series resistors and potential difference.

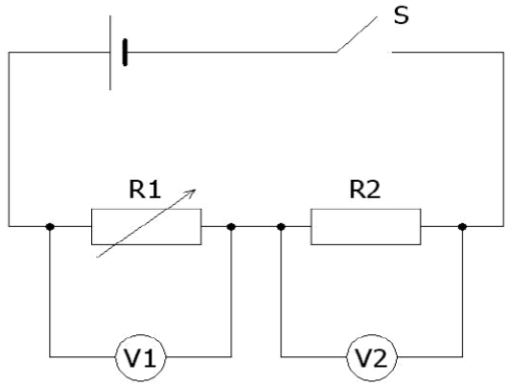

Figure 5.15.: Series resistors and potential difference

The following questions were asked to the learners:

- What will the voltmeters read when the resistances are equal and S is closed? Why?
- What will the voltmeters read when one of the resistances is increased? Why?

Learners were then be allowed to observe the simulation program, after which they would be asked to provide reasons why the circuit behaves this way, with the aim of finding out what meanings the learners give to the voltmeter readings.

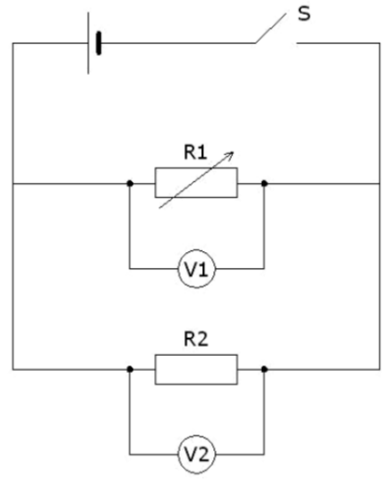

Figure 5.16.: Parallel resistors and potential difference

Learners were shown Figure 5.16., which shows parallel resistors in a circuit and corresponding voltmeter reading. The following questions were asked before switching S on:

- What will the voltmeters read when the resistances are equal? Why?
- What will the voltmeters read when one of the resistances is increased? Why?
- Why does the circuit behave this way?

Learners' responses to the case of resistances connected in a series circuit

Before learners were asked specific questions regarding voltmeter readings in a series circuit, I asked them to explain to the information given by the voltmeter reading. What information does 'V' tell us in a circuit? On the one hand, two learners (Sthandiwe and Lungile) responded by saying that 'V' indicates the amount of voltage needed by a particular resistor in order for the current to flow. Such a response revealed an alternative conception that these learners held regarding voltage or potential difference. They believe that the battery/cell's voltage gives information on how much energy is needed for the current to flow through a resistor. However, a scientifically correct explanation of this is that a voltage (V) can be defined as a measure of the strength of an electrical source of power (i.e., battery or cell) for a given current level (Hagopian, 2006). On the other hand, Ntando correctly referred to the voltmeter as a tool used to measure voltage or potential difference, which is the energy that the power source provides in a circuit. Although this was a simple question, it helped reveal ideas that some of the learners held about 'V' in a circuit.

The interview went on to explore questions that probed learners' understanding of the potential difference in series-connected resistors. The responses showed that learners apply the rule $V_T\ (supply) = V_1 + V_2$ to explain the effect of series connection on the potential difference. Learners also explained that, if the resistance is the same between the two resistors (R_1 and R_2), then the reading on the voltmeter V_1 and V_2 will be the same, but that, if one of the resistors were to change and be bigger than the other, potential difference across each resistor would be divided such that the R with a bigger resistance would measure a higher potential difference across it when compared to the other lesser resistor. The predictions were often correct, but valid reasons were scarce. It has been noted (Marks, 2012) that there are cases in the study of electric circuits where learners have problems with the mental model of potential difference. As a result, whereas answers given to questions might be correct, they may not necessarily be given for the right reason. This was the case in this interview. An example of this can be seen in the extract below:

Interviewer: Let's say uR_1 simukhuphulile lets say mhlampe siyamukhuphula [*let us say R_1 was increased*] ...let me change the simulation…What would happen to the reading in the voltmeter?

Sthandiwe: voltage izo divider [*voltage will divide*]

Interviewer: Kanjani? [how so?] in what sense?

Sthandiwe: Thisha kuzodingeka i-voltage eningi to pass through the charges kule resistor (*learners' voice softens as she sounds unsure of this*) the one ene-resistance eningi compared to kule ene-resistance encane…thisha i..ok..engizama ukusho ukuthi i-series connection iyi-potential difference divider *[(teacher) more voltage will be needed to pass charges through that (points at a bigger resistor) has a more resistance compared to the one with less resistance…(teacher) ok what I am trying to say is that a series connection divides potential difference*.]

The extract shows that Sthandiwe knows that the voltage is divided in the series-connected resistors. However, she sounded unsure when giving explanation of why this was the case. She also expressed that the reading on the voltmeter across the bigger resistor will be more than that of a smaller resistor because “more voltage is needed to pass through the charges in the bigger resistor”.

Learners’ responses to the case of resistances connected in a parallel circuit

Learners predicted that potential difference would be the same across two parallel equal resistors, citing the reason that p.d is the same in a parallel circuit but current divides. Once the resistors were made unequal, the difficulty was immediately increased. Ntando insisted that the potential difference would remain unchanged even if one of the resistors had a bigger resistance. Whereas the others seemed to share that opinion, there were uncertainties in their reasons. I then played the simulation to show the prediction, and learners were delighted to find that their predictions were correct. However, I was not sure whether all learners had predicted this correctly because they understood it or because Ntando (who is one of the high-quality learners) had made this prediction first, thus prompting the others to follow suit. The fact that learners wanted to respond in the same manner as Ntando, whom they trust to be most likely correct, is one of the limitations of conducting a group interview. I was unable to gather concrete evidence that all learners understood that potential difference remains the same even if the resistors are unequal in a parallel circuit. It is therefore recommended for future studies on conceptual understanding that interviews be conducted on individuals rather than on groups.

The 4th interview question – Differentiating between current and voltage

I. Aim of the 4th interview question

The aim of this interview question was to see whether learners were now able to distinguish voltage from current. Having conducted an experiment with them in class and used the PhET simulations, it was expected that learners would know that an ammeter is a device used to measure current while a voltmeter is used to measure potential difference. Learners were also expected to know that ammeters are always connected in series while voltmeters are connected in parallel with resistors, so that current and potential difference, respectively, can be measured.

The circuit diagram in Figure 5.17 below was shown to the learners in the simulations program, and they were asked to observe the simulation.

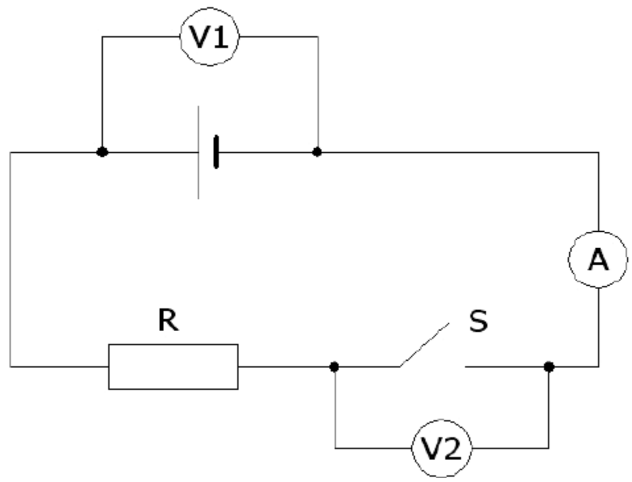

Figure 5.17.: Voltmeters across the battery and switch

The learners were asked to perform the following tasks:

- Comment on what happens to the readings on voltmeters V_1, V_2, when connected as shown, and to the ammeter A, when S is switched ON. Give reasons for your answers.
- With S switched OFF, what can you say about the readings on V_1, V_2 and the ammeter A? Give reasons for your answers.

After the learners had performed the tasks, the switch was turned on in the simulation program and the voltmeters connected as shown in Figure 5.17. Learners were asked to explain any discrepancies between predictions, links in the concept map and practical results.

II. <u>Predictions on meter readings when switch S is open and closed</u>

It was this part of the POE task which gave concrete evidence for the fact that learners understood the difference between current and potential difference. Ntando was a standout performer during this interview as he showed clear understanding of electricity through correct predictions backed by scientifically acceptable reasons. The other interviewees, however, still struggled to provide valid reasons to back their predictions. The results of the interview are shown below.

Readings when switch S is closed

When interviewees were asked to comment on the readings of V_1 and V_2, as well as the ammeter, it was Ntando who predicted that when the switch is closed, current will begin to flow, and this will be shown by the reading in the ammeter which will be the same anywhere in the circuit since a resistor is placed in series. He also predicted that the voltmeter reading on V_1 would be higher than that of V_2 because some of the energy will be used up by the resistor since S offers no resistance. Other learners seemed to agree with this prediction. Lungile said, "yeah (teacher) it is what Ntando is saying" but she did not provide reasons as to why she agreed with him. Although Ntando's prediction was correct, he did not specify the amount of potential difference expected in V_2 (i.e., zero). Nevertheless, his prediction showed that he understood the difference between current and potential difference.

Readings when switch S is open

When S was open, learners realized that since there is no current flowing in a circuit, both voltmeters V_1 and V_2 would be the same. The following is an extract from the transcript, which indicates this in prediction.

Rethabile: The time iswitch ivulekile ayikho icurrent ehambayo [*…when the switch is open, there will be no current flow*]

Lungile: Thisha nami ngivumelana naye uRethabile i…i-voltage izofana i-ammeter ngeke ize ibekhona ngoba ayikho icurrent ehambayo shuthi ivoltage izofana ngoba ilo engani icurrent ayihambi? Ibattery izofana kwi battery nalaphayana kwi switch izofana ngoba ayikho esebenzile kwi resistor..yah izofana [*(teacher) I agree with Rethabile, the voltage will be the same, in the ammeter there will be no current reading, which means the voltage will be the same because there is no current flowing. It will be the same in the battery and in the switch because there is (no energy) used in the resistor*]

Overall summary and conclusion

The semi-structured interview described above was undertaken to try and look more deeply into learners' understanding of the relationships between key concepts of electric circuits. Four learners from different groups were chosen to be interviewed in order to reveal various ideas they had developed during the lessons and concept mapping sessions. A holistic picture of learners' understanding of the relationship between key concepts was expected to show how the learners' knowledge had evolved as they made use of concept maps to deepen their understanding of electric circuits.

At the beginning, when learners talked about current flow, they gave a sequential and conventional description, which may have been a reproduction of how some teachers describe current in circuits during teaching and learning. Shipstone (1984) opines that sometimes a teacher might describe the direction of the current flow as starting from the positive terminal of the battery, passing through the lamp L_1, then splitting up at the junction with some going to lamp L_2 and the rest going to the variable R before going back to the negative terminal of the battery. A conventional direction of current flow and a sequence of events is thus described. This was the case when learners described current flow in a circuit in this present study, just at it had been Marks's (2012) study. Shipstone (1984) argues that teachers ought to be more careful during teaching to avoid sequential descriptions, as this has been proven to be problematic for learners. He further encourages teachers to emphasize a system view of the electric circuit to their learners. These interview questions also revealed some of the alternative conceptions that learners held about the meanings given to resistance. For instance, some learners said that 'a big resistance indicates that more current is needed to pass through'. This alternative conception was also evident in the audio transcripts of their concept map discussions. It therefore seems that some alternative conceptions can persist even after teaching.

Concerning the relationship between current and resistance, learners seem to have a expected understanding of how this relationship can be described. Moreover, when the fact that resistance in parallel has a reduced total resistance was emphasized using the POE task, some learners went as far as explaining that changing resistors from series to parallel will increase the reading on the ammeter, signifying a reduced total resistance in a circuit. The use of a POE technique provided a good opportunity to show whether learners understood concepts or just knew the basics. It also motivated learners to try and provide reasons for their predictions, thus reinforcing deeper understanding. It can be said that learners were not shy about making predictions on the ideas they had about electric circuits. However, there were issues about the scientific quality of the reasons they provided once those predictions were made. Some learners showed understanding of the relationships but lacked reasoning as to why the circuit behaved that way. This was not unexpected, as previous studies have shown similar difficulties (Marks, 2012; Moodley & Gaigher, 2015; Pesman & Eryilmaz, 2010).

The outcomes of the interview showed that although learners have some understanding of the relationship between potential difference, resistance and electric current, it was still important to discuss this with an emphasis on causes and their effects. The goal of this study was to gauge learners' understanding of key concepts, and to have learners reach a point where they have a holistic understanding of an electric circuit as a system and are able to provide valid reasons as to why circuits work the way they do.

CHAPTER SIX – FINDINGS, INTERPRETATION AND DISCUSSION OF RESULTS

This study explored Grade 11 learners' understanding of key concepts in electric circuits, as they were engaged in three collaborative concept mapping (CCM) activities during teaching and learning of the electric circuits topic. Guided by a constructivist framework, the goal of the study was to observe and examine the evolution of learners' understanding as they deepened their knowledge of this topic through the construction of concept maps. Data in the form of concept maps, transcribed audio recordings of the concept mapping process, and transcribed audio recording of the semi-structured interview were generated and presented in the previous chapter. The first level analysis of the concept maps was guided by the Novak analytical framework of concept maps (Novak & Gowin, 1984). I also presented the findings from the semi-structured focus group interview which I conducted with four (4) learners, one (1) from each of the four (4) groups that were involved in the CCM. In this chapter, I present the thematic analysis as described by Braun and Clarke (2014), of the findings and interpretations presented in the previous chapter. In the thematic analysis I presented emerging themes from the concept maps collaboratively constructed by the learners in four (4) groups as well as their responses from the semi-structured interview. The purpose of this analysis was to identify patterns that were relevant to answering the two research questions which guide this study.

The two research questions were answered in the form of assertions as described by Gallagher and Tobin (1991). This approach posits that qualitative researchers make sense of their findings through assertions and sub-assertions. In this study, each assertion corresponds to a particular theme, and is supported by an analysis of the assertion in terms of the case at hand. I also provide examples of screenshots from the concept maps, excerpts from the audio discussions and/or interview discussions as supporting evidence for the assertions I propose. This study was guided by the following two research questions:

1. What are Grade 11 Physical Sciences learners' understanding of key concepts in electric circuits?

2. How have Grade 11 Physical Sciences learners' understanding of key concepts in electric circuits developed as they collaboratively constructed concept maps to deepen their understanding of these concepts?

This chapter is divided into three main sections. I present assertions related to each of the two questions, followed by a discussion, and then conclude with a summary of the researched case of 20 Grade 11 Physical Sciences learners collaboratively constructing concept maps in an attempt to understand the key concepts in electric circuits and how they relate to each other.

6.1. What are Grade 11 Physical Sciences learners' understanding of key concepts in electric circuits?

My answer to the first research question is provided in the main assertion below. The assertion is a combination of sub-assertions, put together to answer different aspects of the answer. Each theme starts with a sub-assertion which I support by providing evidence from the findings on the case analysis.

Assertion 1: *From the teaching that encouraged constructive learning through collaboratively constructing concept maps, learners developed understanding of the key concepts of current, resistance, and potential difference. Learners also developed understanding of the relationship between the electric current and resistance. Learners applied the following mathematical rules:* $I_T = I_1 + I_2 \ldots$ *and* $I_T = I_1 = I_2 \ldots$ *to explain the effect of resistances to the electric current, as well as* $V_{T\,(supply)} = V_1 + V_2 \ldots$ *and* $V_{T\,(supply)} = V_1 = V_2 \ldots$ *to explain the effect of series and parallel resistances to the potential difference. However, learners showed some alternative conceptions with regard to the meanings attributed to the voltmeter readings that hindered some of them from fully understanding the essential concept of potential difference.*

6.1.1. Learners’ understanding of the key concepts (current, resistance, and potential difference)

Assertion 1a: *Learners had expected understanding of electric current, potential difference, and resistance as key concepts in electric circuits, which they further developed as they constructed concept maps.*

Electric current as the key concept

When it comes to ideas about an electric current, learners expressed a few of these in their concept maps and during the interview. In most instances, current was expressed in relation to other key concepts such as potential difference/voltage and resistance. Learners’ concept maps showed that they regarded current as a “central concept”. For instance, in the first round of CCM, learners in Group A made the following propositions about relationships between current and the other concepts on their map (screenshot from Figure 5.1):

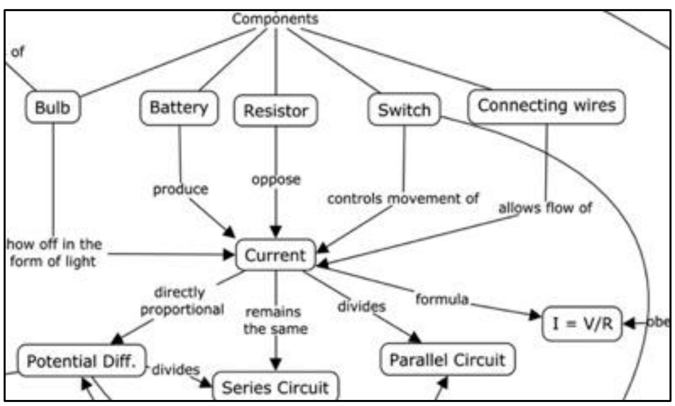

Figure 6.1.: Screenshot from (Figure 5.1)

In the screenshot above, learners centered the components of an electric circuit around the current key concept because of knowledge that the working of an electric circuit is dependent on the flow of current. Hence, learners understood current to be the key and central concept in electric circuits. They commonly related the other concepts to it. Group C defined electric current as “the flow of charges”. The remaining groups (B and D) mainly showed current in relation to potential difference and resistance. The understanding that current is something flowing inside a circuit when a switch is closed was also mentioned during the interview when Ntando said: “uhm uma uyivala leya switch leyana ama…i-current across ama wires izo-starter i flow” [*uhm if we close that switch…the current across the wires will start to flow*]. Sthandiwe described the current flow as something moving from “the positive part of the battery to completing the circuit”. Shipstone (1984) explains that sometimes a teacher might describe the direction of the current flow as being from the positive terminal of the battery, passing through the lamp L_1, then splitting up at the junction with some going to lamp L_2, while the rest goes to the variable R and back to the negative terminal of the battery. The view of the electric current that these learners have is called a closed-circuit model (Osborne, 1980; Shipstone, 1984), and is a correct description of the current. However, they did not mention which charges (positive, negative or electrons in particular) were able to flow in a circuit, or the units of measurement. They did however, show a link between current and Ohm’s Law (which was indicated by a formula $I = V/R$). Tarciso Borges and Gilbert (1999) assert that in a closed-circuit model, learners describe current as something circulating around the circuit in a particular direction, where the circuit only functions when the switch is closed. They contend that this model recognizes the bipolarity of the circuit components (in this case the battery) but suggest that current is not conserved because learners may have an idea of the electric current but lack the ability to differentiate between current and energy.

Potential difference as the key concept

The potential difference key concept appeared to be well understood by learners. In their concept maps, learners stated that the potential difference or voltage is produced by the battery in the electric circuit. Group A referred to the potential difference as a stored energy. The clearest description of this key concept was expressed by Group D in their round 1 concept map, and is shown in the screenshot (from Figure 5.3.) below.

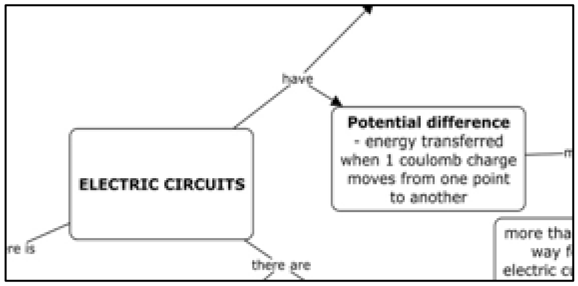

Figure 6.2.: Screenshot from (Figure 5.3.)

Learners described the potential difference as the energy transferred when 1 Coulomb charge moves from one point to another in an electric circuit. Group D said that it can be measured across a resistor. They went on to discuss the explanation of this concept in round 2 of concept mapping,

Khule: I-potential difference iyona le esikhiphela i-current [*The potential difference is what produces current*]

Nolwazi: I-potential difference ima eh eh i-move ama-charges ukuze ama-charges akhiph…[*The potential difference, wait eh ehe moves charges so that charges produ…*]

Khule: I-potential difference is measured between two point. The potential difference between two points in a conductor is work done to move a charge.

Mhlengi: I-potential difference mina engikwaziyo is measured between two points angithi uthisha uze wenza example wabeka i-light bulb here waqeda wabeka leyanto e calculator i-potential difference yabekwa between lendawo le isaya khona nala isiphuma yabona okushuthi yonake i-calculator la phakathi nendawo kulama two points lawa. [*The potential difference, from what I know is measured between two points, remember the teacher made an example by placing a light bulb here (points) and then placed that thing (ammeter) that calculates the potential difference between those two places*]

(silence)…

Nolwazi: Izwa izwa angithi i-potential difference iphuma kwi battery ne i-cause ama-charges ukuthi a move mese move(ile) ama-charges mese ku create(eka) i-current [*Listen, listen, the potential difference comes from the battery, then causes charges to move, which creates the current*]
[Group D Round 2 CCM]

The above excerpt is supporting evidence that learners understood the concept of potential difference as the energy transferred by a resistor, and can be measured between two points.

Learners also mentioned the idea that the potential difference and voltage are one and the same thing. The excerpt is also evidence that CCM stimulated discussions about key concepts where learners constructed meanings of these concepts. Another important point to note at this stage is that Group D was diagnosed with power supply alternative conception in the first round of CCM, even though this alternative conception appeared to be addressed. Whereas during round 1 CCM learners discussed as follows:

> Nolwazi: Battery is...
>
> Khule: is a..mese ubhala u-power source…mese uthi power source produces electric current [*is a…and then write 'power source'…and say the power source produces current*] [Group D Round 2 CCM]

this idea had changed in round 2:

> Nolwazi: Izwa izwa angithi i-potential difference iphuma kwi battery ne i-cause ama-charges ukuthi a move mese move(ile) ama-charges mese ku create(eka) i-current [*Listen, listen, the potential difference comes from the battery, then causes charges to move, which creates the current*] [Group D Round 2 CCM]

These excerpts from the discussions show that, whereas learners initially thought of a battery as a constant current source, this idea changed in round 2 of CCM. Learners had a scientifically correct view that the battery produces voltage/potential difference which then causes charges to move, thus creating current. Therefore, the efforts to address this alternative conception were successful, and helped learners' understanding to develop.

Learners also noted that the potential difference is directly proportional to the electric current in a circuit, provided the temperature remained constant. This is an important relationship and revealed understanding of the Ohm's Law.

Resistance as the key concept

With regards to the resistance in a circuit, learners showed that they understood this concept very well. They proposed that resistance is caused by a resistor in a circuit, and that a light bulb is one of the examples of a typical resistor. Evidence from the concept maps and transcribed audio discussions suggests that learners thought of a resistor as “something that opposes current” (as seen from the screenshot below.

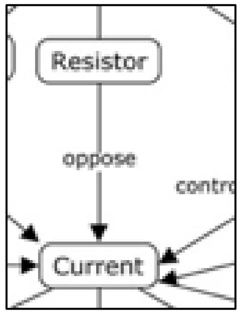

Figure 6.3.: Screenshot from (Figure 5.1.)

Learners also explained that a resistor uses up energy as current flows through it. They made real world examples (prior knowledge) in terms of the energy conversions that occur within the resistor. The following screenshot from Group D round 1 concept map provides important information regarding their understanding of what a resistor does.

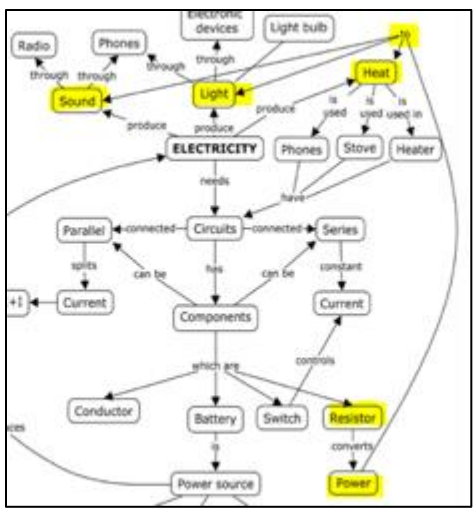

Figure 6.4.: Screenshot from (Figure 5.4.)

Group D proposed that a resistor converts power to heat, light, and sound. The concept of power in this context was used synonymously with energy, since power is the capacity of energy being used up by the resistor. Group C went a step further to explain that the resistance of a circuit depends on the thickness of a conductor, the length of a conductor, and the temperature of a conductor. I infer that learners understood the concept of resistance in a circuit as something that opposes current and can convert energy carried by the charges to various forms.

6.1.2. Learners' understanding about the relationship between electric current and resistance

Assertion 1b:

Learners understood the relationship between electric current and resistance

Learners showed understanding of the relationship between electric current and resistance in a circuit. In their concept maps, learners first made a proposition that a resistor resists the flow of current. Group C expressed that *"the greater the resistance the smaller the current"* [Figure 5.10]. Below are the screenshots from Figures 5.6. and 5.10. that show how learners view the relationship between current and resistance.

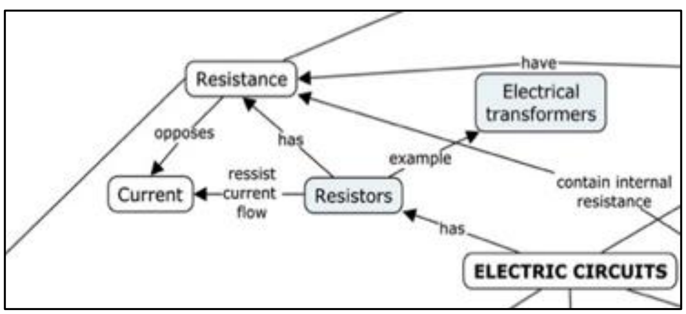

Figure 6.5.: Screenshot from (Figure 5.6.)

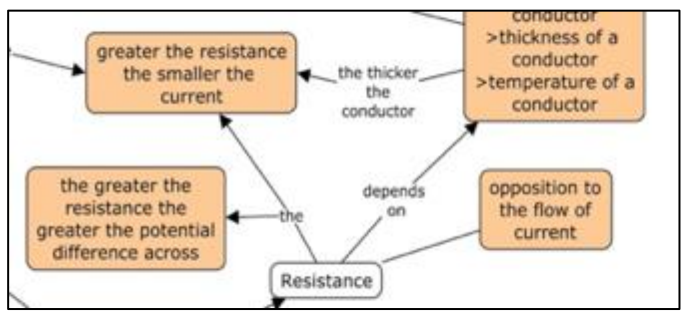

Figure 6.6.: Screenshot from (Figure 5.10.)

The following discussion ensued among the Group B learners, during the 2nd round of CCM:

Ntando: I-resistor ikhipha i-resistance...i-resistor iyi-resistance [*a resistor causes resistance… a resistor is a resistance*]

Melusi : I-resistor iyi-resistance kwi-current..yebo [*a resistor is a resistance to the current*]

Sthembiso: Aybo! eh eh asithi i-resitor has iresistance in a bulb angithi phela? [*aybo! Eh eh let us say, a resistor has resistance in a bulb right?*]

Melusi: Cha, wena ithi resist current ..mese uthi current flow [*No, you must say (it) resist the current*]

Sthembiso: Angini i-resistance nale..i-bulb...i-bulb i-resistor? [*I mean, this is also resistance…a bulb…a bulb is a resistor?*] [Group B, 2nd round of CCM]

The above excerpt from the audio transcript shows learners discussing the two key concepts (current and resistance). They seem to understand how these concepts are related, even going on to say that a bulb has resistivity. Although learners did not elaborate on how a bulb can act as a resistor, they still pointed out that a resistor can resist the flow of current in a circuit. This proposition shows understanding of the relationship between resistance and current. In an interview, learners described this relationship in terms of the readings in the ammeter when there is a change in the resistivity of the circuit. The following extract is an example of how Sthandiwe and Lungile described this relationship,

Sthandiwe: Yebo thisha nami ngicabanga kanjalo, ukuthi mhlampe, ok thisha njengoba sibona ukuthi icurrent iyaflow(a) laphaya, ngcabanga ukuthi enye into eyenza ukuthi icurrent ibe u 0.90 Amps, mhlampe [*yes (teacher) I also think that maybe…ok (teacher) as we can see the current flowing there, I think one of the reason why it 0.9 amps is because*] resistance has something to do with current esiyibona laphayana kwi-ammeter [*that we see in the ammeter*]… maybe if i-resistance iningi icurrent izobancane icurrent ezoflow(a) mhlampe I assume ukuth iresistance kule circuit iningi njengoba icurrent incane nalapha kwi ammeter [*maybe if the resistance was big, the current flowing would be small, my assumption is that the resistance in this (points to the simulation) circuit is small as shown in the ammeter*]

Lungile reiterated this relationship by using more scientific language.

Lungile: Shuthi laphaya uSthandiwe mechaza shuthi mina ngibona ukuthi i-resistance ne-current ba inversely proportional shuthi okunye maku…iresistance mayinkulu, i-current izobancane, shuthi i-current mayincane iresistance izobankulu. [*it means that there (points to the sim.) as Sthandiwe was explaining that resistance and current are inversely proportional… if there is a big resistance, the current will be small, and if the current is small, the resistance must be big*]

The above extracts from discussions during CCM show that learners now have a better understanding of the relationship between the concepts of current and resistance. This provides evidence of how engaging in CCM can help learners improve their understanding of concepts. The relationship between the electric current and resistance in a circuit is one of the most fundamental relationships in the study of electric circuits because it helps us understand the basic principle of Ohm's Law (Marks, 2012). It was therefore important that learners express some understanding of this relationship.

6.1.3. Learners' understanding of the effect of series and parallel connections on the electric current and potential difference

Assertion 1c: *Learners applied the mathematical rules: $I_T = I_1 + I_2 \ldots$ and $I_T = I_1 = I_2 \ldots$ to explain the effect of resistances to the electric current as well as $V_{T\ (supply)} = V_1 + V_2 \ldots$ and $V_{T\ (supply)} = V_1 = V_2 \ldots$ to explain the effect of series and parallel resistances to the potential difference. However, learners showed some alternative conceptions with regard to the meanings attributed to the voltmeter readings that hindered some of them from fully understanding the essential concept of potential difference.*

The effect that resistors connected in series and then in parallel have on the potential difference and electric current was well understood by the learners. This was evident from both the learners' concept maps and their lengthy discussions during the CCM activity. In the next page, are the screenshots from each group's concept map (A, B, C, and D) where they showed how current and potential difference behaves in relation to a series-parallel connection.

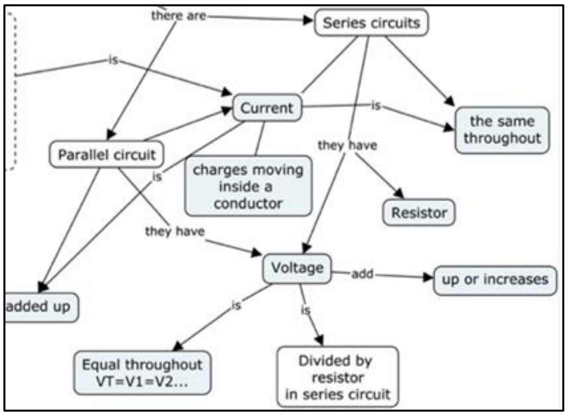

Figure 6.7.: Screenshot from (Figure 5.1. - Group A)

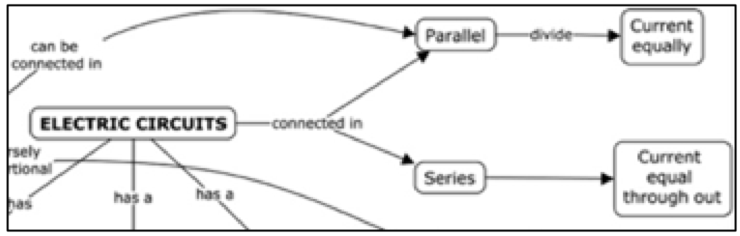

Figure 6.8.: Screenshot from (Figure 5.2. - Group B)

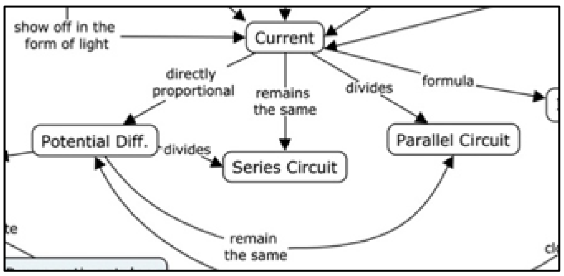

Figure 6.9.: Screenshot from (Figure 5.3. - Group C)

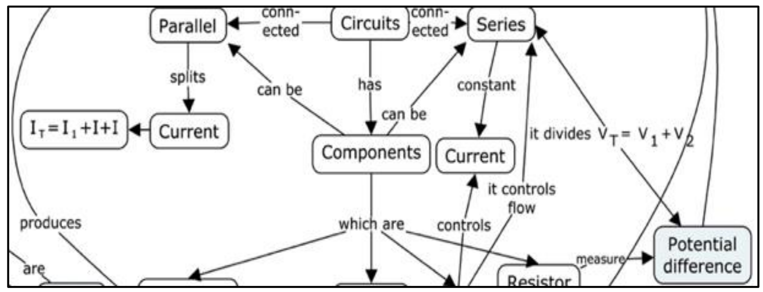

Figure 6.10.: Screenshot from (Figure 5.8. - Group D)

Data from the concept maps indicate that learners are aware of the effect that a series and parallel connection can have on both current and potential difference. The representation of this 'effect' using mathematical equations showed that learners have expected understanding of these concepts as well as their application to problem-solving in electric circuits. This was also evident in the audio transcripts during collaborative episodes (as shown in the excerpt below) where learners discussed how the current would behave if resistors were connected in series or parallel.

Nolwazi:	Besekuthi lana lokhu oku-connected in parallel, i-current yenzenjani, iya-splitter? but doesn't divide, iya-splitter? [*And then here where it's connected in parallel, how does the current behave? Does it split? But doesn't divide, it splits?*]
Sthandiwe:	Ok parallel circuit splits current...
Nolwazi:	Splits current neh? after that mesekuthi kuma series… eish! yabona sengenza ukuba umuntu omnyamake ha ha ha, i-current iba constant [*and then in series… eish! You see now I'm being a black person ha ha ha, the current becomes constant*]
Snakho:	Ama parallel circuit are current dividers mesekuthi..ama series circuit… [*The parallel circuit are current dividers, and then the series circuit…*]
Nolwazi:	Imake shuthi mawubhala iformula yakhona ubhala uthini? [*Wait! Which formula are we going to write?*]

Snakho: Ehhe! aybo ithi $I_T = I_1$ yabo kanjalo [*Yes! Oh no, you must say* $I_T = I_1$]
Sthandiwe: Kule usho e-parallel? [*In the one that is parallel?*]
Snakho: Ku-parallel uthi $I_T = I_1 + I_2$ yabo kuyaqhubekake makuwukuthi kuyaqhubeka...parallel yabo cos once ya-split i-current ifike ihambe la at a point i-split meseyahamba at a point ifike i-split yabo intekanjalo yabo [*In the parallel you say* $I_T = I_1 + I_2$ *it continues…in the parallel, you see once the current splits, it goes to a point where it splits and then goes to a point where it splits, you know something like that*] [1st Round of CCM, Group D]

Ideas presented by learners in the above excerpt were indicative of clear understanding of the key concept of electric current in relation to the resistors that are connected in series and parallel. Such knowledge forms the basis of Ohm's law and is one of the learning objectives in the CAPS curriculum.

The effect of identical parallel-connected resistors to the electric current

During an interview, all learners commented that the electric current would remain the same in series connection but would be split if the resistors are in parallel. Although the responses were correct, it was essential to ask questions that explored situations where resistors were identical or unidentical, because the changes in the resistances also affect the flow of current in an electric circuit. In a prediction related to the comparison of ammeter reading (current) in a parallel circuit, learners said that the reading in the ammeter will decrease when the total resistance of a circuit is increased. This is shown by the following discussion between the interviewer and Ntando:

Interviewer: If the same resistors were connected in parallel, what would happen to the reading in the ammeter?
Ntando: I think thisha izokhuphuka [*I think (teacher) it will increase*]
Interviewer: Why do you think that is going to happen?
Ntando: kodwa thisha mina ngizoyichaza in terms of ama calculations ukuthi njengoba sino 10 resistor ngenhla no 10 resistor ngezansi shuthi i-current izo-splitter ilingana kule resistor engenhla nalengezansi shuthi since lama resistor e-parallel, I think ukuthi i-total resistance azoyi adder njengoba e-parallel itotal resistance yawo isizobancane ngeke isaba… ngeke ize ifike ku 10…[*but (teacher) I will explain it in terms of calculations that we have a 10 (ohms) resistor at the top and another 10 (ohms) resistor below it means the current will split equally to the top and bottom since the resistors are connected in parallel, I think their total resistance will be small…*]
Lungile: Nami ngivumelana noNtando ngoba kwi parallel circuit ilo ilo i-current iya divideka so lokhu okushiwo uNtando i think kuyikona. [*I also agree with*

Ntando because in parallel circuit it is where current will be divided, I think what Ntando is saying is correct]

Rethabile: Thisha ngivumelana nabo. [*I also agree with them*]

Sthandiwe: Nami ngivumelana nabo ukuthi kule connection le i-current izokhuphuka kodwake…nokuthi i-total resistance izoba…(paused) ok…ngifuna ukuthini?..ehh ngifuna ukuthi thisha i..i..i-current i..ngicabanga ukuthi izofana kuleli point leli (points at the sim.) lokuqala naleli lesibili (points at a sim) ngoba i-resistance iyalingana [*I also agree that this (parallel) connection current will increase but, total resistance will (paused) ok what do I want to say? Uhm I want to say that (teacher) the current will…I think it will be the same at this point at the start because the resistance is the same*.]

Interviewer: Why do you think izofana (will be the same) between those two?

Sthandiwe: Because thisha i-resistance iyalingana kulama resistor lawa… [*because the resistance is the same between these resistors*]

Learners agreed that the reading in the ammeter will decrease because total resistance in a parallel circuit is less than that of a series circuit. However, Sthandiwe's response about the current going to each resistor being the same due to identical resistors led to a follow up question which probed what the reading on the ammeter would be if the resistors were unidentical.

Interviewer: But what if i-resistance ibingalingani what do you think would've happened?

Sthandiwe: I think i-current ibizo splitter..yes.. [*I think current would split*]

Her response seems to suggest that if unidentical resistors are connected in parallel, the electric current would split. She was then asked, what would happen if the sizes of the resistors were changed? She then replied,

Sthandiwe: Thisha I think i-current ebizohamba ku 15 ohm ibizobancane compared to i-current ebiya ku 10 ohm ngenxa yokuthi laphaya ku 15 ohm i-resistance iningi compared to i-resistance eku 10 ohm. [*Teacher, I think the current that will pass through the 15 ohm (resistor) will be small compared to the current that will pass through the 10 ohm (resistor) because (where) there is more resistance at the 15 ohm (resistor) compared to the 10 ohm (resistor).*]

The above excerpt shows evidence that Sthandiwe understands that more current flows through a smaller resistor than a bigger one. Her response also confirms understanding of the inverse relationship between the current and resistance in a circuit that she and her fellow group members drew in a concept map.

The effect of unidentical series-connected resistors on the electric current

When the resistance was changed in a series circuit, learners predicted that when we add more resistance (to one of the resistors in series), that leads to an increase in the total resistance of the circuit. Below are responses from Ntando and Sthandiwe:

Ntando:	I think thisha I ammeter izo reader i-current encane because mawukhuphula ilo i-resistance i-current iya decrease… [*I think it will read a lesser current because when you increase the resistance, current will decrease*]
Sthandiwe:	Shuthi thisha into eyenzeka laphaya (points at the simulation) noma i-resistance kuma resistors engafani as long as i-circuit i-connected in series, i-current will be the same throughout. [*it means (teacher) what is happening there is that even if the resistance is not the same in the resistor, as long as the circuit is connected in series, the current will be the same throughout*.]

Ntando and Sthandiwe made the correct prediction that when we add more resistance (to one of the resistors in series), that leads to an increase in the total resistance of the circuit and, therefore, to a decrease in the reading on the ammeter. This was further confirmation that learners understood the inverse relationship of resistance and electric current.

The effect of series and parallel connected resistors to the potential difference

When learners were asked specific questions about the effect of resistances to the potential difference, the responses showed that they applied the rules: $V_{T\ (supply)} = V_1 + V_2$ and $V_{T\ (supply)} = V_1 = V_2$ to explain the effect of series and parallel connection to the potential difference. Learners also explained that (in a series circuit) if the resistance is the same between the two resistors (R_1 and R_2) then the reading on the voltmeter V_1 and V_2 across these resistors will be the same. However, if one of the resistors were to change and be bigger than the other, potential difference across each resistor would be divided such that the 'R' with a bigger resistance would measure a higher potential difference across it when compared to the other lesser resistor. These responses were good but learners found it difficult to explain why the circuit works this way.

In some cases, the responses that learners provided were often correct, but valid reasons were scarce. This was also noted in Marks' (2012) study. He argued that one of the reasons learners often fail to provide good reasons for questions related to potential difference was due to problems with the mental model of potential difference. As a result, answers given to the questions might be correct without necessarily being backed by the right reasons. An example of this can be seen from the following extract:

Interviewer:	Let's say uR_1 simukhuphulile let's say mhlampe siyamukhuphula [*let us say R_1 was increased*]..let me change isimulation
Sthandiwe:	Voltage izo-divider [*voltage will divide*]
Interviewer:	Kanjani? [*how so?*] in what sense?
Sthandiwe:	Thisha kuzodingeka ivoltage eningi to pass through the charges kule resistor (*learners' voice softens as she sounds unsure of this*) the one ene-resistance eningi compared to kule ene resistance encane…thisha i..ok..engizama ukusho ukuthi i-series connection iyi potential difference divider *[(teacher) more voltage will be needed to pass charges through that (points at a bigger resistor) has a more resistance compared to the one with less resistance…(teacher) ok what I am trying to say is that a series connection divides potential difference.*]

The above extract shows that, whereas Sthandiwe knows that potential difference will be divided if resistors are in series, she finds it difficult to explain why this is the case. She goes on to say that the reason a bigger resistor will show a higher voltmeter reading is because "more current is needed to pass through it". This reasoning is incorrect and is similar to an alternative conception that was identified in Lungile's explanation when she first responded to the question related to the meanings given to the voltmeter readings. Attempts to address this alternative conception by the teacher seem to have failed, despite having used resources such as the PhET simulation (Marks, 2012) and a water tank analogy (Breithaupt, 2000) to explain the concepts of potential difference and resistance. It has been argued by scholars that alternative conceptions that are deeply rooted in the learner's cognitive structure can be difficult to root out (Küçüközer & Kocakülah, 2007; Nkopane et al., 2011; Van der Merwe & Gaigher, 2011). However, this particular alternative conception does not necessarily show learners' lack of understanding of the concepts but rather that learners lack mental models of concepts (Marks, 2012).

Nevertheless, some alternative conceptions that were addressed in the classroom appeared to have changed. For instance, Lungile and her Group A team stated in their concept map that a battery is a source of current (as seen below in the screenshot from Figure 5.1.). This is a *constant current source* alternative conception which is also found in the literature (Cohen et al., 1983; Heller & Finley, 1992; Psillos, Tiberghien, & Koumaras, 1988).

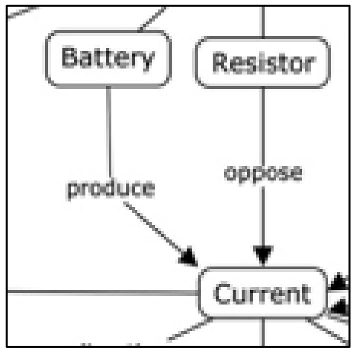

Figure 6.11.: Screenshot from (Figure 5.1. - Group A)

Although this group did not remove this proposition from their concept map, Lungile's response during the interview when asked about the meanings attributed to the reading shown in the ammeter showed that this alternative conception had been removed from her cognitive structure:

Interviewer: What affects the ammeter reading, and why?

Lungile: Thisha ngicabanga ukuthi ehh engine ebonile ekuqaleni ukuthi ibisavulekile? mese usuyivala ehh ilo..ilo..i energy esuka kwi battery isiyakwazike manje ukwenza iflow(a) njengoba kade eseshilo Sthandiwe ukuthi izoqala from the positive side shuthi ngeskhathi isiflow(a) laphoke sekuzo determine(ka) i-current esi-flow. Shuthi icurrent eflow(ayo) idluliswa ibattery yah mese uyatholake laphaya ukuthi icurrent iwubanike. *[(teacher) I think that as you saw previously that it (switch) was open? If you close it, the energy from the battery is able (to cause) the flow, as Sthandiwe said (earlier) that the current will flow past the battery from the positive side, it means (that at) the time it flows we can determine the current that is flowing. It means the reason current flows is because of the battery…yeah, then you can get there (points at the ammeter) the value of a current*.]

The interview further probed learners' understanding of how the parallel connected resistors affects the potential difference. The responses showed that learners had the basic understanding of what happens to the potential difference in the case of parallel connection. In the POE task, learners predicted that potential difference would be the same across two parallel equal resistors, arguing that the *"reason is that the potential difference is the same in a parallel circuit but current divides"* [Rethabile]. Once the resistors were unidentical, the difficulty was immediately increased. Ntando insisted that the potential difference would remain unchanged even if one of the resistors had a bigger resistance. Whereas the others seemed to agree with his prediction, there were uncertainties in their reasons. One could therefore not be totally sure whether all learners predicted this correctly because they understood it or because Ntando (who was a high-quality learner) had made this prediction first, thus prompting the others to follow suit.

I infer from this that some learners had difficulty in understanding the concept of voltage/potential difference in relation to resistance. They did not clearly understand the meanings attributed to the voltmeter reading, but they were able to apply the rules: $V_{T\ (supply)} = V_1 + V_2$ and $V_{T\ (supply)} = V_1 = V_2$ to explain the effect that a series and parallel resistors have on potential difference. The fact that some learners found it difficult to substantiate their answers was an indication that they did not fully understand these concepts (although they know their mathematical expressions). Their superficial knowledge of the relationship between resistance and potential difference also indicated that learners did not fully understand the concept of Ohm's Law, even though they could state it and write it mathematically. Again, this showed that learners' thinking is focused more on knowing formulas and how they work instead of in-depth understanding of the key concepts.

6.2. How have Grade 11 Physical Sciences learners' understanding of key concepts developed as they constructed concept maps?

In order to find evidence of whether learners' understanding of key concepts had developed, I analyzed the concept maps that each group constructed over the three rounds of CCM as well as the audio discussion transcripts. Evidence of how learners' understanding of key concepts improved over time is given through the following assertion:

Assertion 2: *Collaborative concept mapping prompted discussion amongst learners about scientific concepts, and this improved their understanding of the relationships between key concepts (resistance and electric current) as they continued to construct and reconstruct their concept maps. The development of understanding of key concepts was revealed by their concept maps becoming more complex over the three rounds of CCM. In addition, the integration of relevant prior knowledge to new knowledge in the learning of key concepts (resistance, electric current, and potential) played a partial role in the development of understanding during concept mapping, since previously learners had mainly focused on memorizing facts without much care about how those facts relate to their daily personal experiences.*

In the following section, I have broken down the above assertion into three parts which I elaborate on. I do a thematic analysis of the case to answer the question of whether learners' understanding had developed as they constructed concept maps.

6.2.1. Learners' development of understanding during discussions as they co-construct meanings of key concepts

Assertion 2a: *Collaborative concept mapping prompted discussions amongst learners about scientific concepts, and this improved their understanding of the relationships between key concepts as they continued to construct and reconstruct their concept maps.*

As expected, the CCM engaged learners in discussions about the relationships between concepts in electric circuits. During the CCM, learners worked together on a common task to create shared meanings of the relationships between concepts. The construction of a concept map gave opportunities to members of the group to articulate their thoughts about concepts, which improved their understanding of key concepts. This was in line with van Boxtel et al.'s (2002) finding that, when learners engage in a CCM activity with their peers, they develop conceptual understanding of concepts. The following example from the Group D audio transcript shows the process of co-construction of meanings which led to the development of understanding of the relationship between potential difference and resistance.

Nolwazi: I-potential difference ungayi measure(isha) noma ilaphi [*You can measure the p.d. anywhere*]

Mhlengi: Between any two points as long as isetshenzisiwe lapho imeasure(isha) khona… Yah! as long as isetshenzisiwe ngeke, uthi lo line lo (points) ingekho into eysebenzisayo mese nje ugaxa la ayngeke... [*Between any two points as long as it's being used there… Yeah! As long as it's being used, you can't just say thi line here (points) even if it's not being used*]

Nolwazi: Kwi kwi series i-potential difference isuke injani? [*How is the p.d. in a series (circuit)?*]

Mhlengi: Uzo measure(isha) khona futhi [*You can measure it there as well*]

Nolwazi: Ima! isuke i-divided noma isuke [*Wait! It's being divided or?*]

Mhlengi: Anizweni la anizweni la i-potential difference [*Listen here, the p.d.*], is an amount of energy transferred in each point.

Khule: So kuchaza ukuthi layidlula khona ifike ithathwe iqhubeke ihambe, transferred yabo..angithi uma into i-transferred uyaythatha uphinde ishintshe uyise kwenye indawo angithi? so lakuthiwa khona connected in series it divides.. [*So, it means that it goes past a point where it is transferred…I mean if something is transferred you take it somewhere else right? So, where it is connected in series it divides*]

Nolwazi: Uma i-connected in series? [*If it's connected in series?*]

Khule: Iya divide uma i-parallel i-remain constant [*It divides then in parallel it remains constant*]

Mhlengi: Imake sikhuluma ngani vele? [*Wait…what exactly are we talking about?*]

Nolwazi: Nge potential difference ukuthi uma angithi sithena kuma resistor ungakwazi uku measure i-potential difference ne then uma ikwi-series circuit iya divide if ikwi-parallel iba constant. [*About the potential difference, we said we can measure it (across) a resistor and if it's a series circuit, it will divide*] [Group D, 1st Round of CCM]

This collaborative episode contributed to the learning of the concepts of potential difference and resistance. Even learners who at times appeared to be confused were able to get help from their peers who pointed out inconsistencies and were able to give more explanation. I suggest that the CCM helped develop learners' understanding due to such discussions.

6.2.2. Learners' development of understanding of key concepts as they constructed their concept maps.

Assertion 2b: *The development of understanding of key concepts was revealed by learners' concept maps becoming more complex over the three rounds of CCM.*

Learners' concept maps improved over time as they constructed and reconstructed them. These improvements were indicative of learning that had taken place, leading to the development of understanding of concepts. The following example of concept maps drawn by Group C over three rounds of CCM illustrates the development of their understanding of key concepts.

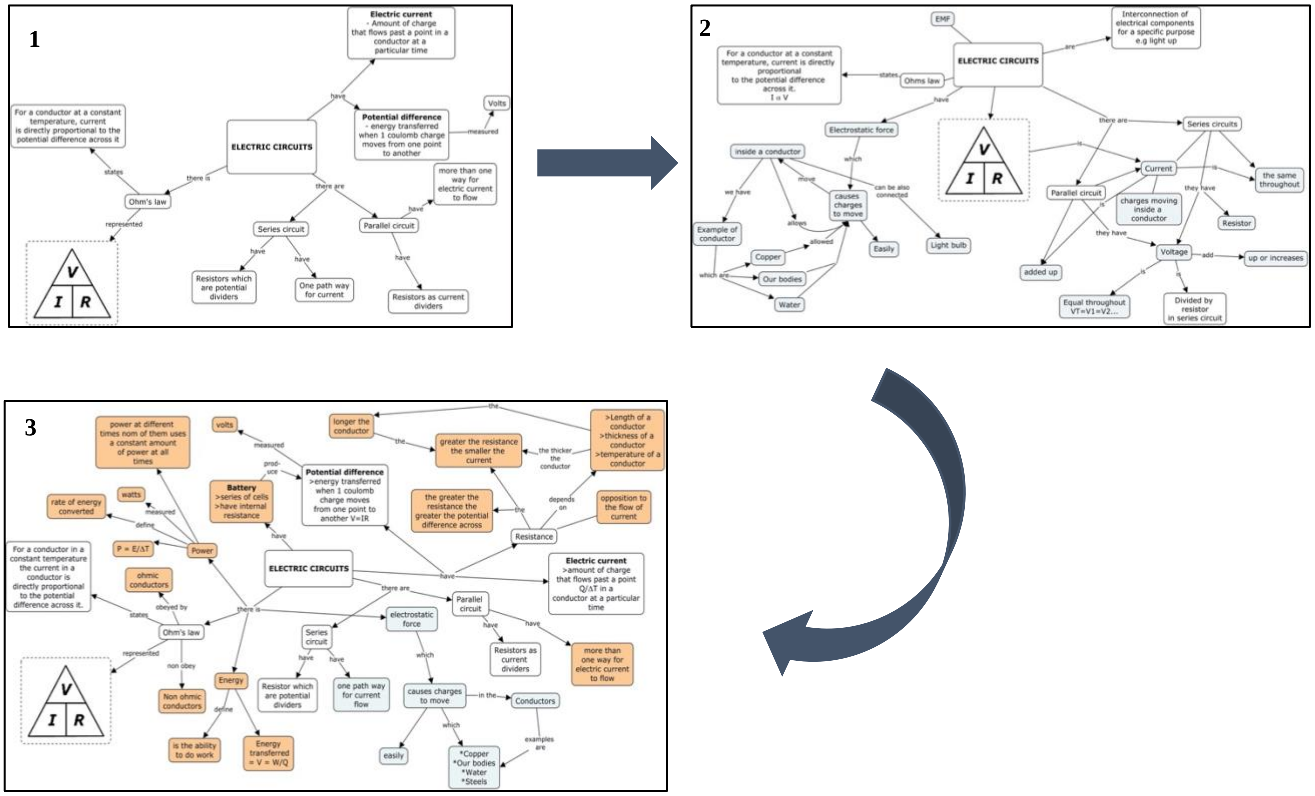

Figure 6.12.: Different concept maps constructed by Group C in three rounds of CCM

The above concept maps show how learners' understanding of concepts evolved over time. In the first concept map, learners mentioned a few expected concepts, namely, current, potential difference, and resistance, but did not elaborate or provide examples of their relationships. They did however, express the relationship between current and resistance in a circuit. Learners did not mention anything regarding the components of an electric circuit (e.g. ammeter, conductors, switch, and a battery as a power source); absence of such information indicated naivety in their understanding of the topic. The second concept map showed slight improvement as learners were zooming in on specific concepts such as, charges (flowing inside a conductor), electrostatic force (causing charges to move), and types of conductors (i.e. ohmic and non-ohmic conductors). They also provided real-world examples of conductors, namely, copper, water, and a human body (as something that can conduct electricity). Yet, they did not mention anything about insulators and semi-conductors which was expected as their prior knowledge from Grade 10. The relationship between voltage and resistance was correctly expressed; and was described in words as well as by formula $V_T = V_1 = V_2 \ldots$ to show how voltage behaves in parallel-connected resistors. Learners in this group also drew the Ohm's law triangle to show its application in solving problems related to electric circuits. The information learners provided in their second concept map showed that their understanding of the relationships between concepts was gradually improving. The third and final concept map was more complex, and revealed a lot of in-depth understanding of key concepts. Learners also showed more confident in their understanding of the topic by going over and above to describe some of the key concepts. The addition of critical concepts such as power and energy, and how these concepts are related showed that learners' knowledge of the topic was expanding beyond the scope of what was discussed in the classroom. They also added a clear description of the Ohm's law, and the condition at which this law applies. An electric circuit was also described as the interconnection of electrical components. Learners also included some of the factors that affect the resistance in an electric circuit. The battery concept was also clearly described as a series of cells with internal resistance. All this was evidence of how their knowledge had developed, and that they were thinking of more than just knowing concepts but also how to apply the mathematical expressions of these relationships in problem-solving.

Although I only showed Group C's development of understandings of key concepts in this section, other groups also showed some form of knowledge development as they constructed and reconstructed their concepts (see chapter 5). Evidence of this was revealed by the addition of new concepts and propositions, as well as the complexity of the final concept maps that learners constructed in their groups.

6.2.3. The role of prior knowledge in the learners' development of understanding during collaborative concept mapping

Assertion 2c: *The integration of relevant prior knowledge to new knowledge in the learning of key concepts (resistance, electric current, and potential) played a partial role in the development of understanding during concept mapping, since previously learners had mainly focused on memorizing facts without much care about how those facts relate to their daily personal experiences.*

The idea that in-depth understanding of new concepts is influenced by the learner's use of their already existing knowledge is asserted by many Constructivists. This idea was partially evident in this study as learners made use of CCM to reflect on what was taught in class in order to deepen their understanding of key concepts such as electric current, potential difference, and resistance. This study found that, as learners constructed concept maps, their prior knowledge was mainly elicited when trying to make sense of the main concept of electricity. Beyond that, learners relied on recollection of what was taught in the classroom. There were few instances where they related key concepts such as voltage, current, and resistance to the relevant prior experiences. Their descriptions of the relationships between key concepts focused on what they had learned in class instead of making sense of what they were taught by relating it to their prior experiences. An example of this can be seen in one of the screenshots from Group D's initial concept map (Figure 5.4.).

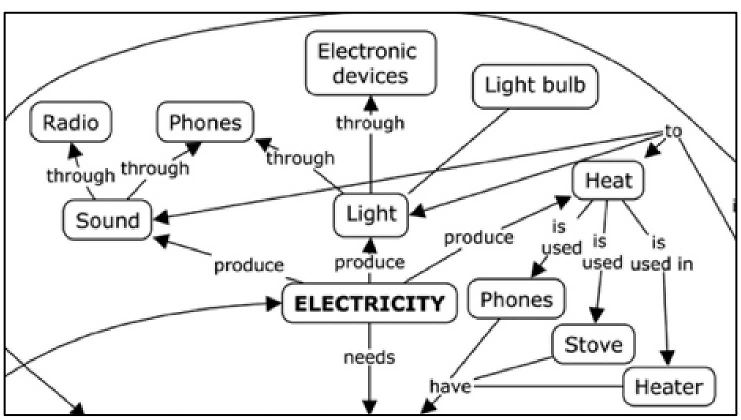

Figure 6.13.: Screenshot from (Figure 5.4.- Group D)

In the screenshot above, Group D gave examples of everyday devices and appliances to show how they relate to their main concept "electricity". Group A, however, made some effort to use their prior learning experiences when they related a light bulb (existing concept in a learner's mind) to the electric current (key concept):

Lungile:	Angani uyazi ukuthi kwi-photosynthesis iproduct ilo i-glucose ne-oxygen ilento engiyishoyoke nami ukuthi i-battery ne connecting wire i-product yakhona i-electricity ephuma kuphi kwi-bulb..iyezwakala lento engiyishoyo? [*you know that in photosynthesis the product is glucose and oxygen…that is what I mean when I say the battery and connecting wires produce electricity which shows up in a bulb, do you get what I am trying to say?*]
Amanda:	Ehhe!
Sthandiwe:	I-bulb it shows off i-current in a form of light.. [Group A: 1st Round of CCM]

The above excerpt illustrates how learners used the process of photosynthesis as an analogy to explain why light bulbs give out light. Learners used the idea that, during the process of photosynthesis, glucose and oxygen are released to explain light coming out of a bulb due to the current flowing through it. This was one of the few instances where prior knowledge was linked to new knowledge. Another instance was when Group B showed in their concept map that light bulbs and electricity transformers have resistance in them. The responses from the interview also showed no indication that learners relied much on what they already know to explain how key concepts are related. Their responses indicated that they mainly relied on what they learned in class to answer questions for the interview.

The study also found that the learners' inconsistent prior knowledge could lead to the formulation of alternative conceptions. For example, a Group A discussion revealed an alternative conception regarding some of the ways that Eskom distributes electricity to consumers:

Lungile:	Uke ubone kwezinye iyndawo kunalezizinto nike niybone lezonto ezingathi ziyi-fan? [*have you noticed that some areas have things that look like fans?*]
Sthandiwe:	Oh yah...
Sindiswa:	Ama water mi....ama water mill noma? ama wind mills? [*you mean water mill or? Wind mills?*]
Lungile:	Abanyeke basebenzisa wona ziningi iyndlela akuwona ama pylons kuphela... [*some people use that, there are many ways (to transport electricity) it's not just pylons only*] [Group A: 2nd Round]

Learners in this group seem to have an alternative understanding of windmill technology. They think that windmills are used to distribute electricity in the same way as pylons. Although the idea of windmills stems from learners' everyday life, in this case learners appear confused as to how this technology is used in the real world. As a result, the role played by their prior knowledge in this case proved to be counterproductive as it led to the formulation of an alternative conception which needed to be addressed.

6.3. Discussion

This discussion of the findings is based on learners' understanding of key concepts and the collaborative learning strategy which they were required to use. Under the learners' understanding of key concepts, I discuss some of the knowledge they obtained during the study as well as some of the alternative conceptions that were revealed. The collaborative learning strategy is discussed next with focus on how CCM helped learners in the quest to deepen their understanding of key concepts in electric circuits. I also discuss how this strategy may have elicited some alternative conceptions. I move on to discuss how the co-construction of meanings helped develop learners' understanding of concepts as they shared knowledge with their peers as well as the role of prior knowledge in learning theoretical concepts in electric circuits.

Learners' understanding of key concepts

The analysis of the concept maps, audio transcripts, and learners' responses from the interview questions revealed that learners have expected understandings of the relationships between key concepts. This was shown by the learners' ability to formulate important concepts in their concept maps and engaging in meaningful discussions. The study found that learners were familiar with the concept of Ohm's Law and could state it in words and express it mathematically. They were also aware of the Ohmic and non-Ohmic conductors and what type of conductor obeys Ohm's Law. This knowledge is crucial in Grade 12 and is one of the objectives of the CAPS (Department of Basic Education, 2011).

The first round of CCM saw the four (4) groups add several concepts to their maps. This was an indication that learners were reflecting on what was taught in class in order to improve their understanding. Group C however found it difficult to construct a clear and simple concept map at the beginning of the CCM process. They used the 'mention and describe' method of constructing a concept map, which made it difficult to distinguish which concept related to what. Despite this weakness, the information they provided in their concept map and the audio transcript were enough to gauge their understanding of concepts at the time. Bressington et al. (2018) also found that learners often faced difficulties when constructing concept maps for the first time. Much like in Bressington et al. study, learners in this present study experienced difficulties at first but, as the study progressed, they grew more confident in their discussions and added more concepts to their existing maps, thus reflecting the enhancement of their understanding. A few alternative conceptions were noted in the concept maps and some of them were addressed during normal teaching. Research shows that learners have a number of alternative conceptions about simple circuits which hinder their development of understanding of key concepts in this topic (Moodley & Gaigher, 2015; Nkopane et al., 2011; Önder et al., 2017). Concept maps and audio transcripts helped diagnose some the documented alternative conceptions (Bressington et al., 2018; Cañas et al., 2003). Awareness of these alternative conceptions helped inform my teaching methods as I sought to rectify the alternative conceptions. A study by Moodley and Gaigher (2015) also found that teachers who were aware of alternative conceptions were able to diagnose them from their learners and improve their overall understanding of key concepts in electric circuits. The positive outcome of this was seen through learners' improved understanding of key concepts.

The interview examined learners' conceptual understanding and was conducted with only four (Ntando, Lungile, Rethabile, and Sthandiwe) out of the 20 learners that participated in the CCM tasks. The goal here was to give these learners a chance to prove that what they constructed in their concept maps with their peers was in fact embedded in their cognitive structure. All four learners were able to display expected understanding of the relationships between key concepts. However, some of them had alternative conceptions related to the meanings attributed to the potential difference. These alternative conceptions were revealed when, for instance, learners were asked about the meanings attributed to the voltmeter reading, and three (3) of the four (4) failed to elaborate on the answers their groups had given during the POE tasks. Similar findings were confirmed by Marks (2012) who also found that learners related to the mental model of the potential difference. This can be shown by a learner's inability to explain the meanings attributed to the voltmeter readings.

Although their responses in the interview were often satisfactory, some of the learners (Lungile, Sthandiwe, and Rethabile) did not provide alternative explanations or good reasons as to why the potential difference measured across parallel resistors remained the same, but split between resistors in a series circuit. Their explanation (which was also in their group concept maps) was that "*series resistors are potential difference dividers*", an assertion that they could not explain. However, Ntando (a high-quality learner) showed scientifically acceptable understanding of the concept of potential difference/voltage. Group D was also able to explain the concept of potential difference in a discussion when they said, "*The potential difference is the energy transferred. So, it means that it goes past a point where it is transferred…I mean if something is transferred you put it somewhere else right? So, where it is connected in series it will divide*" (Khule). To sum it up, it can be said that some learners understood the concept of potential difference while others only knew how it is affected by the series and parallel connections but not what it is or the role it plays in the electric circuit.

Contrary to the findings made by Saglam (2015) in his study of 114 preservice teachers, learners in the present study understood the effect of parallel-connected resistors on the potential difference in a circuit. In Saglam's study, participants found it difficult to provide adequate answers when answering diagnostic questions on potential difference in parallel-connected resistors. The study indicated that these participants had several alternative conceptions and many of them incorrectly manipulated the formula ($V = I \times R$). They also could not differentiate between the potential difference and electric current in parallel-connected resistors. However, learners in this present study showed good understanding of the relationship between the potential difference and resistances; but lacked in-depth understanding of the concept of potential difference. Learners even used mathematical operations to show that the total current splits in the parallel circuit while the potential difference remains the same and vice versa when it comes to the series circuit. These findings are similar to what Anita et al. (2018) observed in their study, which found that learners make use of mathematical operations to explain the effect of series and parallel circuits on current and the potential difference. This was an important finding in this study because the diagnostic reports and the literature show that learners were struggling to master this concept in the examination.

The results also showed that all learners had a microscopic view of current as something flowing in a circuit. Sthandiwe saw the direction of this flow as going from the positive side of the battery to the negative side (i.e., sequential and conventional current). Indeed, in the interview, only one (1) learner (Ntando) out of the four (4) participants verbally described current flow as charges flowing from all parts of the circuit. This trend is, however, not unique to the sample examined here as studies dating back to the 1980s show that this concept is problematic to learners (Anita et al., 2018; Shipstone, 1984; Tarciso Borges & Gilbert, 1999). Nevertheless, understanding of electric current as the key concept as well as how resistances affect the flow of charges in a circuit is of critical importance at this stage of the development of learners' conceptions.

Concerning the energy source of an electric circuit, only three learners found it relevant to mention the importance of the 'push' or 'energy source' which charges the need for current flow. One learner just looked at the importance of having current flowing in a circuit when the switch is closed. It was essential to explore such ideas as they form the basis for understanding of the topic. Explanations given about these ideas were mostly based on what learners had learned thus far and provided no evidence of the use of prior knowledge but, instead, recollection of what was learnt during the lessons. Furthermore, some alternative conceptions that learners had in their concept maps appeared to have changed at this stage and were now scientifically acceptable, indicating the positive effect that CCM had in improving learners' understanding as they learned from one another and corrected each other. The omission of the energy source for the electric circuit from learners' responses during the interview was worrisome as this is a very important aspect of this topic, especially given that Group A appeared to have had an alternative conception related to this concept. However, it was encouraging to see that Groups B and C mentioned the role played by the battery (energy source) and showed clear understanding of the concepts. Group C went as far as explaining that a battery produces the potential difference, which is the energy transferred when one Coulomb charge moves from one point to another. It was unclear why Rethabile (from Group C) failed to mention this idea since her group had a heated discussion around it. Nonetheless, one can conclude that some learners understand the concept of the energy source in the circuit while some still lack clarity on this concept.

It can be said that learners were not shy to make predictions (during the POE tasks) on the ideas they had about electric circuits. However, there were issues about the scientific quality of the reasons they provided once those predictions were made. Some learners showed understanding of the relationships between key concepts but lacked reasons as to why the circuit behaved that way. This was not unexpected, as previous studies have shown similar difficulties (Anita et al., 2018; Marks, 2012). This indicates that learners have partial understanding of key concepts or they lack confidence in their knowledge of the topic. However, the overall analysis of the learners' understanding of key concepts shows that they have expected understanding in electric circuits. While some concepts were reasonably well understood, others still required some remedial action. Since this was an action research study, reflections and remedial actions were an ongoing process even after data collection had concluded because the goal was to help learners gain complete understanding of these key concepts by the time they reach Grade 12.

Collaborative learning strategy

The collaborative learning strategy that was adopted in this study was collaborative concept mapping (CCM). This strategy was instrumental in allowing learners to discuss some of the key concepts as they reflected on what they had learned in class. This was observed from their concept maps and audio transcripts. Episodes of collaborative learning stimulated discussions about important concepts as learners tried to make sense of the topic of electric circuits. Previous studies had also made a similar finding (George-Walker & Tyler, 2014; Stoica et al., 2011; van Boxtel et al., 2002).

Co-construction of meanings

CCM provoked episodes of co-construction of meanings, which led to the achievement of positive learning outcomes. Evidence from the data shows that participants learned from each other, helped clarify certain concepts where some members of the group experienced difficulties or confusion, engaged in critical and focused thinking about key concepts, bridged knowledge gaps under ZPD, and developed basic understanding of important concepts in electric circuits, which would prove crucial in Grade 12. However, collaborative learning also resulted in alternative conceptions. Van Boxtel et al. (2002) also found that during CCM, alternative conceptions can be formed as learners discuss ideas that they either do not fully understand or misunderstand altogether. In such cases, they recommend that teachers watch out for potential alternative conceptions that may arise during a CCM task, and quickly diagnose and address them.

Prior knowledge

Literature shows that meaningful learning occurs when learning strategies adopted in the classroom enable learners to be active participants in the process of knowledge construction. As noted by Fergusson (2007), learners are able to make sense of new concepts when they are engaged in knowledge construction themselves and with their peers. They do so by linking their relevant prior knowledge with new knowledge. CCM provided a platform where learners could negotiate meanings by bringing their individual prior experiences to share with their peers. However, there were few instances where this happened in this study. To put it accurately, it was observed that the discussions that involved learners' prior experiences took place in the first round of CCM where learners were still trying to make sense of the topic of electricity in general. As CCM continued, learners relied less on prior knowledge as they focused on reflecting on what they had learned in class about this topic in order to incorporate it into their concept maps. CCM sessions were mostly driven by the motive to try and understand concepts that learners would need to complete tasks. Kock et al. (2014) made a similar finding.

Overall, the study showed the importance of learners' interactions and confirmed that CCM provided a platform where learners could reflect on what they learned in class to sharpen their understanding. It also showed that concept mapping alone is not enough to help learners with understanding of concepts. Other learning strategies which focus mainly on individual rather than group learning would need to be incorporated into the classroom. Furthermore, in an era where most teaching is focused on helping learners pass exams, our learners have been conditioned to focus mainly on the concepts which would help them succeed in examination tasks rather than explore in-depth understanding of concepts. Learners seem to believe that the only way to answer a question or draw a concept map is by describing textbook facts. This could be blamed on my own teaching strategies as well, and would need to be addressed as I move forward in my career. Overall, learners do possess some basic understanding of key concepts in electricity and collaborative concept mapping was essential in stimulating and supporting meaningful discussions.

6.4. Summary of the findings

The study showed that the 20 Grade 11 Physical Sciences learners who participated in it had expected understanding of the relationships between key concepts in electric circuits. These relationships are important aspects of the Ohm's Law principle. For instance, Liégeois et al. (2003) list three (3) important relationships that learners must know in order to demonstrate the understanding of Ohm's Law: the relationship between potential difference and resistance (at a constant temperature), the relationship between current and potential difference (at a constant resistance), and the fact that the mathematical expression of Ohm's Law is V = I.R. All 20 learners mentioned some, if not all these relationships in their concept maps and interview. However, some of the learners were diagnosed with alternative conceptions. What was missing from their understanding was the in-depth explanation of why the circuit behaved in a certain way. Learners were often able to state these relationships but could not elaborate any further than just providing a mathematical model of them.

Collaborative concept mapping assisted a great deal in developing learners' conceptual understanding and bridging knowledge gaps under ZPD. However, not all learners acquired scientific knowledge while working in their groups. This was evident from the alternative conceptions that persisted throughout the study despite remedial actions. Bozhovich (2009) argues that not all learners (during collaborative learning) improve their knowledge of the subject under ZPD because of a possibility that no one within that group has mastered the concepts well enough to explain it to his/her peers.

The findings also revealed that, whereas learners used their prior experiences to understand the overall topic, when it came to in-depth understanding of the relationships between key concepts, they relied upon the explanation of facts that they learned in class. This is not a bad thing but it can hinder their progress if learners think the goal of education is to memorize facts and formulas instead of in-depth understanding of concepts. Nevertheless, the overall understanding that Grade 11 Physical Sciences learners have can be used as a good foundation for future learning.

6.5. Reflecting on the main problem

The problem that this study tried to address is the difficulties learners experience when studying electric circuits. The research was therefore conducted with the goal to help my Grade 11 Physical Sciences learners gain holistic understanding of the relationship between key concepts in electric circuits. An action research approach located within a social constructivism framework was deemed fit for the emancipatory nature of this study.

This study was undertaken at a school where I teach Physical Sciences. This school has seen consistently poor results in this subject over the years. The topic of electric circuits, being a conceptually complex and challenging topic to learn, and the one in which I identified the most problems with my learners, was used as an opportunity to explore learners' understanding once they are exposed to constructivist learning strategies such as collaborative concept mapping. A case study of 20 Grade 11 Physical Sciences learners learning electric circuits was carried out. Concept maps, audio recordings, and a group semi-structured interview were used to collect data.

Discussions are used to present the findings of the case study in order to answer my two research questions.

Question 1

What are Grade 11 Physical Sciences learners' understanding of key concepts in electric circuits?

From the teaching that encouraged constructive learning and collaboratively constructing concept maps, learners developed expected understanding of key concepts (current, resistance, and potential difference). Learners understood the concepts of resistance, current, and potential difference and the relationship between the electric current and resistance (also known as the Ohm's law). They applied the following mathematical rules: $I_T = I_1 + I_2\ldots$ and $I_T = I_1 = I_2\ldots$ to explain the effect of resistances to the electric current as well as $V_{T\,(supply)} = V_1 + V_2\ldots$ and $V_{T\,(supply)} = V_1 = V_2\ldots$ to explain the effect of series and parallel resistances to the potential difference. Evidence from their concept maps also suggested that learners have some understanding of the concept of *power* in an electric circuit, and how it relates to energy transferred by the resistor. Learners expressed this relationship in mathematical form as power = work done / time. In addition, learners also showed knowledge of the relationship between *voltage (V)*, *work done (W)*, and an electric *charge (Q)* through the formula V = W/Q. Such findings showed that learners had acquired significant aspects of the relationship between key concepts in electric circuits which would serve as a good foundation for future learning. However, learners showed some alternative conceptions with regard to the meanings attributed to the voltmeter readings that hindered some of them from fully understanding the essential concept of potential difference. Other alternative conception such as the idea that the battery produces current was diagnosed in some but not all the groups which showed that not all learners struggled with the concept of a power source.

In general, CCM helped learners reflect on what they had learned in class and engage in discussions which improved how they view and understand concepts in this topic. Learners were well versed in mathematical operations in this topic. They showed this in their concept maps, and when providing reasons for the answers in the interview. This was evidence of knowledge of the topic and confidence gained due to learning with their peers. However, in-depth understanding of the concept of potential difference remained an issue for some learners. These findings are similar to what was found in the literature. This study also found that participants had some of the most frequently reported alternative conceptions in South Africa, Indonesia, and Turkey. In this present study, the teacher-researcher made attempts to address identified alternative conceptions through various methods such as YouTube videos, PhET simulations, simplified PowerPoint demonstrations and conducting CAPS-recommended practical work. Although, some of the alternative conceptions were successfully addressed, others that were not previously diagnosed in the concept maps were subsequently revealed in the interview. Despite most studies revealing that concept mapping evokes prior knowledge in the learner's mind in order to make sense of new knowledge, this study showed that the integration of prior knowledge with new knowledge did not seem to have much influence in CCM since these tasks were designed to help learners reflect on what they had just studied in class. The learners thus mainly focused on discussing concepts recently introduced to them in class in order to deepen their understanding of them.

Question 2

How have Grade 11 Physical Sciences learners' understanding of key concepts in electric circuits developed as they constructed concept maps?

Collaborative concept mapping prompted discussions amongst learners about scientific concepts, and this improved their understanding of the relationships between key concepts (resistance and electric current) as they continued to construct and reconstruct their concept maps. The development of understanding of key concepts was revealed by their concept maps becoming more complex over the three rounds of CCM. In addition, the integration of relevant prior knowledge into new knowledge in the learning of key concepts (resistance, electric current, and potential) played a partial role in the development of understanding during concept mapping since previously learners had mainly focused on memorizing facts without much care about how those facts related to their daily personal experiences.

Making use of collaborative concept mapping (CCM) as a learning strategy helped develop learners' understanding of key concepts. CCM activities provoked discussions and mutual support among learners that contributed to the development of their knowledge over time. This was reflected in the quality of discussions as well as in the addition of more concepts and propositions to the concept maps over the three (3) rounds of CCM. Although most of the concepts and propositions were incorporated into the concept maps during the first round, the second round showed more meaningful discussions and had some of the groups reconstructing their concept maps because they had new ideas they wanted to add. These ideas included showing relationships in mathematical form as learners tried to express new knowledge gained over the course of the study. Whereas the third round had the least activity for most of the groups, Group C showed a great deal of improvement in their concept map in that round as compared to the first two rounds. At any rate, all this was indicative of the development of understanding and confidence in knowledge of the topic over the three rounds of CCM.

6.6. Alignment of the learning aspects of this study with the socio-constructivism framework and concept mapping

The learning aspects adopted in this study were like those stated in the socio-constructivism framework and the concept mapping theory. Learners worked collaboratively to construct concept maps in order to deepen their understanding of key concepts in electric circuits. The collaborative learning strategy was informed by Vygotsky's (1976) zone of proximal development theory. As recommended by Vygotsky, the goal was to create a social context where learners could share knowledge, and those who understood certain aspects of electric circuits could help others. Collaborative concept mapping was deemed fit for this study because it encouraged peer learning and collaboration. The Novak framework for analyzing concept maps was used to make sense of the learners' diagrams under the following constructs: network of concepts and links, scientific propositions, integration of prior knowledge with new knowledge, and alternative conceptions. These constructs informed the learners' understanding of concepts and were used to present and analyze the data. A deductive approach (informed by socio-constructivism, concept mapping, and literature) was used to interpret and discuss the findings. The link between socio-constructivism theory and Novak's theory of collaborative concept mapping was shown in Figure 2.1.

6.7. Limitations and Implications of the study

The findings of this study cannot be generalized for all Physical Sciences learners in South Africa. However, the study is useful in shedding light on the learning strategies that teachers can use with their learners in science classrooms. The school I selected for the study is one of many underperforming schools in Physical Sciences, and the understanding is that learners in this school are not well equipped with learning strategies that help them take charge of their learning. Therefore, it would appear that the slightly positive outcomes of this study will assist learners in gaining holistic understanding of concepts in electric circuits as they plan for their Grade 12 year.

One of the limitations of this study was the amount of time it took to construct a concept map. Even though CCM tasks were done after normal teaching time, I still found it challenging to keep learners focused on their drawings for longer durations. Group discussions were difficult to manage and control. In most cases, the discussions strayed from the topic or learners spent too much time debating one concept; this meant that learners could not find enough time to add all the necessary ideas that were expected.

I also faced complications in teaching learners how to construct a clear and informative concept map. Challenges that were evident in the concept maps include connecting arrows which were sometimes drawn as lines with no arrowheads, missing linking words between concepts, few hierarchies, excessive information inside a concept circle, and limited understanding of the use of a cross-link. There was also a significant number of expected concepts that learners did not incorporate into their concept maps. Another challenge arose from learners treating the construction of a concept map as if it were a test in which they had to mention and describe certain facts instead of reflecting and stating what they felt was important for understanding the relationships of concepts in this topic. The interview was slightly worse since it was conducted with four learners in the same venue and at the same time. Most of the time, they seemed to agree with each other. Initially, I had hoped that interviewing in this way might spark a debate about concepts as each learner wrestled with giving his/her unique explanation over others. But instead, they seemed keen to agree on most issues and this affected the reliability of the results from the interview.

I would also like to present my final findings to the learners in order to obtain their opinions and check whether I have represented their true views. However, this may not be possible because, at the time of the conclusion of this thesis, these learners would have already completed Grade 12 and left the school.

It is recommended that further research be done, which includes multiple cases and different teaching and learning environments, especially under conditions where examination does not hold such high stakes. The study was conducted to have an idea of learners' understanding of key concepts in electric circuits, and to equip my own learners with necessary learning strategies that can help them learn other topics. Concept mapping is an exceptional teaching and learning tool that teachers and learners could use. With new software such as CmapTool, concept mapping has been made even easier and fun. It is recommended for teachers to explore this instrument for learning so that they may improve their science classrooms. I have learned many things that I previously was not aware of in my profession from conducting this study. It is my hope that the learners with whom I worked in this study continue to make use of concept mapping to try and better understand Physical Sciences.

7. References

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APPENDICES

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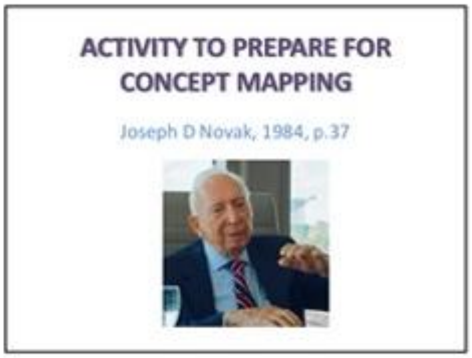
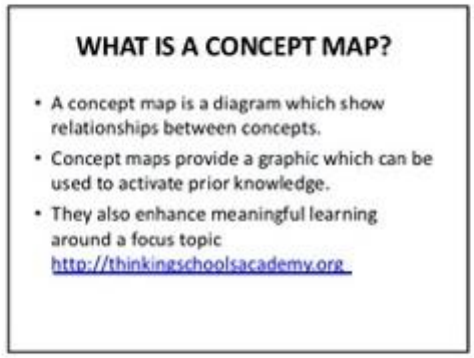
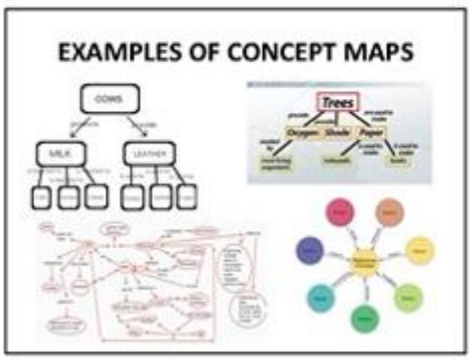
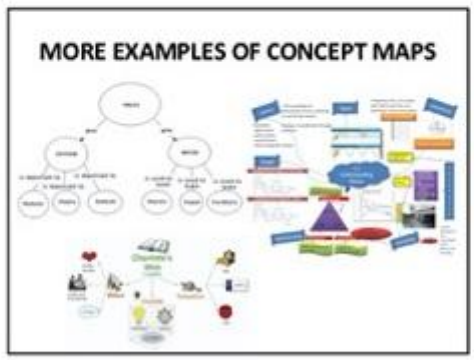
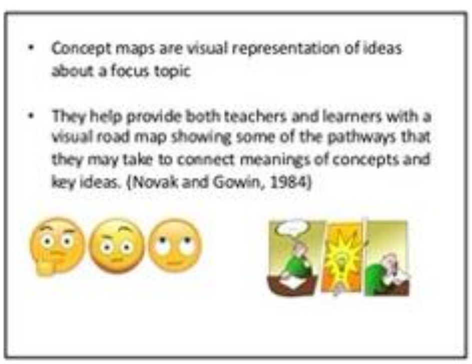
Appendix A: PowerPoint activity to prepare for concept mapping used in the pilot study

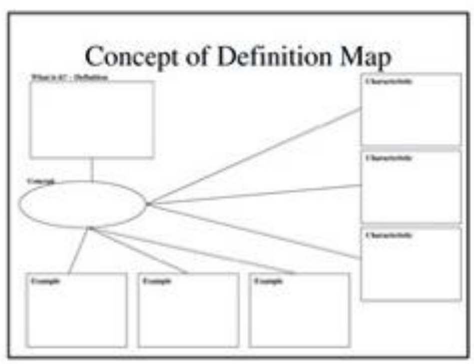




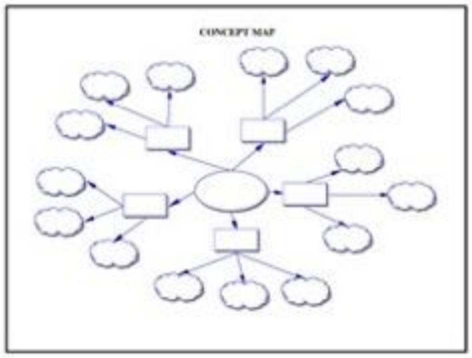








1



A CONCEPT MAPPING ACTIVITY

OBJECTS
- Dog
- Car
- Chair
- Tree
- Cloud
- book

EVENTS
- Raining
- Playing
- Washing
- Birthday party
- Thunder

a) Describe how the two lists differ.
b) What do you think when you hear the words, dog, car, chair?
c) Can you see that even though we use the same words but each of us have a different mental image of the word?
d) These mental images are our **CONCEPTS**

Linking words

- Are
- Where
- The
- Is
- Then
- With

What comes to your mind when you hear each of the words listed above?

THESE ARE NOT CONCEPTS BUT THEY ARE LINKING WORDS. WE CALL THEM THAT BECAUSE WE USE THEM IN SPEAKING AND WRITING.

Linking words used together with concepts to construct sentences that have meaning.

HOW LINKING WORDS • CONCEPTS ARE USED BY HUMANS TO CONVEY MEANINGS E.G.:

a) The **dog** is running.
b) There are **clouds** and thunder.
c) The **car** is speeding.

CONSTRUCT YOUR OWN FIVE SENTENCES, AND IDENTIFY CONCEPT WORDS AND LINKING WORDS. ALSO STATE WHETHER THE WORDS ARE OBJECTS OR EVENTS.

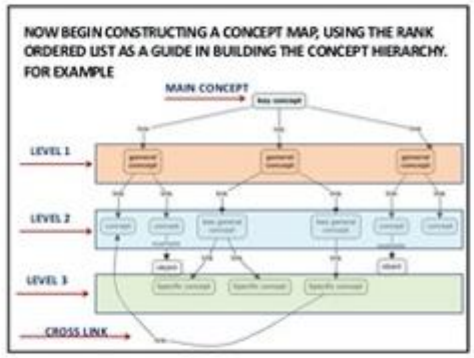
READ THE FOLLOWING PASSAGE AND IDENTIFY KEY CONCEPTS. ALSO, NOTE SOME LINKING WORDS AND CONCEPT WORDS THAT ARE MOST IMPORTANT TO THE STORY LINE.

Electricity Basics

When beginning to explore the world of electricity and electronics, it is vital to start by understanding the basics of voltage, current, and resistance. These are the three basic building blocks required to manipulate and utilize electricity. At first, these concepts can be difficult to understand because we cannot "see" them. One cannot see with the naked eye the energy flowing through a wire or the voltage of a battery sitting on a table. Even the lightning in the sky, while visible, is not truly the energy exchange happening from the clouds to the earth, but a reaction in the air to the energy passing through it. In order to detect this energy transfer, we must use measurement tools such as multimeters, spectrum analyzers, and oscilloscopes to visualize what is happening with the charge in a system. Fear not, however, this tutorial will give you the basic understanding of voltage, current, and resistance and how the three relate to each other.

2

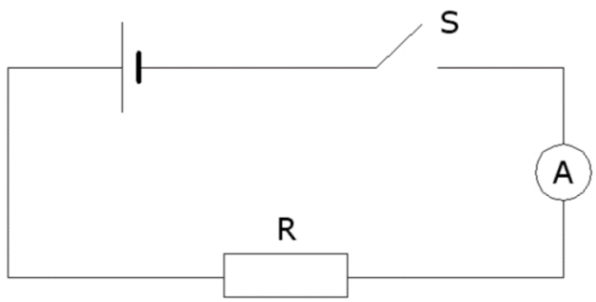

Concept words
Events words
Linking words
• Electricity
• Current
• Voltage
• Resistance
• Energy
• Battery
• Tools
• Wire
• Flowing
• Transfer
• Passing
• Detect
• Measure
• Building blocks
• Is
• The
• To
• Through
• Required
• Use
➢ Which concept is most important, most inclusive idea in the text?
➢ Put most inclusive at the head of the list.
➢ List the next most general, most inclusive concepts until all concepts are ranked.


NOW BEGIN CONSTRUCTING A CONCEPT MAP, USING THE RANK ORDERED LIST AS A GUIDE IN BUILDING THE CONCEPT HIERARCHY. FOR EXAMPLE
MAIN CONCEPT
LEVEL 1
LEVEL 2
LEVEL 3
CROSS LINK

3

Appendix B: Interview schedule used with four learners in a semi-structured focus group interview

1st interview: Current in a simple circuit



A simple circuit were shown to learners and asked the following questions:

Based on your own understanding of electricity, describe your mental picture of what is happening in this electric circuit when S is switched on.

a) What affects the ammeter reading? Why?
b) What do you imagine is happening within the circuit? What prior ideas do you have as you give this answer?

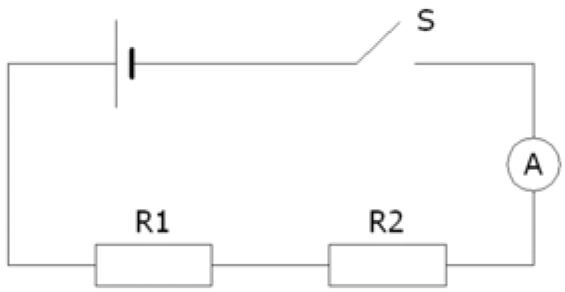
The learners were asked to predict what will happen when the circuit is switched on, giving reasons for the prediction.

The following questions were asked:

- If you switch S on, what would you notice? Why?
- Will it make a difference to the ammeter reading if the position of the ammeter is changed and it is placed on the other side of the resistance? Why?

2nd interview: Resistance in parallel and series circuits

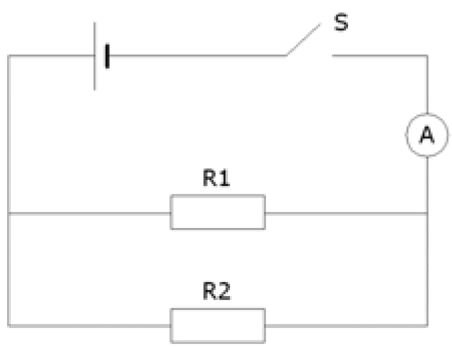
The learners were shown the circuit diagram in Figure 2 and told that R_1 and R_2 are two equal resistors connected in series.



A series circuit

The following questions were asked, before switching S on:

- In this circuit using two equal resistances, what happens when S is switched on? Why?
- Would the ammeter reading change if we change its position?
- In the same circuit, if we increase one of the resistors, what will happen to the reading on the ammeter and why?

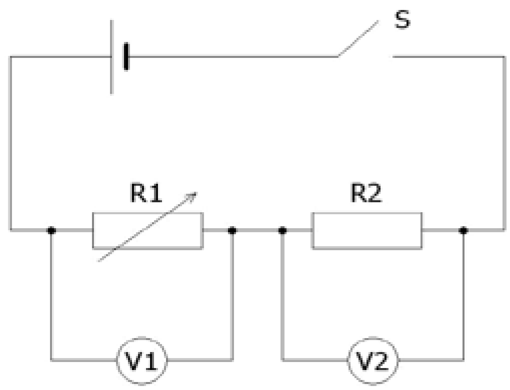


A parallel circuit

- What happens to the ammeter reading now, when S is on (comparing it to when the resistances were connected in series)? Does it increase, stay the same or decrease? Why?

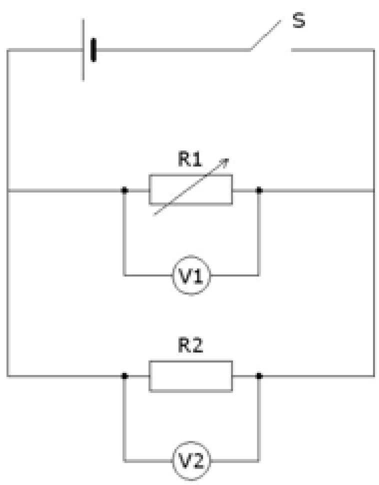
3rd interview: Meanings attributed to voltmeter readings

The learners were shown the circuit diagram in Figure 4 and asked to observe the simulation program, and refer to their concept map for the relationship between series resistors and potential difference.



The following questions were be asked to the learners:

- What will the voltmeters read when the resistances are equal and S is closed? Why?
- What will the voltmeters read when one of the resistances is increased? Why?



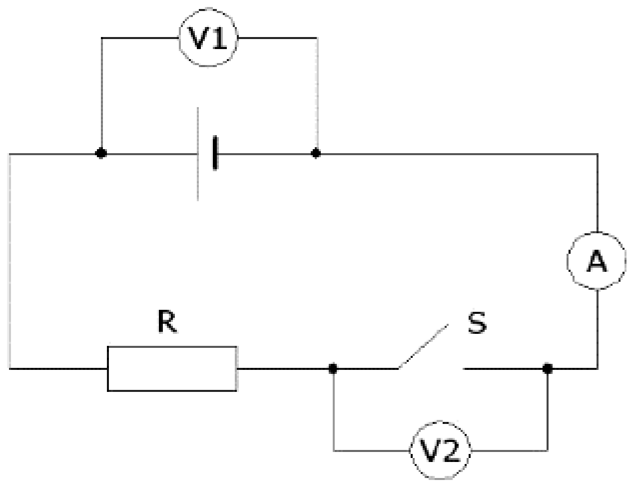
Voltmeter readings in a parallel circuit

The following questions will be asked <u>before switching S on</u>:

- What will the voltmeters read when the resistances are equal? Why?
- What will the voltmeters read when one of the resistances is increased? Why?
- Why does the circuit behave this way?

4th Interview – Differentiating between current and voltage

Voltmeters across the battery and switch



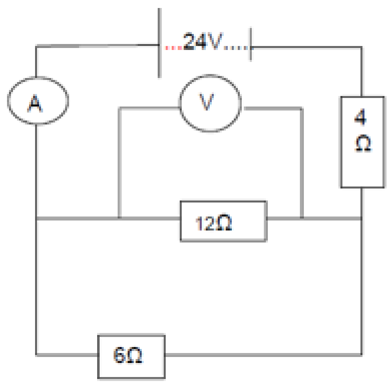
The learners were asked the following questions:

- Comment on what happens to the readings on voltmeters V_1, V_2, when connected as shown, and to the ammeter A, when S is switched ON? Give reasons for your answers.
- With S switched OFF, what can you say about the readings on V_1, V_2 and the ammeter A? Give reasons for your answers.

Appendix C: Grade 11 Tutorial - Problems related to electric circuits from past exam papers

Question 1 (From Mindset learn Xtra – CAPS)

A battery of emf 24 V, which has no internal resistance, is connected in a circuit, as in the diagram. The resistance of the ammeter is negligible.



1.1 Calculate the total resistance of the circuit.

1.2 Calculate the reading on the ammeter.

1.3 Calculate the reading on the volt meter.

1.4 Calculate the current through the 6Ω resistor.

1.5 Calculate the amount of electrical energy transferred by the 12Ω resistor in 5 minutes' time.

Question 2

Three 1,5V cells are connected in series to form a battery with negligible internal resistance. Four identical bulbs are connected in the circuit. L1 is connected in series with the battery and an ammeter that reads the current through the battery. L2 and L3 are in connected in series in a parallel branch. L4 is connected in the second parallel branch. A voltmeter, V1, reads the potential difference across the battery and a second voltmeter, V2, reads the potential difference across L4.

2.1 Draw the circuit diagram of the circuit.

2.2 Calculate the reading on the ammeter.

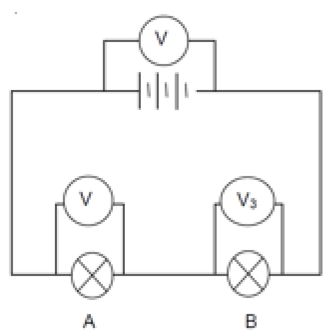
2.3 Calculate the readings on V1 and V2

2.4 Predict what you would observe about the brightness of the bulbs.

Explain your answer by doing some calculations.

Question 3

Theo used the following circuit in an investigation to determine the relationship between resistance and current in a circuit. He first connects the bulbs in series then in parallel. The emf of each cell is 1,5 V and the resistance of the bulbs A and B is 2 Ω and 3 Ω respectively.



3.1 What is the reading on voltmeter 1?

3.2 What is the reading on V2 & V3 respectively.

3.3 Calculate the energy transferred to bulb B in 3 seconds.

3.4 Calculate the resistance in the circuit.

3.5 Calculate the current in the circuit.

3.6 Write an investigative question for the experiments Theo performed.

3.7 Write a conclusion for the investigation.

APPLICATION OF OHM'S LAW

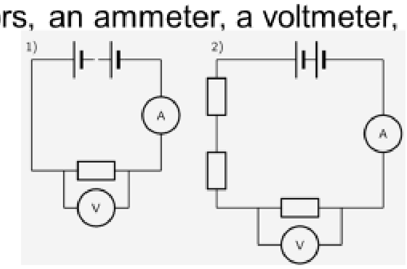
General experiment:

Aim

To determine the relationship between the current going through a resistor and the potential difference (voltage) across the same resistor.

Apparatus

4 cells, 4 resistors, an ammeter, a voltmeter, connecting wires



APPLICATION OF OHM'S LAW

Method

This experiment has two parts. In the first part we will vary the applied voltage across the resistor and measure the resulting current through the circuit. In the second part we will vary the current in the circuit and measure the resulting voltage across the resistor. After obtaining both sets of measurements, we will examine the relationship between the current and the voltage across the resistor.

Varying the voltage:

1. Set up the circuit according to circuit diagram 1), starting with just one cell.
2. Draw the following table in your lab book.

APPLICATION OF OHM'S LAW

Method

Draw the following table in your lab book.

Number of cells	Voltage, V (V)	Current, I (A)
1		
2		
3		
4		

APPLICATION OF OHM'S LAW

Method

Get your teacher to check the circuit before turning the power on.

- Measure the voltage across the resistor using the voltmeter, and the current in the circuit using the ammeter.
- Add one more 1,5V cell to the circuit and repeat your measurements.
- Repeat until you have four cells and you have completed your table.

APPLICATION OF OHM'S LAW

Method

Varying the current:

1. Set up the circuit according to circuit diagram 2), starting with only 1 resistor in the circuit.
2. Draw the following table in your lab book.

Voltage, V (V)	Current, I (A)

APPLICATION OF OHM'S LAW

Method

Get your teacher to check your circuit before turning the power on.

- Measure the current and measure the voltage across the single resistor.

- Now add another resistor in series in the circuit and measure the current and the voltage across only the original resistor again. Continue adding resistors until you have four in series, but remember to only measure the voltage across the original resistor each time. Enter the values you measure into the table.

APPLICATION OF OHM'S LAW

Analysis and results

1. Using the data you recorded in the first table, draw a graph of current versus voltage. Since the voltage is the variable which we are directly varying, it is the independent variable and will be plotted on the x-axis. The current is the dependent variable and must be plotted on the y-axis.
2. Using the data you recorded in the second table, draw a graph of voltage vs. current. In this case the independent variable is the current which must be plotted on the x-axis, and the voltage is the dependent variable and must be plotted on the y-axis.

APPLICATION OF OHM'S LAW

Conclusions

1. Examine the graph you made from the first table. What happens to the current through the resistor when the voltage across it is increased? i.e. Does it increase or decrease?
2. Examine the graph you made from the second table. What happens to the voltage across the resistor when the current increases through the resistor? i.e. Does it increase or decrease?
3. Do your experimental results verify Ohm's Law? Explain.

Source: https://www.siyavula.com/read/science/grade-11/electric-circuits/11-electric-circuits-02

Appendix D: Ohm's Law formula sheet

PROBLEM SOLVING USING OHMS LAW

Some useful formulae

To calculate a current flowing in each branch of a parallel:

$$I_1 = \frac{R_p}{R_1} \times I_{total} \quad \text{OR} \quad I_1 = \frac{V_p}{R_1}$$

$$I_2 = \frac{R_p}{R_2} \times I_{total} \qquad I_2 = \frac{V_p}{R_2}$$

To calculate voltage/potential difference across a resistor in a series circuit.

$$V_1 = I.R_1 \qquad V_1 = \frac{V_T}{R_T} \times R_1 \qquad V_1 = \frac{V_1}{R_T} \times V_T$$

To calculate energy transferred by a resistor: $V = \frac{W}{Q}$

Appendix E: Sample of the parents' consent letter

INCWADI YOMZALI YESIVUMELWANO

<u>Ulwazi nesivumelwano sokubayingxenye yocwaningo</u>

Usuku: 31 kuMfumfu 2018

Mzali othandekayo

Igama lami ngingu-Mpumelelo Blessing Gumede ofundela iziqu ze-Masters eNyuvesi yakwaZulu Natali.

Umntwana wakho uyamenywa ukuba abe yingxenye yocwaningo emkhakheni wesifundo se-Sayensi. Inhloso yalolucwaningo ukusiza abantwana abafunda ibanga le-11 ukuqonda isihloko sikagesi ngokusebenzisa i-concept map esifundweni se-Physical Sciences. Lolucwaningo luzosebenzisana nabantwana abangama-20 abafunda [redacted] Ucwaningo luzothatha isikhathi esingangezinsuku ezinhlanu (5) kuya kweziyishumi (10).

Lolucwaningo luzoba inzuzo ngalezindlela ezilandelayo: ukusiza abantwana ngezindlela ezahlukahlukene zokufunda isifundo se-Sayensi kanye nokucebisa othisha be-Sayensi ngezindlela eziphusile zokufundisa abantwana ezikoleni ngokuqonda.

Uma kwenzeka abantwana becelwa ukuba beze esikoleni ngoMgqibelo noma ngeholidi, umcwaningi uyena ozohlangabezana nezindleko zokubagibelisa kanye nokudla.

Uma unombuzo noma ukukhathazeka, uyacelwa ukuba uthintane neKomidi elibhekelela ukuziphatha kwabacwaningi e-UKZN:

HUMANITIES & SOCIAL SCIENCES RESEARCH ETHICS ADMINISTRATION
Research Office, Westville Campus
Govan Mbeki Building
Private Bag X 54001
Durban
4000
KwaZulu-Natal, SOUTH AFRICA
Tel: 27 31 2604557- Fax: 27 31 2604609
Email: HSSREC@ukzn.ac.za

Ukuba yingxenye yalolucwaningo akusiyo impoqo kepha kungukuzithandela. Isikole esifisa ukubayingxenye yalolucwaningo kudingeka sisayine lencwadi yesivumelwano ukugunyaza ucwaningo ukuthi luqhubeke. Umntwana unelungelo lokuhoxa nanoma yinini kulolucwaningo. Uma umntwana ezohoxa, uyacelwa ukuba azise umcwaningi, ukuze akwazi ukuthola isikhathi sokuthungatha omunye umntwana ozakuba yingxenye yocwaningo.

Ukuqinisekisa ukuvikeleka kwabantwana abayingxenye yocwaningo, ngizokusebenzisa amagama okungesiwo awabo angempela, kanti futhi, ngizokuqinisekisa ukuthi kuba yimfihlo ukuba yingxenye kwabo yalolucwaningo. I-datha ezokutholakala kulolucwaningo izogcinwa nguThishelakazi wami waseNyuvesi bese kuthi emva kweminyaka emihlanu (5) iyakushiswa.

ISIVUMELWANO

Mina [redacted] ngiyavuma ukuba umntwana wami abe yingxenye yalolucwaningo, ebesengichazeliwe ngalo nguMnumzane Mpumelelo Blessing Gumede.

Ngiyayiqonda inhloso kanye nenqubo yalolucwaningo.

Nginikeziwe ithuba lokubuza imibuzo ngocwaningo, futhi ngagculiseka ngezimpendulo engizitholileyo.

Ngiyavuma ukuthi ukubayingxenye yalolucwaningo kungukuthanda kwami, kanti futhi ngingahoxa nanoma yinini.

Ngiyavuma ukuthi:

Ingxoxo yomntwana wami (interview) ingaqoshwa	YEBO / CHA
Umntwana wami engathwetshulwa (photographs/video)	YEBO / CHA

[redacted]

15/11/2018
Usuku

Uma unemibuzo noma kukhona ofisa ukukwazi mayelana nocwaningo uyacelwa ukuba uthintane noMcwaningi kulenombolo: [redacted] kule imeyili [redacted]

Appendix F: Sample of the participants' consent letter

INCWADI YOMFUNDI YESIVUMELWANO

<u>Ulwazi nesivumelwano sokubayingxenye yocwaningo</u>

Usuku: 31 kuMfumfu 2018

Mfundi othandekayo

Igama lami ngingu-Mpumelelo Blessing Gumede ofundela iziqu ze-Masters eNyuvesi yaKwaZulu Natali.

Uyamenywa ukuba ubeyingxenye yocwaningo emkhakheni wesifundo se-Sayensi. Inhloso yalolucwaningo ukusiza abantwana abafunda ibanga le-11 ukuqonda isihloko sikagesi ngokusebenzisa i-concept map esifundweni se-Physical Sciences. Lolucwaningo luzosebenzisana nabantwana abangama-20 abafunda e-[redacted]. Ucwaningo luzothatha isikhathi esingangezinsuku ezinhlanu (5) kuya kweziyishumi (10).

Lolucwaningo luzoba inzuzo ngalezindlela ezilandelayo: ukusiza abantwana ngezindlela ezahlukahlukene zokufunda isifundo se-Sayensi kanye nokucebisa othisha be-Sayensi ngezindlela eziphusile zokufundisa abantwana ezikoleni ngokuqonda.

Uma kwenzeka ucelwa ukuthi uze esikoleni ngoMgqibelo noma ngeholidi, umcwaningi uyena ozohlangabezana nezindleko zetekisi kanye nokudla.

Uma unomubuzo noma ukukhathazeka, uyacelwa ukuba uthintane neKomidi elibhekelela ukuziphatha kwabacwaningi e-UKZN:

HUMANITIES & SOCIAL SCIENCES RESEARCH ETHICS ADMINISTRATION
Research Office, Westville Campus
Govan Mbeki Building
Private Bag X 54001
Durban
4000
KwaZulu-Natal, SOUTH AFRICA
Tel: 27 31 2604557- Fax: 27 31 2604609
Email: HSSREC@ukzn.ac.za

Ukubayingxenye yalolucwaningo akusiyo impoqo kepha kungukuzithandela. Isikole esifisa ukubayingxenye yalolucwaningo kudingeka sisayine lencwadi yesivumelwano ukugunyaza ucwaningo ukuthi luqhubeke. Uma uzohoxa, uyacelwa ukuba wazise umcwaningi, ukuze akwazi ukuthola isikhathi sokuthungatha omunye umntwana ozakuba yingxenye yocwaningo.

1

Ukuqinisekisa ukuvikeleka kwabantwana abayingxenye yocwaningo, ngizokusebenzisa amagama okungesiwo awabo angempela, kanti futhi, ngizokuqinisekisa ukuthi kuyimfihlo ukubayingxenye yalolucwaningo. I-datha ezokutholakala kulolucwaningo izogcinwa nguThishelakazi wami waseNyuvesi bese kuthi emvakweminyaka emihlanu (5) iyakushiswa.

ISIVUMELWANO

Mina [redacted] ngiyavuma ukuba yingxenye yalolucwaningo, ebesengichazeliwe ngalo nguMnumzane Mpumelelo Blessing Gumede.

Ngiyayiqonda inhloso kanye nenqubo yalolucwaningo.

Nginikeziwe ithuba lokubuza imibuzo ngocwaningo, futhi ngagculiseka ngezimpendulo engizitholileyo.

Ngiyavuma ukuthi ukubayingxenye yalolucwaningo kungukuthanda kwami, kanti futhi ngingahoxa nanoma yinini.

Ngiyavuma ukuthi:

Ingxoxo yami (interview) ingaqoshwa	YEBO / CHA
Ngingathwetshulwa (photographs/video)	YEBO / CHA

[redacted]

08/11/2018
Usuku

Uma unemibuzo noma kukhona ofisa ukukwazi mayelana nocwaningo uyacelwa ukuba uthintane noMcwaningi kulenombolo [redacted] noma kule imeyili [redacted]

2

Appendix G: Principal and SGB consent letter

UKZN HUMANITIES AND SOCIAL SCIENCES RESEARCH ETHICS COMMITTEE (HSSREC)

APPLICATION FOR ETHICS APPROVAL
For research with human participants

INFORMED CONSENT

<u>Information Sheet and Consent to Participate in Research</u>

Date: Thursday, October 18, 2018

Dear Principal and the SGB

My name is Mpumelelo Gumede from the University of KwaZulu-Natal

The learners at your school are being invited to consider participating in a study that involves research in the field of Science Education. The aim and purpose of this research is to enhance learners' understanding of electric circuits through concept mapping. The study is expected to enroll 20 learners who are doing grade 11 Physical Sciences at [redacted] The duration of learners' participation if you choose to allow them to enroll and remain in the study is expected to be 5 to 10 days. The study is funded by the University of KwaZulu Natal.

The study may involve the following discomfort: learners may be asked to remain at school for an hour after the normal school time has elapsed or be requested to come to school on a weekend/ or public holiday. I hope that the study will create the following benefits: provide suitable learning strategies for understanding concepts in Physical Sciences; promote meaningful learning of sciences; and provide teachers with alternative instructional tools to help learners construct knowledge.

In a case where learners will be asked to remain after school or come to school on a weekend or holiday, the researcher will cover the costs of transporting those learners who live far from school.

This study has been ethically reviewed and approved by the UKZN Humanities and Social Sciences Research Ethics Committee (approval number_____).

In the event of any problems or concerns/questions you may contact the researcher at (provide contact details) or the UKZN Humanities & Social Sciences Research Ethics Committee, contact details as follows:

HUMANITIES & SOCIAL SCIENCES RESEARCH ETHICS ADMINISTRATION
Research Office, Westville Campus
Govan Mbeki Building
Private Bag X 54001
Durban
4000
KwaZulu-Natal, SOUTH AFRICA
Tel: 27 31 2604557- Fax: 27 31 2604609
Email: HSSREC@ukzn.ac.za

The participation to this study is voluntary and there are no costs involved. Only schools and participants with duly signed response letters will be allowed to participate in the study. Participants are allowed to refuse or withdraw participation to this study, and there will be no penalties or loss of treatment incurred. In the event of a withdrawal from the study, the participants are advised to kindly provide the researcher with a 2 days' notice so that other necessary arrangements can be made to find a replacement. The researcher reserves the right to terminate/remove the participant from the study under the following circumstances: if the participation to the study places the participant at psychological or physical or economical risk; if the involvement of the participant is disruptive and may temper with the outcomes of the study; or any other unforeseen circumstance that my might affect the proceedings of the study.

To ensure anonymity, I will use pseudonyms for the school and for each of the participants involved in the study. No description of participants nor school nor their location nor anything that makes the identity of the participants or their school to be second guessed shall be included in the finished thesis. I shall ensure that all the data collected shall not be made available to other parties including teachers of the participating schools. I shall not discuss anything regarding the participants whether positive or negative with schools authorities. Moreover, all data that will be collected will be stored with my supervisor at UKZN and after 5 years, all data will be shredded or incinerated

---

CONSENT (Edit as required)

I [redacted] have been informed about the study entitled "Meaningful learning through concept mapping: the case of grade 11 pupils' conception of electric circuits" by Mpumelelo Blessing Gumede.

I understand the purpose and procedures of the study.

I have been given an opportunity to answer questions about the study and have had answers to my satisfaction.

I declare that my participation in this study is entirely voluntary and that I may withdraw at any time without affecting any of the benefits that I usually am entitled to.

I have been informed about any available compensation or medical treatment if injury occurs to me as a result of study-related procedures.

If I have any further questions/concerns or queries related to the study I understand that I may contact the researcher at: cell no: [redacted]

If I have any questions or concerns about my rights as a study participant, or if I am concerned about an aspect of the study or the researchers then I may contact:

HUMANITIES & SOCIAL SCIENCES RESEARCH ETHICS ADMINISTRATION
Research Office, Westville Campus
Govan Mbeki Building
Private Bag X 54001
Durban
4000
KwaZulu-Natal, SOUTH AFRICA
Tel: 27 31 2604557 - Fax: 27 31 2604609
Email: HSSREC@ukzn.ac.za

Additional consent, where applicable

I hereby provide consent to:

Audio-record my interview / focus group discussion	YES / NO
Video-record my interview / focus group discussion	YES / NO
Use of my photographs for research purposes	YES / NO

[redacted]ber   19-10-2018
Date

Signature of Witness
(Where applicable)   Date

Signature of Translator
(Where applicable)   Date

Appendix H: Ethical Clearance DoBE KZN

education

Department:
Education
PROVINCE OF KWAZULU-NATAL

Enquiries: Phindile Duma | Tel: 033 392 1063 | Ref.:2/4/8/1648

Mr MB Gumede
PO Box 1095
Pietermaritzburg
3201

Dear Mr Gumede

PERMISSION TO CONDUCT RESEARCH IN THE KZN DoE INSTITUTIONS

Your application to conduct research entitled: **"MEANINGFULL LEARNING VIA CONCEPT MAPPING: THE CASE OF GRADE 11 PUPILS' UNDERSTANDING OF KEY CONCEPTS IN ELECTRIC CIRCUITS"**, in the KwaZulu-Natal Department of Education Institutions has been approved. The conditions of the approval are as follows:

1. The researcher will make all the arrangements concerning the research and interviews.
2. The researcher must ensure that Educator and learning programmes are not interrupted.
3. Interviews are not conducted during the time of writing examinations in schools.
4. Learners, Educators, Schools and Institutions are not identifiable in any way from the results of the research.
5. A copy of this letter is submitted to District Managers, Principals and Heads of Institutions where the Intended research and interviews are to be conducted.
6. The period of investigation is limited to the period from 05 October 2018 to 02 March 2021.
7. Your research and interviews will be limited to the schools you have proposed and approved by the Head of Department. Please note that Principals, Educators, Departmental Officials and Learners are under no obligation to participate or assist you in your investigation.
8. Should you wish to extend the period of your survey at the school(s), please contact Miss Phindile Duma at the contact numbers below,
9. Upon completion of the research, a brief summary of the findings, recommendations or a full report/dissertation/thesis must be submitted to the research office of the Department. Please address it to The Office of the HOD, Private Bag X9137, Pietermaritzburg, 3200.
10. Please note that your research and interviews will be limited to schools and institutions in KwaZulu-Natal Department of Education.

(PLEASE SEE LIST OF SCHOOLS/ INSTITUTIONS ATTACHED)

Dr. EV Nzama
Head of Department: Education
Date: 10 October 2018

...Championing Quality Education - Creating and Securing a Brighter Future

KWAZULU-NATAL DEPARTMENT OF EDUCATION
Postal Address: Private Bag X9137 • Pietermaritzburg • 3200 • Republic of South Africa
Physical Address: 247 Burger Street • Anton Lembede Building • Pietermaritzburg • 3201
Tel.: +27 33 392 1063 • **Fax.:** +27 033 392 1203• **Email:** **Web:** www.kzneducation.gov.za
Facebook: KZNDOE....Twitter: @DBE_KZN....Instagram: kzn_education....Youtube:kzndoe

education

Department:
Education
PROVINCE OF KWAZULU-NATAL

LIST OF SCHOOLS/ INSTITUTIONS

1. [redacted]

..Championing Quality Education - Creating and Securing a Brighter Future

KWAZULU-NATAL DEPARTMENT OF EDUCATION
Postal Address: Private Bag X9137 • Pietermaritzburg • 3200 • Republic of South Africa
Physical Address: 247 Burger Street • Anton Lembede Building • Pietermaritzburg • 3201
Tel.: +27 33 392 1063 • **Fax.:** +27 033 392 1203• **Email:** Web:www.kzneducation.gov.za
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Appendix I: Ethical Clearance from UKZN

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

07 December 2018

Mr Mpumelelo B Gumede 218083444
School of Education
Edgewood Campus

Dear Gumede

Protocol reference number: HSS/2096/018M
Project Title: Meaningful learning via concept mapping: The case of 11 pupils' understanding of electric circuits.

Full Approval – Expedited Application

In response to your application received 14 November 2018, the Humanities & Social Sciences Research Ethics Committee has considered the abovementioned application and the protocol has been granted **FULL APPROVAL.**

Any alteration/s to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form, Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment /modification prior to its implementation. In case you have further queries, please quote the above reference number.

PLEASE NOTE: Research data should be securely stored in the discipline/department for a period of 5 years.

The ethical clearance certificate is only valid for a period of 3 years from the date of issue. Thereafter Recertification must be applied for on an annual basis.

I take this opportunity of wishing you everything of the best with your study.

Yours faithfully

....
Dr Shamila Naidoo

/px

cc Supervisor: Lebala Kolobe
cc. Academic Leader Research: Dr Simon B Khoza
cc. School Administrator: Ms S Jeenaran, Ms M Ngcobo and Mr N Mthembu

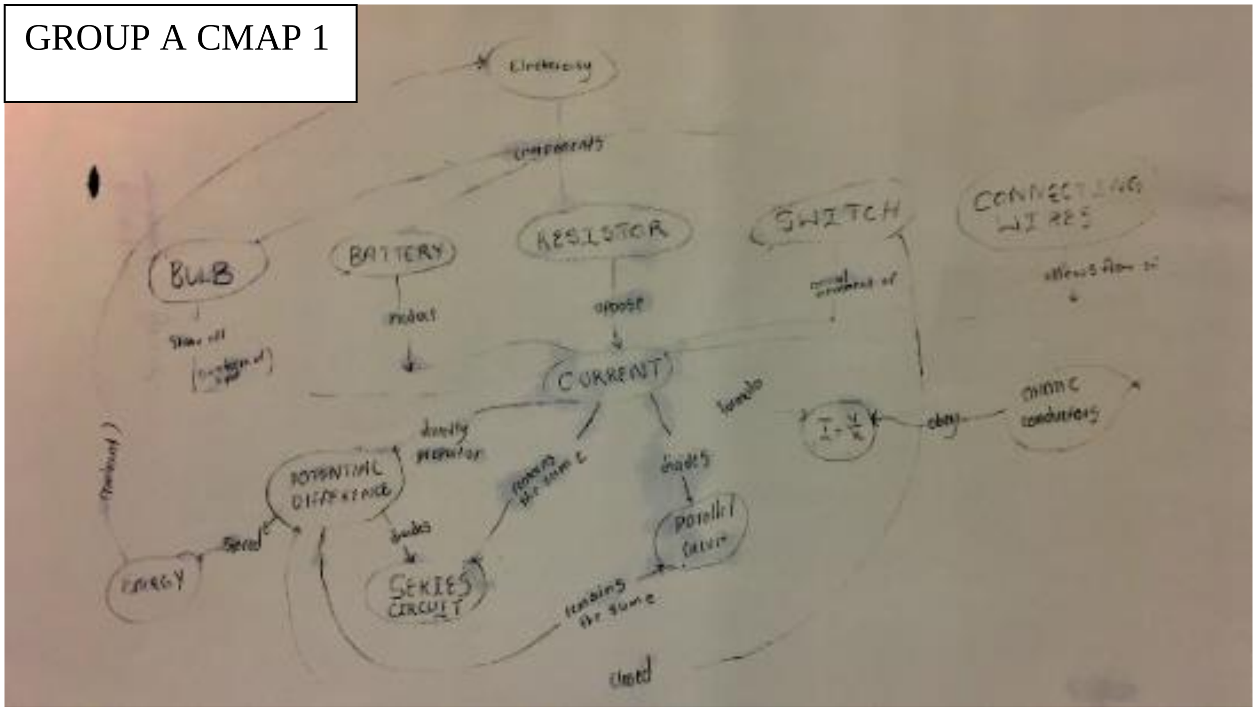
Humanities & Social Sciences Research Ethics Committee
Professor Shenuka Singh (Chair)/Dr Shamila Naidoo (Deputy Chair)
Westville Campus, Govan Mbeki Building
Postal Address: Private Bag X54001, Durban 4000
Telephone: +27 (0) 31 260 3587/8350/4557 **Facsimile:** +27 (0) 31 260 4609 **Email:** ximbap@ukzn.ac.za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

1910 - 2010
100 YEARS OF ACADEMIC EXCELLENCE

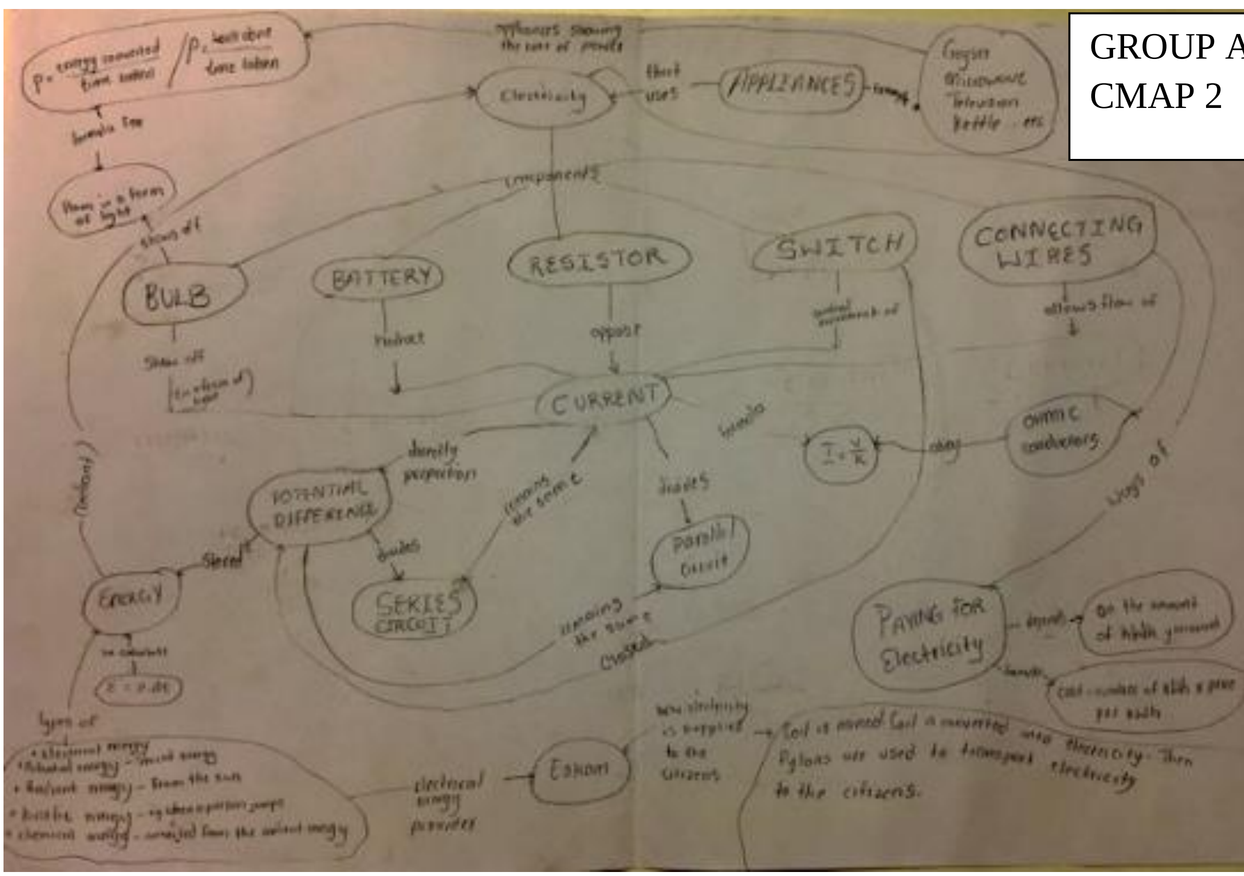
Founding Campuses: Edgewood Howard College Medical School Pietermaritzburg Westville

Appendix J: Concept maps drawn by learners in their groups

GROUP A CMAP 1



GROUP A CMAP 2



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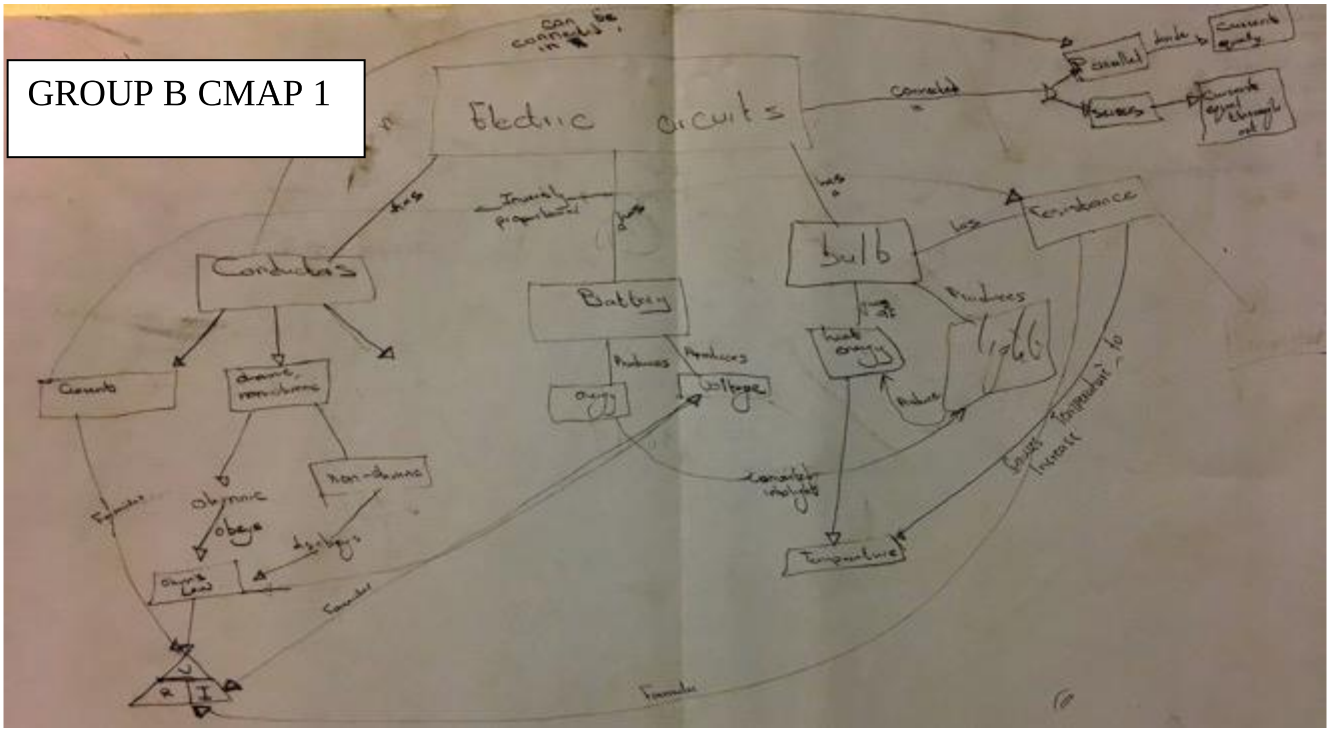

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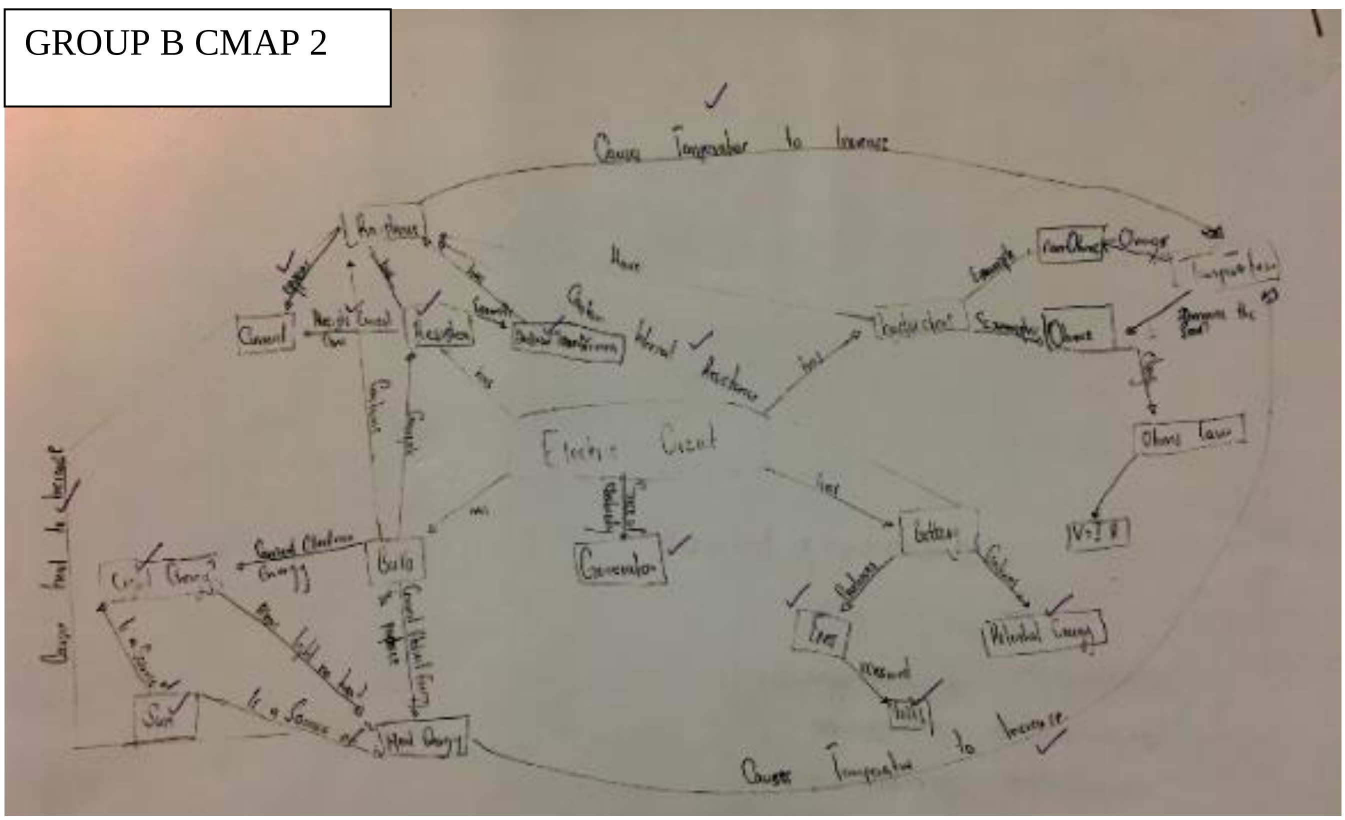
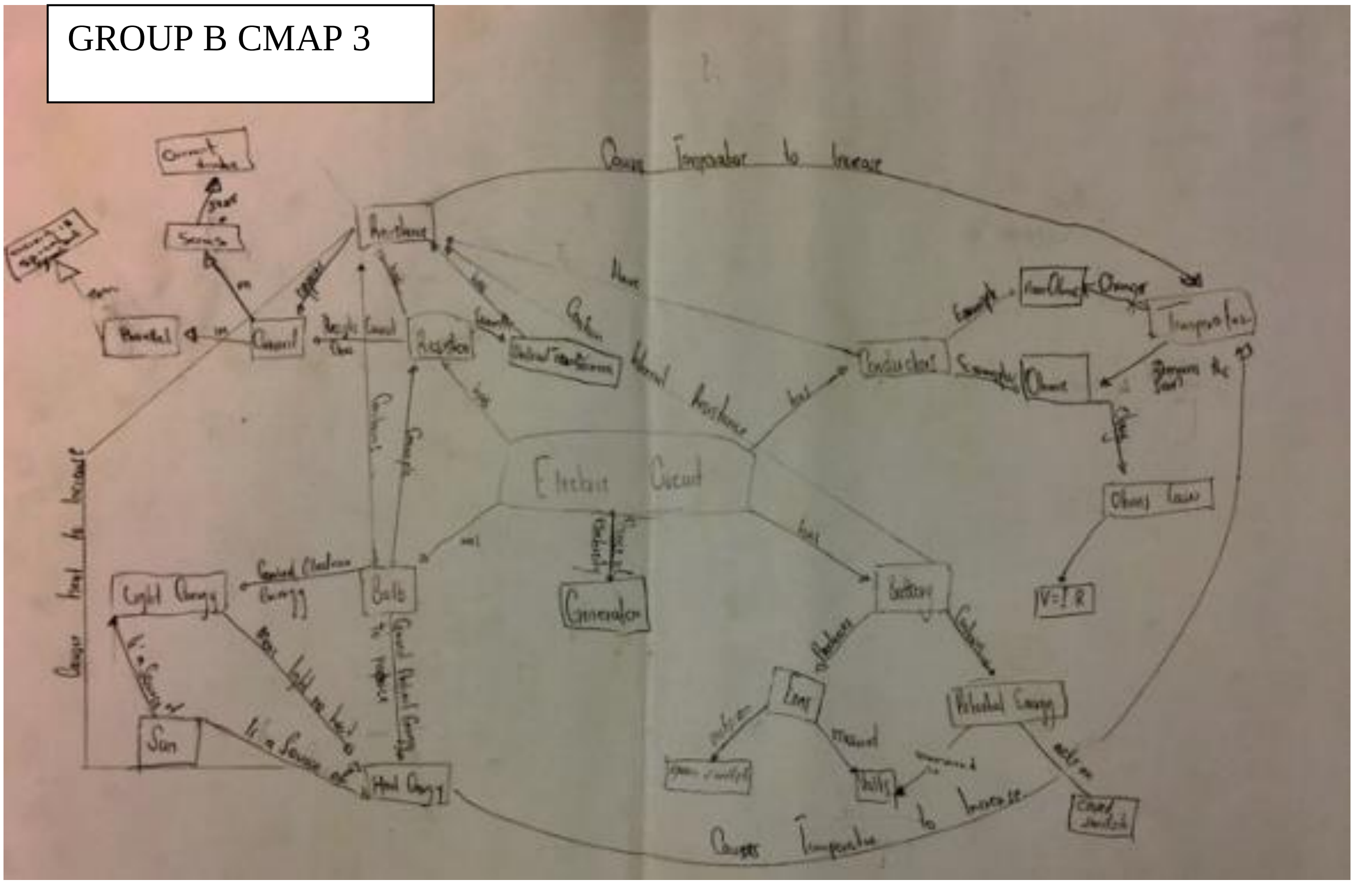


GROUP B CMAP 3



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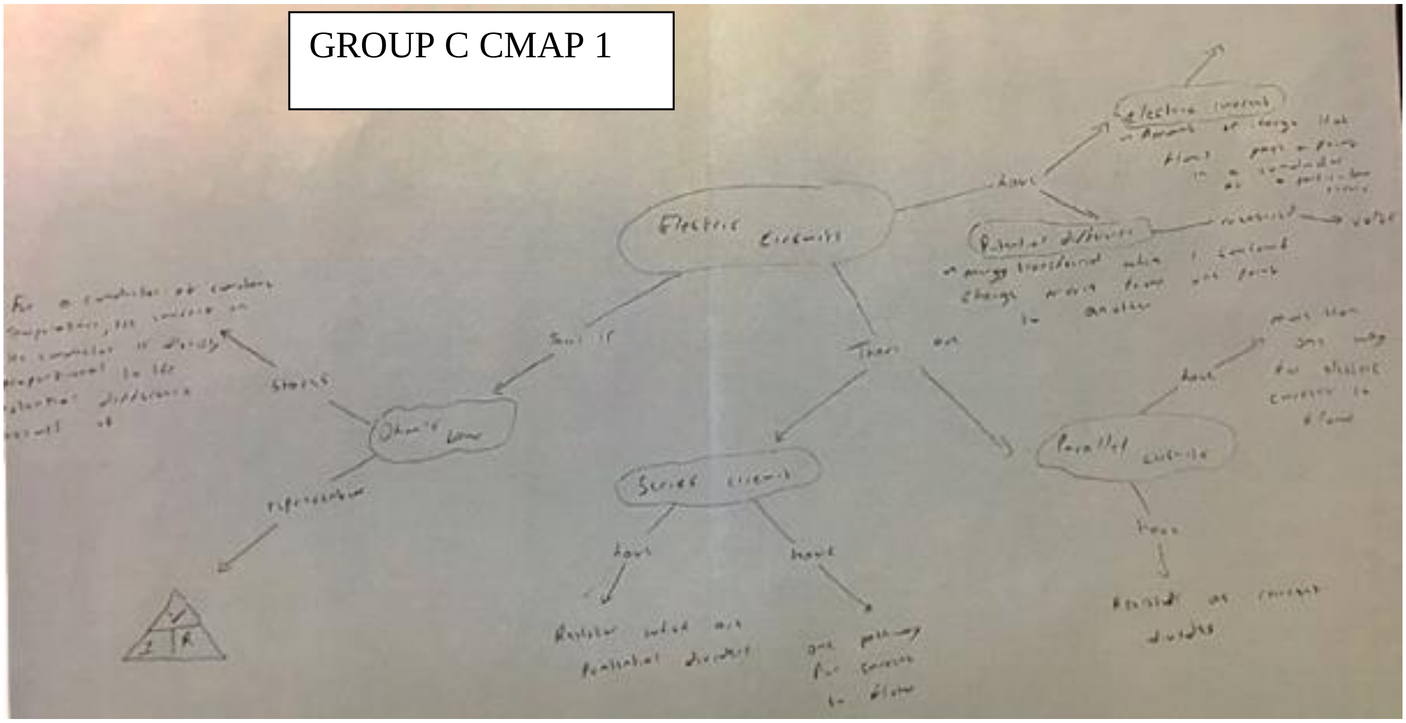
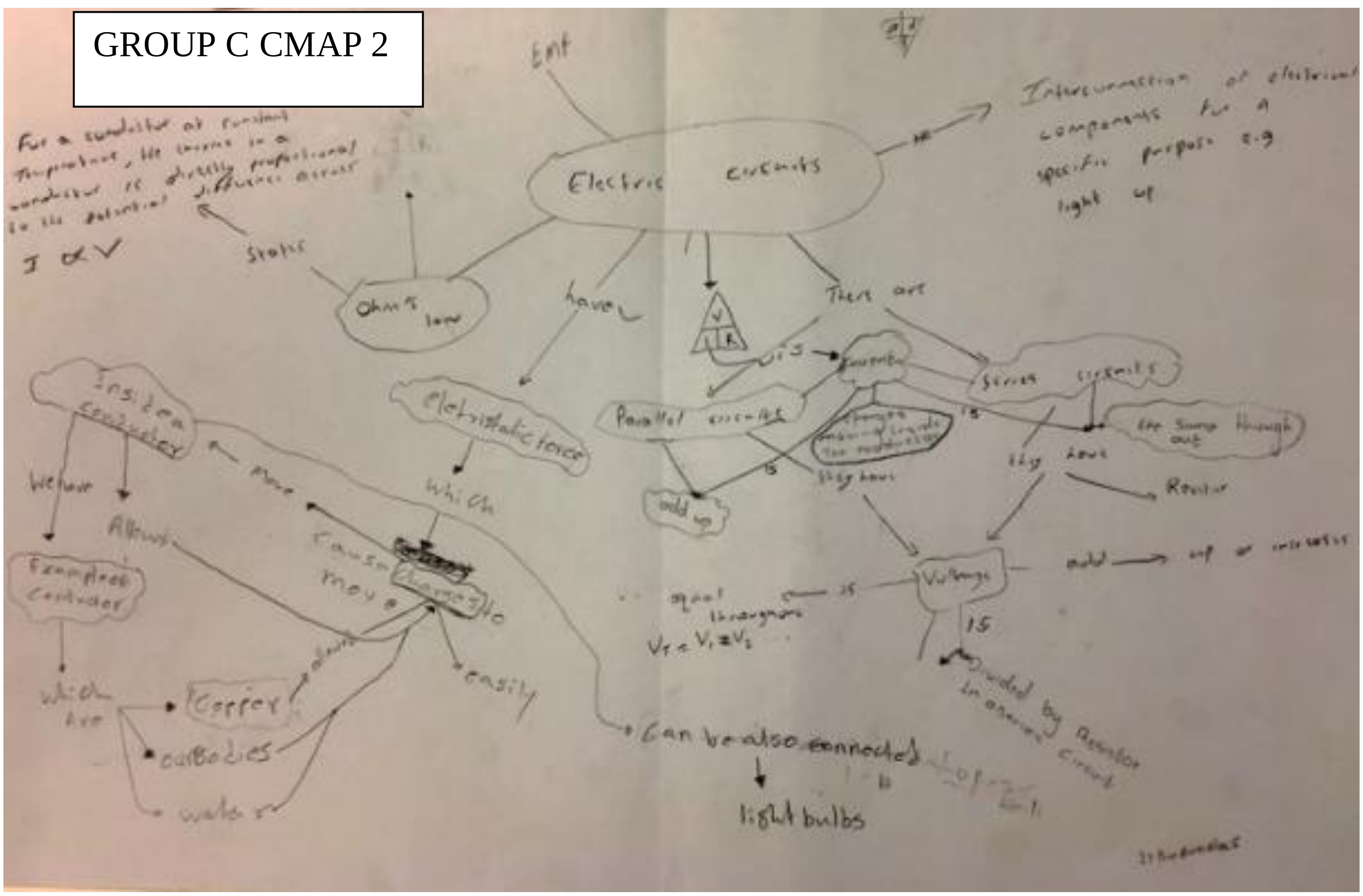


GROUP C CMAP 2



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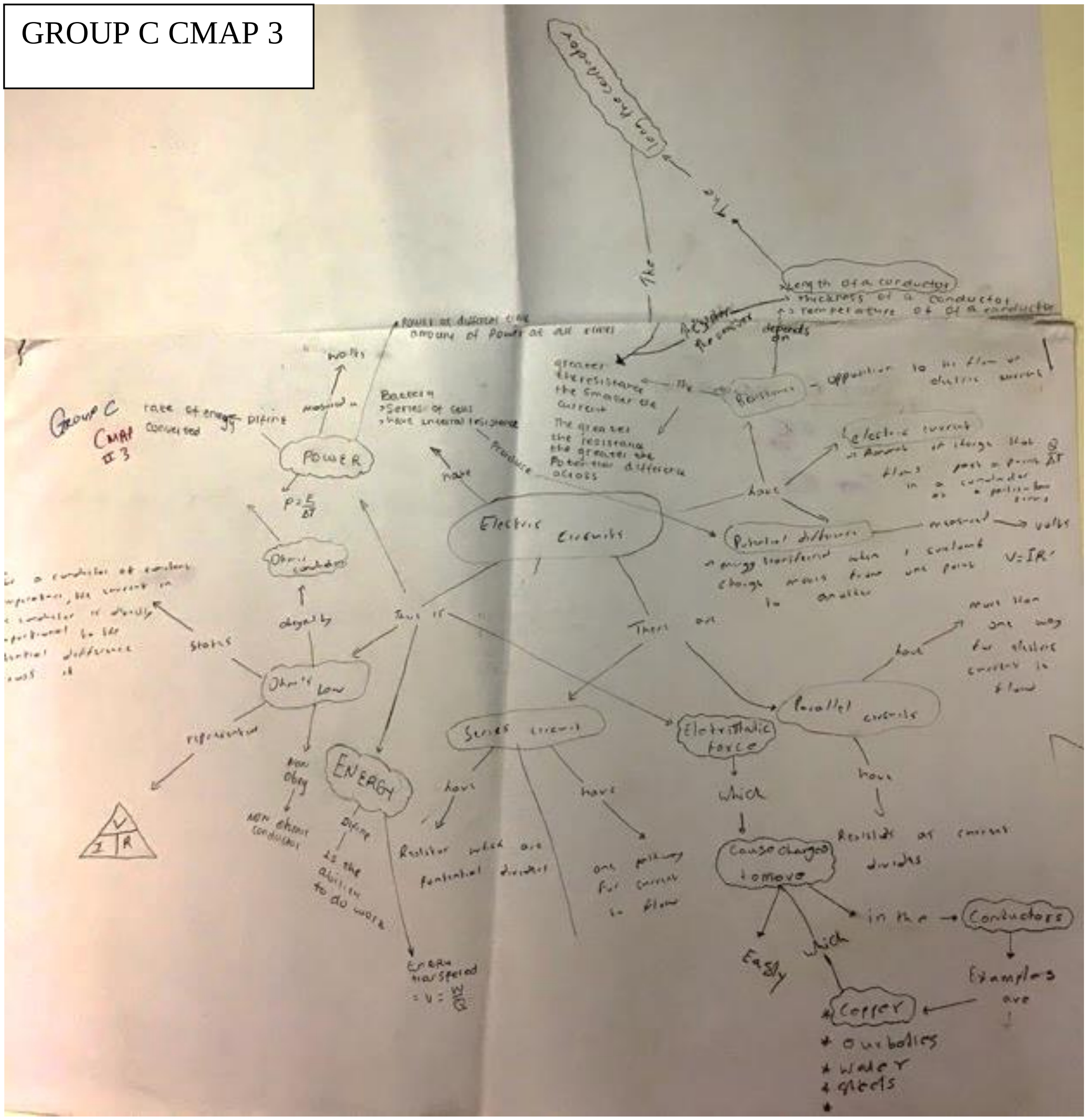
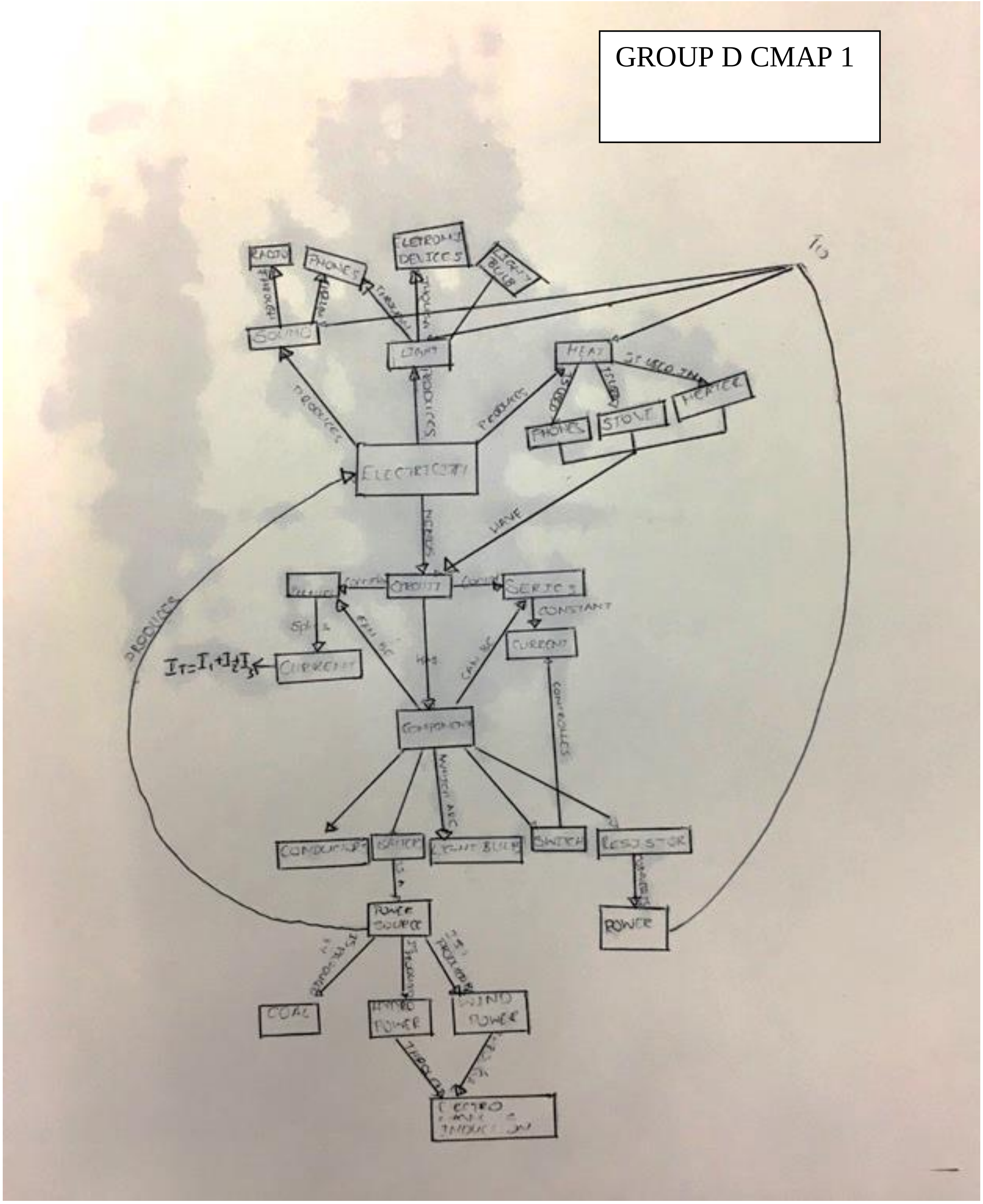
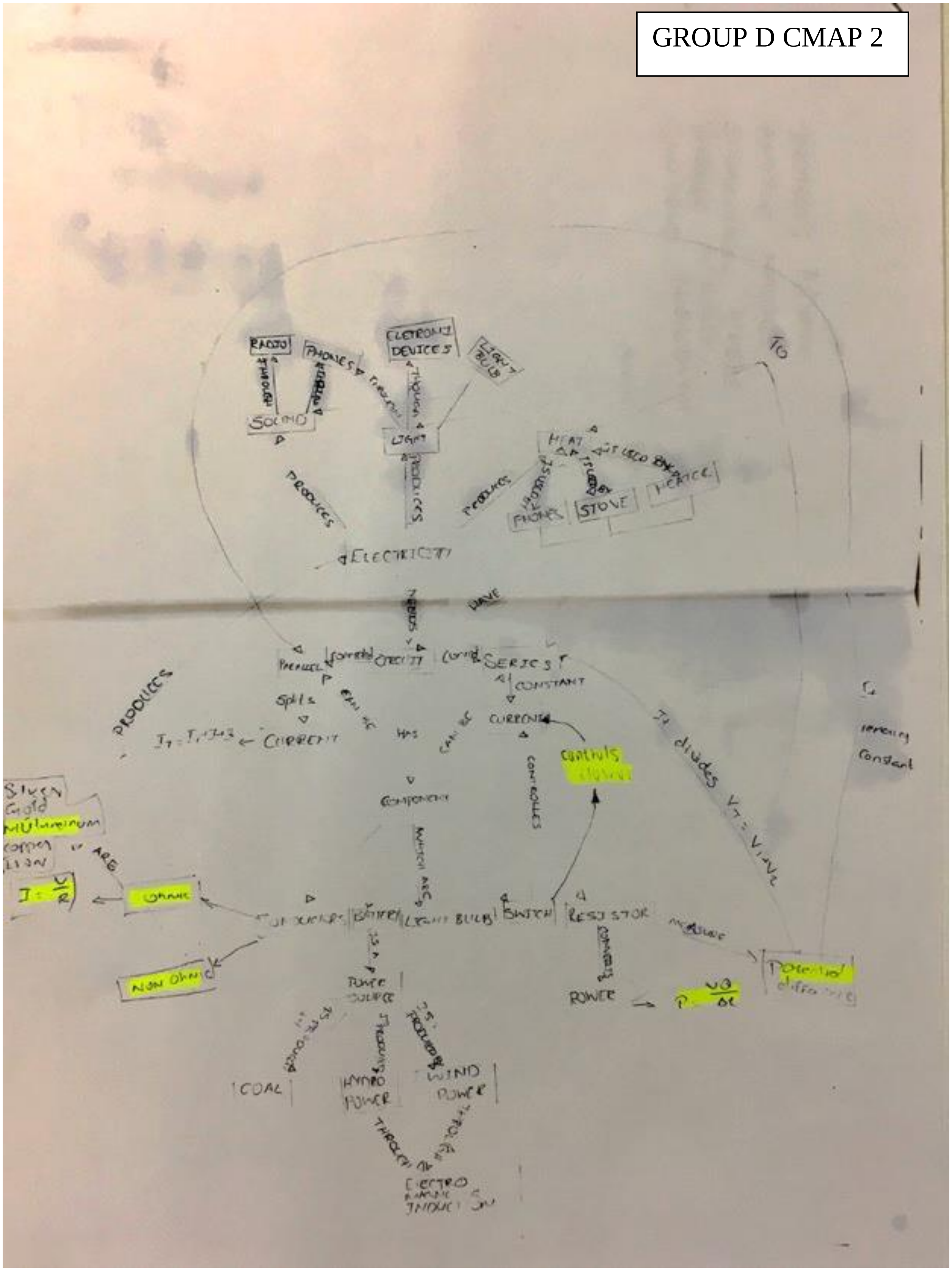


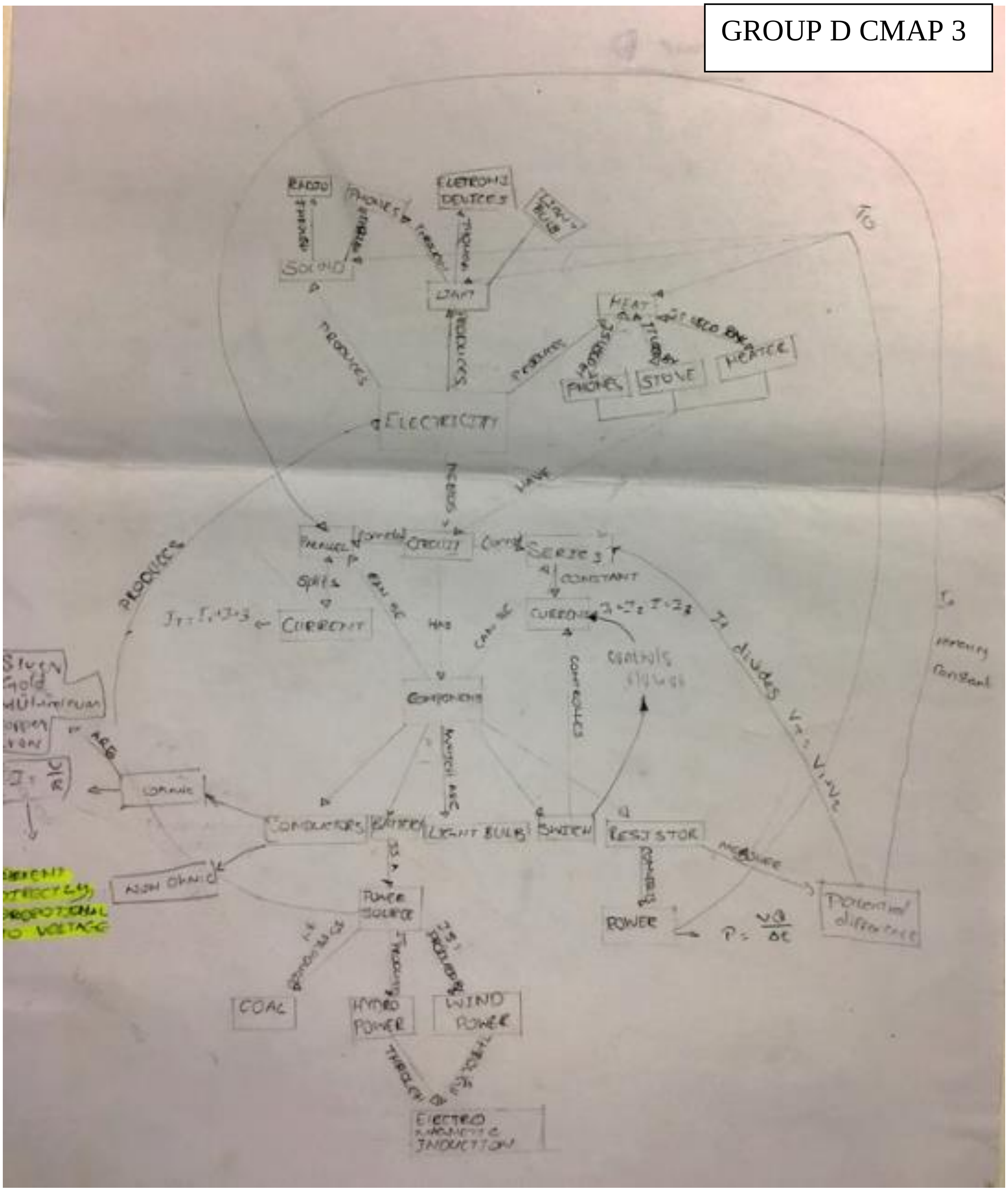
GROUP D CMAP 1



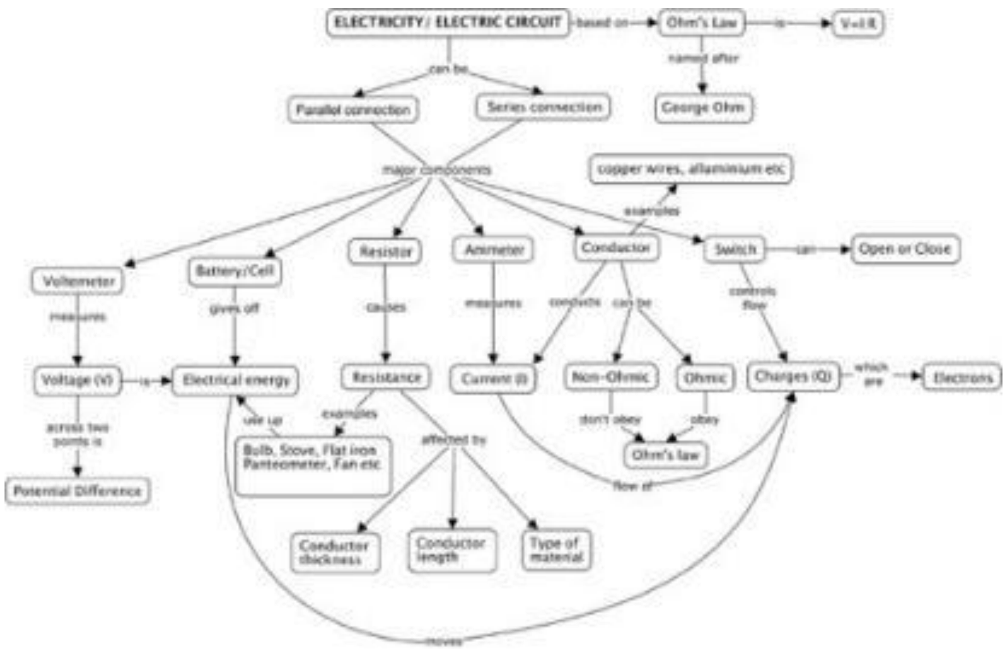
GROUP D CMAP 2

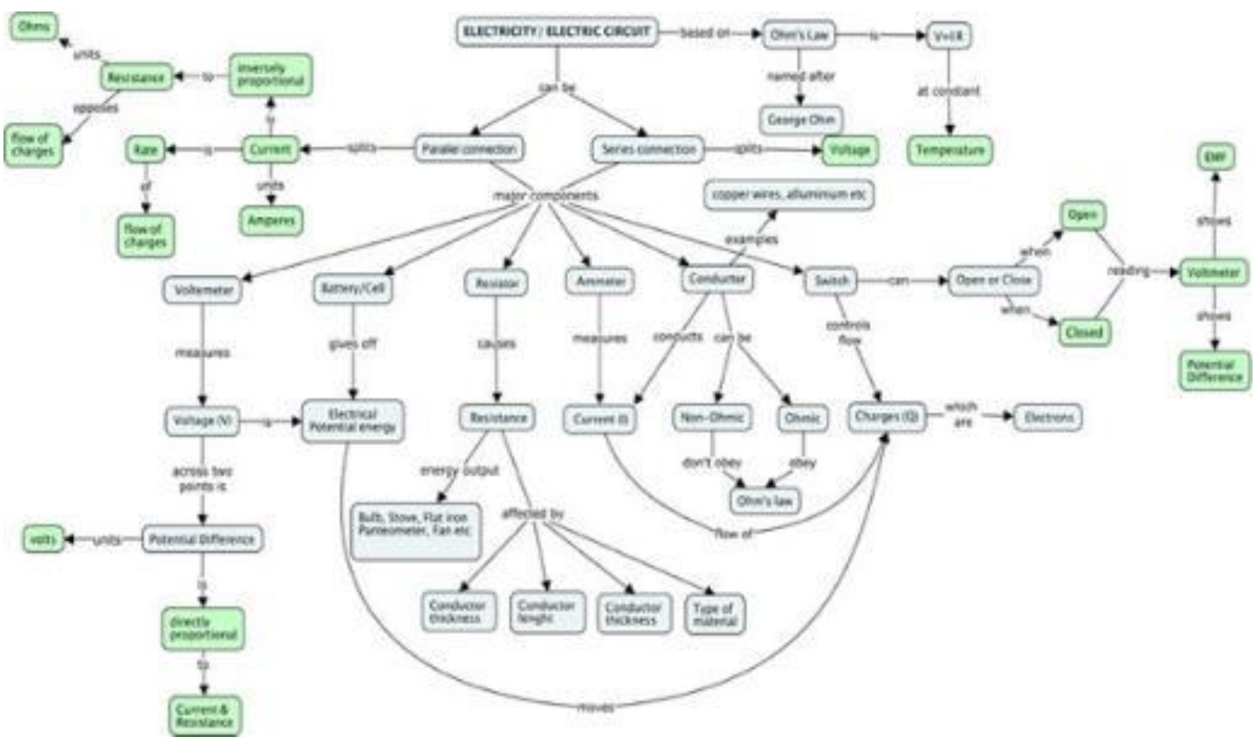


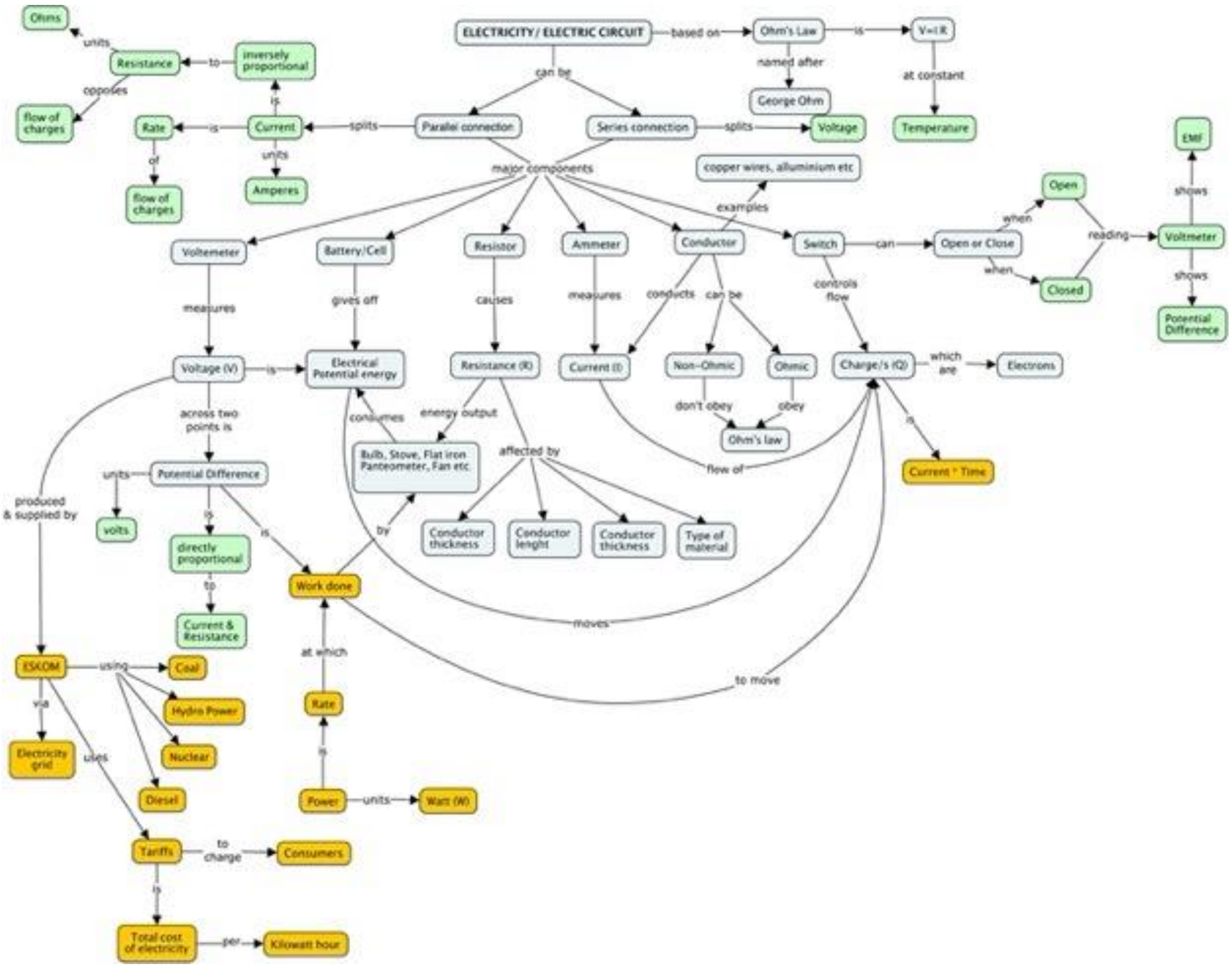
GROUP D CMAP 3



Appendix K: Criterion concept maps and a table of expected relationships in the learners' concept maps







ELECTRICITY / ELECTRIC CIRCUIT
based on
Ohm's Law
is
V=I R
named after
George Ohm
at constant
Temperature
can be
Parallel connection
Series connection
splits
Voltage
splits
Current
is
inversely proportional
to
Resistance
units
Ohms
opposes
flow of charges
is
Rate
of
flow of charges
units
Amperes
major components
Voltemeter
Battery/Cell
Resistor
Ammeter
Conductor
Switch
examples
copper wires, alluminium etc
can
Open or Close
when
Open
when
Closed
reading
Voltmeter
shows
EMF
shows
Potential Difference
measures
gives off
causes
measures
conducts
can be
controls flow
Voltage (V)
is
Electrical Potential energy
Resistance (R)
Current (I)
Non-Ohmic
Ohmic
Charge/s (Q)
which are
Electrons
don't obey
obey
Ohm's law
flow of
is
Current * Time
across two points is
consumes
energy output
Bulb, Stove, Flat iron Panteometer, Fan etc
affected by
Conductor thickness
Conductor lenght
Conductor thickness
Type of material
units
Potential Difference
volts
is
directly proportional
to
Current & Resistance
is
by
Work done
moves
to move
at which
Rate
is
Power
units
Watt (W)
produced & supplied by
ESKOM
using
Coal
Hydro Power
Nuclear
Diesel
via
Electricity grid
uses
Tariffs
to charge
Consumers
is
Total cost of electricity
per
Kilowatt hour

Expected relationships from the concept maps

	Concept	Related concept/ proposition			
Core knowledge	Ohms Law	Potential difference (P.d)	Resistance	Current	
Components of a simple electric circuit	Voltmeter	P.d			
	Battery/Cell	Voltage			
	Resistor	Resistance			
	Ammeter	Current			
	Conductor	Ohmic	Non ohmic		
	Switch	Open/ Close			
Types of connections	Parallel connection	Current splits	P.d remains the same	Resistors	
	Series connection	Current remains the same	P.d splits	Resistors	
Types of conductors	Ohmic	Obeys Ohms law			
	Non ohmic	Do not obey Ohms law			
Critical concepts	Electrical energy/ Voltage	P.d	Charges/ electrons	Current	Voltmeter
	Resistance	Resistor	Directly proportional to P.d	Inversely proportiona l to Current	
	Current	Directly proportional to P.d	Inversely proportional to Resistance	Charges/ electrons	Voltage
	Temperature	Remains constant			
	Potential difference (P.D)	Directly proportional to Current	Directly proportional to Resistance		
	Charges / electrons	Current	Voltage		
	Power	Electrical energy	Time		
S.I units	Volts	P.d			
	Amperes	Current			
	Ohm	Resistance			
	Joules	Energy			
	Watt	Power			

Appendix L: Editor’s Letter

EVERSHIELD LANGUAGE SERVICES

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Zimbabwe

Cell: +263712843535/
+263771716899

Email: manyawu67@gmail.com; manyawuat@staff.msu.ac.zw

EDITORIAL CERTIFICATE

This serves to confirm that the following Master of Education thesis:

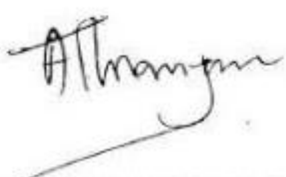
Title: "Exploring Understandings of Key Concepts in Electric Circuits: A Case of 20 Grade 11 Physical Sciences Learners Collaboratively Constructing Concept Maps"

Author: Mpumelelo Blessing Gumede

was edited for English language usage, grammar, spelling, punctuation, phrasing & sentence structure, and cohesion & coherence by an experienced professional editor of scholarly academic works with native or CEFR[1] Level C2 proficiency in English. Every effort was made to ensure that the research content and author's intentions were in no way altered during the editing process.

Name of Editor: Professor Andrew Tichaenzana Manyawu (PhD Linguistics)

Signed



Professor Andrew Tichaenzana Manyawu

[1] Common European Framework of Reference

Appendix M: Turnitin Report

Turnitin Originality Report

- Processed on: 08-Dec-2019 5:02 PM CAT
- ID: 1229299343
- Word Count: 48024
- Submitted: 3

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< 1% match (publications)
Nadaraj Govender. "Developing Pre-service Teachers' Subject Matter Knowledge of Electromagnetism by Integrating Concept Maps and Collaborative Learning", African Journal of Research in Mathematics, Science and Technology Education, 2015

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Submitted to Universiti Teknologi MARA on 2018-11-26

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Zeger-Jan Kock, Ruurd Taconis, Sanneke Bolhuis, Koeno Gravemeijer. "CREATING A CULTURE OF INQUIRY IN THE CLASSROOM WHILE FOSTERING AN UNDERSTANDING OF THEORETICAL CONCEPTS IN DIRECT CURRENT ELECTRIC CIRCUITS: A BALANCED APPROACH", International Journal of Science and Mathematics Education, 2014

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"Overcoming Students' Misconceptions in Science", Springer Nature, 2017

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Rankhumise, Mmushetji Petrus, and Sitwala Namwinji Imenda. "Using a Bicycle Analogy to Alleviate Students' Alternative Conceptions and Conceptual Difficulties in Electric Circuits", Mediterranean Journal of Social Sciences, 2014.

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Laurent Liégeois, G′erard Chasseigne, Sophie Papin, Etienne Mullet. "Improving high school students' understanding of potential difference in simple electric circuits", International Journal of Science Education, 2003

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Submitted to University of Zululand on 2012-04-16

< 1% match (publications)
"Innovating with Concept Mapping", Springer Science and Business Media LLC, 2016

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Petrus, Rankhumise Mmushetji. "Running Head: Activity-Based Learning Using Activity-Based Instructional Approaches in Electric Circuits", Mediterranean Journal of Social Sciences, 2014.

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Submitted to University of KwaZulu-Natal on 2019-06-26

< 1% match (publications)

Zacharia, Zacharias C., and Ton de Jong. "The Effects on Students’ Conceptual Understanding of Electric Circuits of Introducing Virtual Manipulatives Within a Physical Manipulatives-Oriented Curriculum", Cognition and Instruction, 2014.

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Linda De George-Walker, Mark A. Tyler. "Collaborative Concept Mapping: Connecting with Research Team Capacities", Education Research International, 2014

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Submitted to University of Johannsburg on 2019-02-08

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SAGLAMA, Murat. "The Confidence-Accuracy Relationship in Diagnostic Assessment: The Case of the Potential Difference in Parallel Electric Circuits", İletişim Hizmetleri, 2015.

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Submitted to Cambridge Education Group on 2014-03-10

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"Digital Knowledge Maps in Education", Springer Nature, 2014

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http://www.science.gov/topicpages/p/promote+meaningful+learning.html

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Rankhumise Mmushetji Petrus. "Comparing the Performance of National Curriculum Statements and Old Curriculum Students' in Electric Circuits", International Journal of Educational Sciences, 2017

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Grant E. Gardner, Mary Ellen Lohr, Stephen Bartos, Joshua W. Reid. "Comparing Individual and Group-Negotiated Knowledge Structures in an Introductory Biology Course for Majors", Journal of Biological Education, 2018

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Michael Jabot. "Mental Models of Elementary and Middle School Students in Analyzing Simple Battery and Bulb Circuts", School Science and Mathematics, 01/2007

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Appendix N: Example of coding obtained from NVIVO