The relationship between teachers' ideas about teaching electricity and their awareness of learners' misconceptions

by

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To my late father:

“This one’s for you dad!”

Summary

This study explored the relationship between teachers' ideas on teaching electricity and their awareness of learners' misconceptions. A sample of six participants was conveniently selected from six different schools in an urban setting. A multi case design was used, treating each participant as a separate case. Data were collected using a questionnaire and interview. Each question in the questionnaire was designed to probe teachers' knowledge, understanding and addressing of well-known misconceptions about circuits as reported in the literature. Interviews focused on teachers' ideas about content and teaching methods. Results were interpreted using an existing Pedagogical Content Knowledge (PCK) model as conceptual framework.

It was found that teachers' understanding of misconceptions ranged from minimal to insightful. Their strategies to correct misconceptions included teaching factually, mathematically, practically and conceptually. It was found that those teachers who were well aware of their learners' misconceptions also held ideas that science teaching should focus on conceptual understanding and that various teaching methods should be used. Conversely, teachers who demonstrated poor understanding of misconceptions tended to view and teach concepts as isolated facts. It is argued that the relationship between teachers' ideas and their awareness of misconceptions is one of cyclic reinforcement rather than simple cause and effect. The results also showed that teachers' qualifications play a significant role in their ability to facilitate understanding of concepts in electric circuits. A new hierarchical model of pedagogical content knowledge is proposed to explain the results of this study.

Key words: Misconceptions, Electricity, Pedagogical Content Knowledge, Subject Matter Knowledge.

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List of Abbreviations

CAPS: Curriculum Assessment Policy Statement

CCK: Common content knowledge

IQMS: Integrated Quality Management System

KCS: Knowledge of content and student

KCT: Knowledge of content and teacher

PCK: Pedagogical content knowledge

RNCS: Revised National Curriculum Statement

SCK: Specialized content knowledge

SMK: Subject matter knowledge

KC: Knowledge of curriculum

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Chapter 1.

Introduction

1.1. Orientation

Electricity is regarded as an essential topic in the school science curricula worldwide. However, many learners experience difficulty understanding electricity. In fact, problems with regard to teaching and learning electric circuits have been common amongst learners all over the world (see for example: Gilbert & Watts, 1983; Chang, Lui & Chen, 1998; Kucukozer & Kocakulah, 2007). Current literature shows evidence of studies conducted in different countries where similar misconceptions on electric circuits have been found (Kucukozer & Demirci, 2006; Engelhardt & Beichner, 2004; Shipstone, 1985).

Misconceptions occur in many areas of science and are well known in the field of electricity. These misconceptions in general arise from personal experiences from a young age and whilst being taught (Fredette, & Clement, 1981). Misconceptions are fundamental to problems in understanding science because basic content is not mastered. From a constructivist viewpoint, new knowledge is built on existing knowledge (Jones, Carter and Rua**,** 1999), which implies that misconceptions need to be corrected to enable learning of more complex concepts.

In many instances, teachers may know learners' typical mistakes in electric circuits but their understanding of why learners make these mistakes have not been explored extensively (Gunstone, Mulhall, & McKittrick, 2009). It is therefore not clear to what extent teachers recognise misconceptions amongst their learners, understand how learners think, and find methods to resolve misconceptions. Also, teachers' ideas about essential content and methods to teach electric circuits have not yet been investigated. This study aims to investigate these issues by exploring how teachers' understanding of learners' misconceptions relate to what they teach and the teaching methods that they use. Finding some answers to these questions will provide insights that are not available in current research literature.

1.2. Background

In South Africa, electricity has appeared in the subject policies for many years (see Department of Education (DoE), 2002; Department of Basic Education (DoBE), 2011).Starting at a young age with Grade 5 learners, electricity becomes a very detailed section of the science curricula towards the end of the school career (DoBE, 2011). It is therefore important that science teachers have a good understanding of the content to be taught. However, there is a shortage of qualified science teachers in South Africa. In fact, statistics show that approximately only 40% of science teachers in South Africa have a degree; this refers to a degree in any discipline, not necessarily science, (Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008). Before the political changes in 1994, the majority of Grade10-12 science teachers held a 3-year diploma obtained from a college. These diplomas included a level of subject matter knowledge which was equivalent to 1 year of university physics and chemistry. Although attempts by teachers have been made to upgrade their qualifications, the upgrading was typically in education rather than the content areas (Rollnick et al., 2008). Consequently, the majority of science teachers in South Africa are poorly qualified. Science qualifications are relevant to this study because if the teacher does not have sufficient content knowledge, the likelihood of being unaware of misconceptions amongst his/her learners is more likely. From personal experience and observation of other teachers, many teachers do not realise that learners do not understand concepts and do not find methods to help them get a better understanding of the concepts. From Rollnick et al.'s (2008) article we can expect that there is a problem with the availability of teachers that have sufficient subject knowledge of science.

How do misconceptions feature in the typical South African classroom where many teachers are not qualified? Teachers are expected to have mastered the ability to integrate pedagogical content knowledge and subject matter knowledge effectively so that their teaching is efficient and productive. This should support the learners' ability to overcome misconceptions and construct new knowledge in agreement with the scientific model, as well as to comprehend more complex areas of electricity.

1.3. Problem Statement and Rationale

An extensive amount of research has been carried out about misconceptions on electricity for learners of various ages. Cosgrove, Osborne and Carr (1995) and Shipstone (1985) focus on young children; Dupin and Joshua (1987) and Eylon and Ganiel (1990) focus on senior high school students; McDermott and Shaffer (1992), and Vienott and Rainson (1992) focus on undergraduate and postgraduate students; Ameh and Gunstone (1985), Cohen, Eylon, and Ganiel (1983) and Pardhan and Bano (2001) focus on teachers in science; and Stocklmayer and Treagust (1996) focus on novices and experts. These studies have been done in many parts of the world, commonly in France, Turkey and the United States, but a study regarding teachers' awareness of misconceptions in electricity has not been reported in local research.

During my undergraduate studies, I noticed that many of my colleagues and I had difficulties in understanding simple concepts in electricity. It is difficult to understand electric circuits because the concepts are abstract; nobody can see inside a circuit. Potential difference, current, resistance, energy, charge and power are closely linked and often confused. Once I started teaching, I realised that finding teaching methods to explain these concepts are imperative for my learners to understand more complex aspects in electricity such as Ohm's law and internal resistance. I have found that efforts involving the use of models, analogies, and illustrations often confuse learners and I argue that this may be due to poor understanding of the basic concepts or the existence of misconceptions. In most instances, due to limited time and a syllabus to complete, existing misconceptions may be unnoticed and unresolved and new misconceptions could be created. This made me curious to explore how teachers guide their learners to understand these concepts and how they support the learners' development of appropriate knowledge, skills and understanding.

Ideally, misconceptions should be identified to create a possibility for conceptual change (Posner, Strike, Hewson, & Gertzog, 1982) and for construction of new knowledge (Woolfolk, 2010). Treagust (2006) explains that conceptual change is a process of restructuring of existing knowledge to allow deeper understanding and development in particular science concepts. Constructivism as explained by Jones, Carter and Rua (1999) is based on the theory that learners build their own knowledge in relation to their prior knowledge and experiences. This philosophy is a logical perspective for teacher educators who have long realised that teachers' beliefs, views and perspectives are contextually bound to the school setting and their experiences. Teachers' ideas about teaching electricity and their awareness of misconceptions are expected to play a vital role in learners' construction of knowledge. For example, teachers who lack understanding of the content may leave out certain aspects of a topic because they are unaware of how it fits into the curriculum (Rollnick et al., 2008). "Their limited content background has led to teachers' over-reliance on transmission methods of teaching and superficial use of content" (Rogan, 2004, p.178).

Personally, as a science educator, I would like to gain some insight on how my colleagues address problems with regard to electric circuits within the constraints of time and education policies. This introspective will help further my understanding and broaden my knowledge on how better to teach this section to my learners.

1.4. Aim and Research Questions

Misconceptions in electricity are well documented and will be discussed extensively in the literature review. However, it is not known whether teachers are aware of these misconceptions and how such awareness may relate to their ideas about teaching electricity. In this study, a teacher's "awareness of misconception" will refer to the teacher's knowledge about the typical mistake, the understanding of how learners think, and the addressing of the misconception.

The broad aim of this study was to explore the relationship between teachers' ideas of teaching electricity and their awareness of their learners' misconceptions. An "idea" according to the Free Online Dictionary (Farlex, 2010) is a "conception existing in the mind as a result of mental understanding, awareness, or activity. A thought, conception, notion, impression, opinion, view or belief." The "awareness of misconceptions" (Gunstone, Mulhall & McKittrick, 2009) is evident in the knowledge, understanding and ability to address misconceptions. For this dissertation, the phrase "ideas about teaching" refers to opinions, views or beliefs that a teacher has about the content and method that should be used to teach a particular topic, in this case, electricity. These ideas were developed from teachers' background and personal experience of what works best for the learners in his/her class.

When refining the broad research aim, the first objective was to probe teachers' ideas about teaching electricity. Next, I aimed to explore the knowledge that teachers have of the mistakes that their learners make; whether they understand their learners' misconceptions which lead to mistakes and how they address these misconceptions. Finally, I aimed to probe how teachers' awareness of misconceptions relate to their ideas about teaching in electricity. Such a relationship may suggest that a focus on misconceptions may be a useful strategy in teacher development.

The aim of the study was accomplished by exploring the following research question:

Main question: How do teachers' ideas about teaching electricity relate to their awareness of learners' misconceptions in the Senior Phase?

In order to answer this question, four sub questions will be explored:

1. What content about electrical circuits do science teachers think should be taught in the Senior Phase?

2. Which methods do science teachers think should be used to teach electrical circuits in the Senior Phase?

3. To what extent do teachers understand their learners' misconceptions about electrical circuits?

4. How do teachers plan to resolve misconceptions and master the relevant content during lessons?

In order to answer these questions I reviewed current literature with regard to the topic and carried out my own study. The evidence of this study and the currently existing research were then analysed.

1.5. Structure of this Dissertation

This dissertation comprises six chapters. The first chapter is an introduction of the research and a motivation as to why I decided to do this study. It also outlines the current status of research done in this area of study. Chapter two consists of an extensive literature review regarding previous research on misconceptions about electric circuits, factors that contribute to misconceptions, and teaching methods. Chapter three discusses the conceptual framework that underpins this study. It emphasises the importance of Pedagogical Content Knowledge (PCK) and Subject Matter Knowledge (SMK) in teaching and learning and how it is best suited for the analysis of this study. Chapter four outlines the method that I have followed to conduct this study. A description of the sample, instruments, data collection methods, and ethical procedures that needed to be followed is given. Chapter five consists of the data analysis that was done during this study, presenting the outcomes from each instrument used for each participant. Chapter six includes a discussion whereby the data is consolidated and conclusions are drawn from this study. References and annexures follow thereafter.

Chapter 2.

Literature review

2.1. Introduction

Modern life is filled with electricity, from simply lighting our homes to using sophisticated computers. It goes without saying that as learners enter science classrooms; they have a wide range of ideas and beliefs about electricity that they have developed from their everyday experiences (Shipstone, 1984). These ideas, beliefs or preconceptions that they have shape the understanding and construction of knowledge as they are taught. Learners use these internal representations, which are known as models, to predict the behaviour of electricity and to explain electric circuits (Gentner & Gentner, 1983). Unfortunately, many learners' intuitive ideas that constitute their mental models are incomplete and conflict with scientific explanations of electrical circuits (Lee & Law, 2001).

This literature review is introduced by an overview of terminology used in electricity for senior phase learners in South Africa. Specific definitions and general use of terminology are compared to give a general understanding and reveal the confusions that may result from terminology. The next section outlines misconceptions reported in the literature and compares these to the scientific model. Research done on misconceptions and the contributing factors are also discussed. The review is concluded by a section on teachers' beliefs and ideas about teaching and teaching methods.

2.2. Terminology

Electricity is a topic that forms a crucial part of science education. It develops from lower grades and becomes complex at a secondary and tertiary level. What is electricity? This question is complex to answer because the word "*Electricity*" has a range of meanings (Beaty, 1996). These different meanings are related to the popular use of words like power, energy, and charge. Beaty (1996) in his article "What is electricity" gives many interpretations of the term in order to reflect its meaning in different contexts. This makes it difficult to explain the concept of electricity without clarifying other terms that are linked to it. At school level learners are taught that electricity is “the flowing motion of electric charge” (Beaty, 1996, p1). It is from this that we could say that there is an assumption, for example, the existence of charges, and that they can move together in a flowing motion called a current. However, we cannot explain electricity in its complexity to young learners. At the intermediate phase (grade 4-6), learners are taught that there is an “electrical pressure” that causes current.

Electricity is explained to children in terms of static electricity and current electricity. Static electricity is caused by the transfer of charges that can be observed as sparks when objects are rubbed together. For example, when removing a jersey, charged particles create an electrostatic force. Later on, learners are taught that current electricity results when a battery causes an “electrical pressure” in a closed circuit. This lays the foundation for conceptual understanding of a potential difference that must be followed up in higher grades as “energy transfer per unit charge.” At university level, the concept of electrical potential at a point is discussed in depth.

Different attempts to explain abstract terms such as potential difference may be found in textbooks and can be confusing rather than complementary. This may be an origin to misconceptions in electric circuits. Liegeois, Chasseigne, Papin and Mullet (2003) claim that the basic misconception in electric circuits, which leads to further misconceptions, is the inability to distinguish between potential difference and current. In Grade 8, the latest SA curriculum clearly indicates that “Voltage (potential difference) causes current” (DoBE, 2011). Is this the outcome that is being achieved? The failure to understand cause and effect may be the source and route of continual misinterpretations throughout the field of electricity.

Children hear terminology like voltage, current, and power from a young age and this leads to individual conception forming. Difficulties in understanding concepts in electricity stem from learners having created their own understanding of a concept. ”The understanding of DC electricity by learners of all ages before any formal learning experiences is highly idiosyncratic, strongly influenced by everyday uses of words such as: ’power’, ’flow’, and especially, ’voltage’.”(Gunstone et al., 2009, p516). Due to poor understanding of these terms, much confusion is brought about. In the previous Grade 8 syllabus, children were taught that ‘we produce electricity by changing one form of energy into electrical energy’ (Toerien, Clitheroe, Dilley, 2006, p42). A study done by Glauert (2009) shows that children as young as five and six have already developed some form of mental model about electric circuits even though they do not fully understand how and why it functions in that manner. In South Africa, electricity is introduced into the syllabus in Grade 4 with different appliances and safety measures. The CAPS document (2011) shows the progression of the electricity concept by introducing energy first in Grade 8 and energy systems and conversions in Grade 9. In Grade 10, learners are taught the concept of electrostatics, charge, potential difference and current in sequential order. The grade 11 syllabus shows the development and construction of knowledge in problem solving by calculation, and introduces complex concepts such as EMF and internal resistance. Looking at the evolution of conceptual understanding in electricity, we can see that the foundation knowledge is created between Grade 8 and 10.

Potential difference can be defined as “The amount of energy per unit charge needed to move a charged particle from a reference point to a designated point in a static electric field; voltage. Also called potential” (Dictionary of the English language, 2009). High school and university textbooks commonly used in classrooms define potential difference as, “a potential energy per unit charge” (Cummings, Laws, Redish, & Cooney, 2004, p.718). The Siyavula textbook (Horner, Williams, Toerien, Maharaj, Masemula, Jones, Reddy, Diergaardt & Visser, 2011) which is used in many South Africa schools defines potential difference as, “Electrical potential difference as the difference in electrical potential energy per unit charge between two points” (p.275). However, a common understanding of potential difference will be the cause or origin of current flow between two points in a circuit.

Current is defined as: ”The amount of electric charge flowing past a specified circuit point per unit time” (Dictionary of the English Language. 2009). This definition shows us the confusion of concepts about current and charge and how these concepts can be misinterpreted or incorrectly taught to learners. Gilbert and Watts (1983, p.78) argues that, ”there is a recurring problem, too, in both students (and authors) discuss current ‘flow’ (an ambiguity in physical terms) rather than a flow of charge”. Collins English Dictionary explains current as: ”**a.** flow of electric charge through a conductor. **b.** the rate of flow of this charge. It is measured in amperes Symbol **I”.** Both definitions require a good understanding of the underlying concept of charge so as not to confuse learners about the two concepts. The Dictionary of English Language defines current quantitatively, while Collins English Dictionary gives two possible meanings. Similarly, potential difference or voltage can refer to a numerical value or a general concept. Cummings et al. (2004, p.745) explains electric current as ”moving charges”. Siyavula (Horner et al., 2011, p.277) defines current as, “current is the rate at which charges moves past a fixed point in a circuit”. A clear distinction between current and charge is extremely necessary for good understanding. Learners need to understand electricity as a current that flows in one direction and that is conserved (Shipstone, 1985). Teachers often refer to current as flowing water when creating an analogy because there is often confusion between current strength measured in amperes and the actual concept. Osborne (1981, 1983) and van Zee, Evans, Greenberg and McDermott (1982) agree that teachers that do not understand this analogy believe that current is ‘used up’ when it flows through a light bulb. The misconception of the causal relationship between current and potential difference is summarised by Gilbert and Watts (1983, p.77) as, “when an electric current ‘flows’ then ‘voltage’ should be present; when current is interrupted the voltage disappears”. Kriek, Khwanda, Basson, & Lemmer, (2011, p.307), in their research on pre-service teachers conceptual understanding of DC circuits, found that a misconception that teachers have is that, “the current always wants to flow but it is stopped by resistance of the resistor. Switching the switch on deactivates the resistance and hence current starts to flow.”

Jones and Berens (2008, p.377) explain resistance as, “the property of a conductor that limits the flow of charge through it”. Learners identify this definition as meaning that something is physically trying to stop a charge from passing through it. Sadiku (2009, p.6) clarifies “the resistance of an element denotes its ability to resist the flow of electric current”. This concept plays an important role in understanding Ohm’s Law. Cummings et al. (2004, p.753) defines resistance as the “ratio of the potential difference across the element to the current through the element.” This is a more mathematical definition explaining how resistance can be calculated. Learners often view “resistors as consumers of charge rather than as hindrances” (Cosgrove et al., 1995, p.295) to the flow of charge. Siyavula (Horner et al., 2011, p.283) explains resistance as, “Resistance slows down the flow of charge in a circuit”.

“Power is the time rate of expanding or absorbing energy, measured in Watts (W)” (Sadiku, 2009, p6). Textbooks used in high school and university explain power as, “the rate at which work is done by a force”, or “the rate at which electrical energy is delivered to a circuit” (Cummings et al., 2004, p.758). Jones et al. (2008, p.377) explains power as, “the rate at which work is done or energy is transferred”. Some of these definitions emphasise the relationship between current, potential difference, energy and charge with regard to power. Although power is also closely related to potential difference and current, it is commonly explained in mechanics as work done per unit time. In everyday communication, power is often misused for current, charge, energy and creates misunderstanding. Power can be directly observed. The brightness of a bulb is a better observation of the power than either potential difference or current on its own.

How do teachers explain the difference between the many terms used in electricity? Have they found methods or analogies to help them do this?

2.3. Misconceptions

Concepts can be regarded as “ideas, objects or events” that help us to understand the world around us (Eggen and Kauchak, 2004). Misconceptions can be described as incorrect ideas, mental models or understandings that are based on personal experience (Martin, Sexton, and Gerlovich, 2002; Southerland, Abrams, Cummins and Anzelmo, 2001). These incorrect ideas are as a result of predictions that disagree with observation. Misconceptions have also been described as preconceived notions, non-scientific beliefs, naïve theories, mixed conceptions or conceptual misunderstandings (Hanuscin, 2001). There are several terms in research used in this area: misconceptions (Bar and Travis, 1991; Eryilmaz 2002; Schmidt, 1997; Sneider and Ohadi, 1998), naive views or conceptions (Bar, 1989; Hesse and Anderson, 1992; Pine et al., 2001), preconceptions (Benson et al., 1993), alternative views (Bar and Travis, 1991; Sequeira and Leite, 1991; Trend, 2001), and alternative conceptions (Hewson and Hewson, 2003).

Literature shows that children have differences in understanding science and it is often inconsistent with what the teachers intended to achieve during instruction (Bar, 1989; Bar, Zinn, Goldmuntz, and Sneider, 1994; Pine, Messer, and St. John, 2001; Tao and Gunstone, 1999; Trend, 2001). Many possible sources are responsible for creating misconceptions. Experiences do not always lead to the correct conclusions or learners do not always see all possible outcomes in terms of why and how certain occurrences take place. Parents and family members may not always give the correct answer when confronted with questions from their children. Others sources of misconceptions include analogies, the media, teacher explanations and textbooks.

There is a gap between what research has revealed about misconceptions and whether this research is used to bring about some change in instruction in the classroom (Ausubel, 1968; Posner et al., 1982). "What limited research exists regarding teachers and misconceptions has shown that pre-service and novice teachers are often unaware that their students may have misconceptions." (Zwiep, 2008, p438). Even in cases where teachers are aware of their learner's misconceptions, they are unlikely to use this knowledge in their teaching (Halim and Meerah, 2002).

Studies from as early as 1973 (Driver and Easly) show misconceptions amongst learners about electrical circuits. These researchers may have used different terms or names to describe the misconception, but a common thread was found. A South African study done by Kriek et al. (2011) shows that learners have preconceptions, for example, the pre-existing knowledge that they may have from different cultures, experiences, teaching, and misconceptions which are created based on poorly understood pre-existing knowledge. A number of studies were conducted to find common misconceptions in circuits by learners. Most studies found the same misconceptions amongst their learners. Previous researchers (see for example: Sencar & Eryilmaz, 2004; Shipstone, 1985; Engelhardt & Beichner., 2004; Chang et al., 1998; Pesman, & Eryilmaz, 2010) have described these misconceptions as models, for example, ideas of how electricity works, and compared it to relevant concepts according to the accepted scientific model.

Jaakkola et al. (2011) found that most misconceptions in learners' mental models are tenacious and resistant to teaching efforts (Chiu & Lin, 2005; Lee & Law, 2001; McDermott & Shaffer, 1992). Although the learners' initial models are incorrect, they feel that they have a satisfactory explanation (Chiu & Roscoe, 2002; Vosniadou, 2002) and therefore look for evidence to support the initial idea (Dunbar, 1993). They avoid revising their mental model (Chinn & Brever, 1993).

A comparison between common misconceptions and the scientific model is summarised in Table 2.1. The table shows the original researcher and how the misconception compares to scientific view. There are in essence eleven common misconceptions about electric circuits. These misconceptions were used as a basis to design the instruments for my study. Specific attention was paid to the circuit diagrams that were used by these researchers during their studies. The attenuation and sharing current model are not always clearly distinguishable. There is very little work done on the superposition model and therefore I included it in my investigation. The short circuit misconception has not been tested or used in many studies. There are very few authors (Shipstone, Rhoneck, Karrqvist, Dupin, Joshua, & Licht, 1988; Sencar & Eryilmaz, 2004; Pesman & Eryilmaz, 2010) that have included it in their studies. The lack of research done on this misconception indicates a poor awareness of difficulties to understand the concept of a short circuit.

It has been argued that poor understanding of potential difference brings about many misconceptions regarding circuits and current electricity in general. Studies carried out in Turkey and North Carolina proved that potential difference is often confused with current (Engelhardt & Beichner, 2004; Pesman and Eryilmaz, 2010). Licht (1991) and Shipstone et al. (1988) argue that electricity should give priority to concepts such as “electrical energy, voltage and current”. Gilbert and Watts (1983) and Liégeois et al. (2003) found that a common misconception or misinterpretation is that electrical current is the origin of potential difference and potential difference is a mere measure of electric flow. Both researchers carried out similar studies and the results from their investigations made it evident that current is often misinterpreted as being the source of the circuit. An opposing view came from Shaffer and McDermott (1992), who argue that current and not potential difference/energy is the appropriate beginning point for the systematic study of electricity at senior high school/undergraduate levels. They believe that the concept of potential difference should be introduced after practical investigation using a voltmeter over series and parallel circuits. There has not been consensus on this matter and it is not evident how teachers introduce the concepts of current and voltage.

Engelhardt and Beichner (2004) found that learners have three ways of reasoning about circuits: “Sequential”, “local”, “superposition”. These reasoning patterns do not view circuits globally when thinking about changes. Barbas and Psillos (1997) distinguish systemic reasoning and causal reasoning. They explain systemic reasoning as perceiving all components as a system and therefore believe that any disturbance will propagate in all directions. Causal reasoning, on the other hand, comes from their understandings of models, illustrations, scientific descriptions put together to form a basis of their accounts. Engelhardt and Beichner (2004) referred to the disregarding of the arrangement of cells as a “superposition” model. This misconception is seldom mentioned in research literature. This could give rise to the constant current misconception.

Other uncertainties about circuits that were found in literature stem from learners confusing potential difference and current with concepts like power, energy and resistance (Engelhardt & Beichner, 2004; Liégeois & Mullet, 2002). Possible problems that may arise later on for the learner are that they will not understand the concepts of emf and internal resistance. The poor understanding of concepts may lead to confusion of variables in equations such as Ohm’s Law. Due to the poor conceptual understanding of variables in calculations, learners tend to manipulate formulae incorrectly when solving for the unknown scientific quantity (Cosgrove et al., 1995). School textbooks do not always clearly address cause and effect amongst variables in the circuit. This may also mean that learners are unable to conceptualise what would happen within a circuit when one of the variables is altered and all others are kept constant. Even when learners are able to change variables, they struggle because they do not have the conceptual understanding of the phenomenon, despite being able to perform mathematical manipulation (McDermott & Shaffer, 1992).

Table 2. 1: Comparison of well-known misconceptions and scientific model.

Misconception/Model	**Scientific Model**
The **unipolar model** or **sink model**: Learners believe that only one wire connected to a battery is needed for the circuit to work. (Chambers & Andre, 1997)	There needs to be two wires to connect the two poles of the battery to the two sides of the resistor. In one wire current flows from the battery to the resistor and in the second wire, current flows from the resistor back to the battery.
The **attenuation model**: Learners believe that less current returns to the battery. They think each device consumes some of the current passing through it. (Shipstone, 1988)	Current is not consumed by the electric devices: all current returns to the battery. It is energy, not current, that is transferred to the device that causes it to work.
The **sharing current model**: Learners believe that the current is shared by the devices in the circuit, and that less current returns to the battery. (Shipstone, 1988)	Current in a series circuit is the same throughout the circuit, whereas in parallel circuits, current branches and re-joins again such that all current is conserved.
The **sequential model**: Learners believe that a change in the circuit will affect current in parts of the circuit that are located 'ahead' the change, but not in parts located 'behind' the change. (Dupin & Joshua, 1987)	Any change made in a circuit affects the circuit as a whole. For example, if a resistor is added, the current will decrease throughout the entire circuit.
The **clashing current model**: Learners believe that current flows from both poles of the battery in opposite directions to the resistor. These currents are seen as a positive and a negative current which clash in the resistor such that the clash creates energy in the resistor. (Chambers & Andre, 1997)	Current in a circuit flows in one direction. Conventionally, current flows from the positive terminal of a cell, around the circuit to the negative terminal. The current is made up of moving charges carrying electrical potential energy. When the charges collide with atoms in the resistor, the energy is transferred to the resistor.
The **empirical rule model**: Learners believe that if a light bulb is far away from a battery it will glow dimmer. (Heller & Finley, 1992)	Connecting wires have neglible resistance and therefore no energy is transferred to them. Long wires will therefore not make a bulb glow less bright than a short wires. When using identical bulbs and identical batteries, the bulbs in parallel all glow equally bright, and in series they all glow equally dim, regardless of the length of wires.
The **short circuit model**: Learners believe that wires in a circuit with no electrical devices can be ignored when analysing the circuit. (Fredette & Clement, 1981)	A short circuit is a path without resistance that bypasses resistors. If a battery is shorted, other devices will receive no current while the current in the wire and battery will become very large because current takes the way of least resistance. The wires will become very hot and may melt, and the battery will overheat and become exhausted.
The **power supply misconception**: Learners believe that the power supply provides constant current regardless of how the circuit is changed. (Dupin & Joshua, 1987)	An ideal battery supplies a constant voltage, not a constant current. The current is the result of the combined effect of the voltage and the effective resistance of the circuit. This means that changing a device in a circuit changes the current while the voltage is unchanged.
The **parallel circuit misconception**: Learners believe that if the numbers of resistors in parallel are increased, the total resistance will also increase. (Cohen, Eylon & Ganiel, 1983)	Connecting more resistors in parallel reduces the total resistance because it creates more pathways for current to flow in the circuit.
The **local reasoning model**: Learners believe that current splits in equal parts at junctions regardless of the resistance of the branches. (Cohen, 1988). Learners believe if there is a change in a part of the circuit, it affects that part as opposed to the circuit as a whole (Riley et al, 1981) Although these two interpretations may overlap one another they are not identical.	A circuit functions as a complete system and cannot be understood in separate parts. At branch points, less current flow in branches with higher resistance, the branch currents are inversely proportional to the branch resistances.
The **superposition model**: Learners believe the physical arrangement of the cells does not affect the voltage across the circuit. (Sebastia, 1993)	The physical arrangement of the cells determines the potential difference across the battery. When cells are connected in series then each charge moves through all the cells and receives energy from each so the potential differences of the cells add up However, when connected in parallel, each charge travels through only one cell, receiving energy from only that cell, so the potential difference across the battery remains is equal to that of each cell.

2.4. Factors Related to Misconceptions

There are many factors that contribute to the formation of misconceptions amongst learners. Each factor that was found to be common in literature is discussed below.

2.4.1. Gender and background

It is evident from literature that a vast amount of research has been done to identify misconceptions amongst learners. Through these studies, some researchers have found reasons as to how misconceptions are created. Sencar and Eryilmaz (2003) and Engelhardt and Beichner (2004) associate gender with misconceptions. Sencar and Eryilmaz (2003) explains in great detail a number of factors that could influence misconceptions in girls rather than in boys. The ins and outs of the school experiences of learners play a strong role in their attitude towards science. Sencar and Eryilmaz (2003) argues that if a learner is not enthusiastic and positive about science, the possibility of constructing meaning and understanding from electricity lessons is minimal. Girls usually tend to take interest in subjects other than science and this may influence the number of misconceptions in girls. Since girls may be treated differently at home, their background and interest in electricity differs from that of boys. This inevitably will affect the way in which they develop and the knowledge that they may construct and will therefore impact on their knowledge in certain sections of electricity.

Pardhan and Bano (2001, p.304) explains that, “Alternative Conceptions are held by individuals because of their diverse set of personal experiences including direct observation and perception, peer culture and language, teachers’ explanations and instructional materials.” A learner’s experiences outside of school will influence his or her performance inside school. External, social factors are known to have an effect on learner performance amongst all learning areas. It is therefore argued that the different experiences of girls influence their understanding and performance in science. Sencar and Eryilmaz (2003) is greatly supported by Engelhardt and Beichner (2004) who strongly agrees that boys have fewer misconceptions than girls as it was evident in his study where he compared the understanding of direct current resistive electrical circuits through samples of males and females at school and also at university level. However, they are contradicted by Anamuah-Mensah, Otuka, and Mensah (2001) who found that gender does not play a major role in misconceptions in electric circuits. It is, in fact, common amongst both genders. There is no empirical evidence of why boys may perform better in science than girls.

2.4.2. Cognitive perspectives

Sencar and Eryilmaz (2004) argue that age also plays a role in the creation of misconceptions. He views learners as being of different ages and different mental and physical stages. He also sees them as being at different maturity levels so the knowledge that they should construct when they are at a certain stage is not guaranteed and could be hindered by the phase that learners are in within their lives.

Piaget's theory of Cognitive Development explains the ability of learners as their "thinking processes change radically, though slowly, from birth to maturity because we constantly strive to make sense of the world. Piaget identified four factors- biological maturation, activity, social experiences, and equilibration- that interact to influence changes in thinking" (Woolfolk, 2010, p.32). Piaget argues that children develop in stages. At the concrete operational stage (7-11 years) learners are not able to construct and make logical deductions. They cannot transfer their knowledge well at this stage. Cognitive development, as described by Woolfolk (2010, p.26), is "gradual orderly changes by which mental processes become more complex and sophisticated." The difference in cognitive development is possibly responsible for differences in understanding because learners' perceptions and ability to grasp concepts will differ. Sencar and Eryilmaz (2004) argue that due to learners developing at different times, not all learners are able to construct and find understanding in certain sections of electricity. An example of this can be seen in Shipstone's study (1985, p.33) where he explains various understandings of the water pipe analogy by a group of learners in the same grade.

2.4.3. Lack of knowledge

The lack of knowledge amongst learners was mistaken for a misconceptions in many studies. Kucukozer and Dermirci, (2006); Chang et al. (1998) and Smith and Nel, (1997) all found that in many instances, a learner that actually does not have knowledge is thought of as having a misconception regarding the topic. Different learners are being taught by different teachers using different teaching methods at a primary level, and the learners already have a certain amount of prior knowledge.

Chang et al. (1998) suggest that there are three different problems: “discrepancy”, “uncertainty” and “incompleteness”. Discrepancy is the difference of what the learners understand and what the teacher thinks the learner understands. Uncertainty is when the learner is in doubt of his or her understanding of a concept. Incompleteness is when the learner has some knowledge and understanding but does not completely grasp the concept. Chang et al. (1998) suggest methods to solve these problems: “discrepancy” which can be solved by revising the concept, “uncertainty” – which can be corrected by assessing if the learner understands the concept correctly and “incompleteness” – which can be corrected through remedial instruction using methods that are suitable for the learner to grasp the concepts.

2.4.4. Textbooks

The inadequacies in textbooks have been often brought up as one of the reasons contributing to learner misconceptions. Kucukozer and Dermirci (2006) explain that through their study, they found that illustrations and concepts in the textbooks do not explain or help learners to comprehend and construct knowledge meaningfully. He is supported by Smith and Nel (1997) who focused on the student-teachers training in his study and found that textbooks for training teachers are still unclear, and that student-teachers have misconceptions about potential difference and current continue even after they qualify to teach. Textbooks may create confusion in their presentations of concepts making it difficult for learners to interpret and teachers to explain (Mulhall, McKittrick & Gunstone, 2001). In their study, they also found that some textbook writers also have misconceptions and lack of knowledge.

2.4.5. Languages

South Africa has eleven official languages. Language is a factor that has contributed to misconceptions. In a study by Rollnick et al., (2008, p.1369), they explain that in township schools in South Africa “learning is through a second language”. The teachers in her study consider memorising definitions to be important, but the understanding of the concepts are not mentioned. It seems that as long as the learner can memorise the correct answer and reproduce it, it is not necessary to understand why the answer is correct. Some teachers in township schools “make use of students’ home language” (Rollnick et al., 2008, p. 1371) in order to explain the concepts. However, Rollnick et al.s’ (2008) study shows that there is a no link between analogies and concepts or calculations and concepts in the home language. Therefore, the language barrier is seen as a contributing factor to poor teaching. Tallant (1993) explains that in certain languages like Xhosa, there is no word for current, conventional or charge. This makes it difficult to then explain the concept to a secondary language learner because there is no direct translation. Shipstone (1988, p.93) explains that, "lack of precision in children's use of terminology also plays a very significant role in reducing the efficiency of their communication with teachers." If the learner uses incorrect terminology whilst asking questions, the teacher may not fully understand which concept the learner needs more clarity about.

Thus far, much research regarding what misconceptions learners have and factors that influence or contribute to these misconceptions has been done as discussed above. Currently, less research has been conducted to find out if teachers know of the misconceptions, how they understand the misconceptions and how they envisage to address misconceptions.

2.5. Factors Related to Teaching Electricity

Teaching science is influenced by a multitude of factors. In the sections below, factors that may relate to the teaching of electricity are discussed.

2.5.1. Teachers and their beliefs

The experiences (Liégeois et al., 2003) of teachers and their beliefs play an intricate part in the way they teach. This impacts the understanding and interpretation of learners. Many teachers are resistant to change (Kucukozer & Kocakulah, 2007, Pardhan & Bano, 2001). They do not adopt their teaching methods to accommodate the type of learners that they have in terms of background, language, cognitive ability and so forth (Kucukozer & Kocakulah, 2007). Cohen et al. (1983) found that teachers feel that advancing their studies will not help them to avoid learners' misconceptions. Mellado's (1997, p.208) explanation for teachers not advancing their studies is "science education is theoretical, impersonal, and static with little relationship to the practical knowledge of the classroom required when giving the science lesson."

Teachers tend to omit teaching conceptually and think that learners will understand better algorithmically (Mellado, 1997). They therefore try to teach learners how to use formulae or calculate the value of different variables without actually explaining the importance of the calculation and how it is related to the functioning of the circuit. "Student understanding after conventional teaching sequences is little changed (Andersson & Karrqvist, 1979; Fredette & Lochhead, 1980) – abilities to complete algorithmic (and only algorithmic) problems are often enhanced, but little else appears to develop in these situations."(Mulhall et al., 2001, p.576)

Wright and Hounshell (1981) explain that teachers have the "greatest influence in stimulating interest in science" (Hudson & Kidman, 2008, p.436). "The mythical scientifically literate citizen who has positive feelings about science, science teaching, and science teachers may be just a matter of teaching strategy!" (Shymansky & Penick, 1981). One of the roles of a teacher is to motivate learners for academic engagement. Meece (2003) found that teachers that are caring and respectful provide learning experiences that are targeted at the learners' needs allowing for better development in science. There are arguments that the quality of a teacher plays a crucial role in teaching science (Vogt, 2002; Wong, 2005).

A study conducted by Mulhall et al. (2001, p.578) found many issues that arise regarding the teaching of electricity. They found that teachers are reluctant to discuss their own conceptions about current, voltage and other concepts. This could be because they are unsure about their understanding and could have misconceptions themselves. Many teachers do not know what potential difference is. Whilst explaining concepts, teachers tend to use the wrong terminology and create the misunderstanding amongst their learners. Some teachers are disillusioned by analogies, models and metaphors, and therefore do not make an attempt to use them. This limits their teaching methods. In many cases, if a learner uses a model, analogy or metaphor and gets the answer correct, then the model, analogy or metaphor is 'OK'. This shows that the teacher may not completely understand the model analogy or metaphor and simply agrees because the learner has achieved the desired outcome. In this way, the learner has created a misconception and the teacher is unaware of it. Since teachers lack the confidence and knowledge to teach certain areas in the syllabus, they tend to leave it out or spend less time on concepts, which creates misconceptions amongst the learners. South African teachers do not feel that advancing their studies will help their learners because of all the contextual factors that contribute to their teaching (Rollnick et al., 2008).

2.5.2. Conceptual understanding

Teaching learners to understand how an electric circuit functions on a qualitative level is a difficult pedagogical challenge (Hart, 2008; McDermott & Shaffer, 1992; Reiner, Slotta, Chui & Resnick, 2000; Jaakkola, et al 2011). Concepts such as potential difference, current and resistance, which are the central concepts in electricity, are very abstract by nature. Consequently, there is great difficulty in providing learners with accurate information about electric circuits in a comprehensible format.

Finkelstein, White and Gutwill (2005), and Hennessy, Deaney and Ruthven (2006) explain that conceptual understanding through practical manipulation in real circuits can be problematic, because learners can only observe what is happening at the surface level; however, they are unable to grasp underlying processes and mechanisms. Alternatively, learners are provided with an algebraic equation (Frederikson, White & Gutwill, 1999; McDermott & Shaffer, 1992) as a method to teach the model of electric circuits. Students find it difficult to link the quantitative circuit theory to a conceptual "casual model of what is happening in the circuit" (Jaakkola et al. 2011 p.71). Dowker (2005) explains that learners may do well in calculation because of their skills in mathematics but show limited conceptual understanding of it. Mathematical manipulation may conceal the cause-effect relation of voltage and current. Therefore we can assume that learners do not view the circuit as a system, but view each component individually. It is also possible that teachers share this poor conceptual understanding, and avoid teaching conceptually.

According to McDermott and Shaffer (1992), the concept of potential difference can form misconceptions. The debate of whether it should be taught before or after current is argumentative. Studies done by McDermott and Shaffer show that learners that are "able to analyse a circuit quantitatively were often unable to analyse that same circuit qualitatively." (p.995). It has also been found that "the ability to solve a circuit problem numerically does not necessarily indicate a corresponding level of qualitative understanding." (p.996). The learners lack conceptual understanding and are so focused on collecting numerical answers that they do not pay attention to why and how they get these values. For simple calculations at Grade 9 level, learners may find difficulty in mathematical manipulation. As learners start learning more complex calculations in electricity, they will need to integrate the concepts with their numerical understanding in order to answer more complex circuit questions. Gunstone (2008) finds that less emphasis is put on practical work and conceptual understanding but is rather focused on calculations. This results in poor conceptual understanding and a possibility of misconceptions.

Shipstone (1985, p.33) found that part of the problem of misconceptions lies in the fact that "models are resistant to change through instruction". Posner et al. (1982, p.212) explains that, "learning is a rational activity." Therefore, it is important to not only identify misconceptions, but also to understand "some reasons for their persistence," and "how a student's current ideas interact with new, incompatible ideas". In order for a learner to learn, there needs to be some form of dissatisfaction about the existing concept within the learner. The learner needs to find the new concept plausible, which is usually difficult for learners. If the new concept is plausible it must be intelligible. This requires, "an understanding of the component terms and symbols used and the syntax of the mode of expression" (Posner, 1982 p.216). The learner needs to find the new concept to be fruitful in a way that will "lead to new insights and discoveries" (Posner, 1982 p.222). These are the four criteria needed for conceptual change and may be used by teachers to address their learners' misconceptions.

2.5.3. Analogies

An analogy is "a comparison between one thing and another, typically for the purpose of explanation or clarification" (Oxford Dictionary, 2013). In electricity, it is a mental model of how abstract electrical concepts can be viewed in order to create an understanding of the functioning circuit. "For the past two decades, a growing amount of research has shown that the use of analogies in science teaching and learning promotes meaningful understanding" (Chiu and Lin, 2005, p.429). Analogies are a method of learning and constructing knowledge about concepts that are difficult to understand. This method of teaching has been used for years and allows learners to create a picture in their mind of what may be occurring and the process that may be taking place (See for example: Gentner & Gentner, 1983; Glynn, 1989; Harrison & Treagust, 1993; Wong, 1993; Chiu & Lin, 2005). It allows for a visual perspective on a topic to allow for clearer and more in-depth understanding.

Analogies are very popular in science teaching (Yerrick, Doster, Nugent, Parke, & Crawley, 2003; Chiu & Roscoe., 2005; Jaakkola et al., 2011). The water-pipe analogy described by Shipstone (1985) is a well-documented analogy to explain the flow of charge. Learners start constructing knowledge with prior knowledge that they have before they enter the classroom. When they are introduced to an analogy, they already create an idea of how it relates to the real situation. “We found that the reason the students had difficulty understanding the concept of electricity was because of their ontological presupposition of the concept” (Chiu et al., 2005, p.429). They use their existing knowledge of what they understand about the situation and make sense of concepts based on this understanding and find it difficult to reassign that concept to another set of ideas. Therefore, if they have a particular understanding of how something works, they interpret any new knowledge in accordance with their pre-existing idea. However, it is important to find a link between the previous knowledge and the expected target. Gentner and Gentner (1983) proposed the Structure-Mapping theory which opened a whole new field of how man can solve and confront problems. The theory indicates the relationship between the familiar and unfamiliar domain and how analogies can help in the construction of knowledge, “through the analogical relationship between the domains” (Chui et al., 2005. p.430). He uses the example of “the flow of electricity is similar to the flow of water”, so the familiar domain is the flow of water and the unfamiliar domain is electricity. These mental images or mental representation are known as “mental simulations” of the real situation (Gentner & Gentner, 1983). Johnson-Laird (1983), describes this phenomenon as analogical representations of reality or a working model. This theory has played a key role in science because it is understood that it is used by novices and experts for different reasons but allows for creative thinking. In fact, famous philosophers and scientists such as Plato, Aristotle, Maxwell and Franklin have found that analogies play a crucial role in theory development itself (Shipstone, 1985).

Teachers who are unaware of analogies themselves struggle to find analogies that are “the same as the real thing” (Mulhall et al., 2001, p.578). Yet, analogies should not be seen as a simplistic solution. Dagher (1994) and Chi (1992) argue that analogies are not effective because they do not bring about conceptual change. Instead, using analogies allows for “assimilating new knowledge” (p. 431) and “served as references for initial explanations or conjectures” (p. 431). Therefore, the use of an analogy will only be effective if the learner is able to construct new knowledge or other assimilated knowledge. Futhermore, there are studies that have found that analogies may cause a great amount of confusion. Yerrick et al. (2003) claims that the teacher's role in using analogies is a crucial one. He believes that if the teacher does not scaffold the lesson so that learners move towards the knowledge they are meant to construct, it may cause many misconceptions. Gunstone et al. (2009) also looked at the range of analogies that were used to explain concepts and found that inappropriate analogies create misconceptions.

The success of analogies can be understood in terms of Greeno's theory of multiple representations which explains that by using different types of analogies to explain a concept, learners understand and find meaning easier (Greeno & Hall, 1997). Learners understand the content better due to the use of analogies which in essence is a formation of an idea or picture in their minds. The physicist Klein (1972) has noted that it is characteristic of the physicist to want to strive to condense information and reduce it to the essentials, which can be achieved by observing the essentials of the analogy (Mulhall et al., 2001).

2.5.4. Practical work

Hands-on practical work is considered an integral part of science education (Lunetta & Tamir, 1979; Millar, Le Maréchal & Tiberghien, 1999). The House of Commons Science and Technology (London, 2002) comments that:

> *In our view, practical work, including fieldwork, is a vital part of science education. It helps students to develop their understanding of science, appreciate that science is based on evidence and acquire hands-on skills that are essential if students are to progress in science. Students should be given the opportunity to do exciting and varied experimental and investigative work. (para. 40)*

A survey done by Cerini, Murray and Reiss (2003) shows that students find practical work to be more enjoyable than other science teaching and learning activities. Although practical work is used widely as a teaching strategy, its effectiveness is still questioned. Hodson (1991) claims that practical work, as practiced in many schools, is ill-conceived, confusing and unproductive. There is often no link between what goes on in the laboratory and how it contributes to learning in science. Tiberghien (2000) distinguishes between two domains of knowledge in practical work.

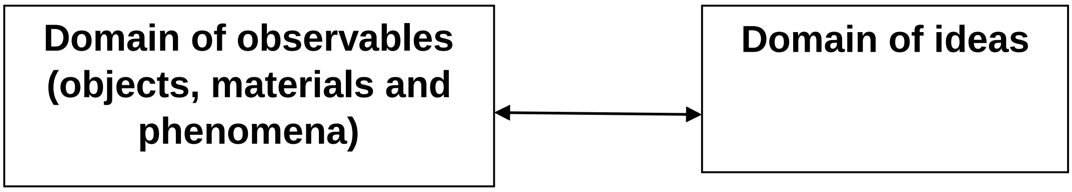


Figure 2.1: Practical work: linking two domains (Tiberghien, 2000)

The domain of observables involve the materials given to learners by the teacher to generate the data. Later they recall their observations and the data that they collected. The domain of ideas involve learners thinking about their observations and using the teachers' ideas to create their own ideas, showing understanding of how the task was designed to help them learn. This is how new knowledge is constructed. However, because not all thinking is synonymous, some learners may not reach the outcome (Abrahams & Millar, 2008). Therefore, even though most teachers' do practical work in small groups it is only regarded as beneficial if the learners achieve the desired outcome.

Some teachers prefer to do teacher demonstrations rather than having learners do practical work in small groups. McNeil (1983) found that some teachers prefer demonstrations because it is seen as "defensive learning" to maintain control in the classroom.

2.5.5. Simulations

Simulations as a new method of teaching is found to be beneficial but require instructional support. Jaakkola, Nurmi and Veermans (2011) found that simulations do not provide an additional gain of understanding as compared to real life circuits. In fact, it slows down the learning process. Computer simulations merely provide support with regard to the conceptual understanding of electric circuits that learners already have, and should be used as a tool for additional support, not as the only form of teaching. Jaakkola et al. claims that "an interactive computer-simulation that models electric circuits has the potential to help learners overcome their misconceptions and learn the scientific model of electric circuits (e.g.,Carlsen & Andre, 1992; Frederiksen et al., 1999; Finkelsten et al., 2005; Jaakkola & Nurmi, 2008; Zacharia, 2007)." Simulations allow students to engage actively instead of merely watching a demonstration because they are able to set up virtual circuits and change circuit variables to observe the outcome (de Jong, 2006; Wieman, Adams & Perkins, 2008). Some simulations are useful because they present different quantities such as electric current, potential difference, energy, and resistance in different colours so that learners can see how they work together in the circuit. However, many schools are not resourced with interactive technology such as smart boards where learners can play around with the different quantities, change the circuits, add new components, and see how it impacts on the circuit.

The debate about computer simulations and hands-on practical work has been investigated in many studies (Finkelstein et al., 2005; Klahr, Triona & Williams, 2007; Triona & Klahr, 2003). Hands-on practical work is regarded as important authentic experience (National Science Teachers Association, 2007). Learners need to engage with real material and not distorted reality (Scheckler, 2003). Recent research shows that a combination of virtual (computer simulations) and real (hands-on practical work) is most beneficial (Zacharia, 2007; Ronen & Eliahu, 2000). Even though demonstrations are a form of practical work, demonstrations are done by the teacher only, where as practical work is done by the learners.

2.6. Summary

Findings of studies on the different misconceptions about electric circuits, and factors related to these misconceptions have been discussed in the literature review. Teaching methods and ideas that teachers have about teaching electric circuits were also discussed, as these may influence understanding amongst learners. The concept of teachers' pedagogical content knowledge, which will be used as theoretical framework for this study, is discussed in the next chapter.

Chapter 3.
Theoretical Framework

Recent literature (Rollnick et al., 2008; Hill et al, 2008; Usak, 2009) shows that learners' misconceptions are strongly related to the manner in which they are taught. It is therefore expected that teachers' pedagogical content knowledge (PCK) may impact on misconceptions amongst learners. Studies on PCK and content knowledge (SMK), (Magnusson, Borko, Krajcik, 1994; Appleton & Kindt, 2000; Loughrun, Gunstone, Berry, Milroy, & Mulhall, 2000; Usak, 2009) showed that teachers are often not able to make the link between the two.

The concept PCK was introduced by Shulman (1986a, 1986b, 1987) and it was assumed that this type of knowledge would contribute to effective teaching and learning. Shulman distinguished three types of knowledge, subject knowledge, pedagogical knowledge and curricular knowledge. Shulman (1986b, p. 9) described PCK as, "the ways of representing the subject that make it comprehensible to others." Different scholars summarised by Kind (2009) attempt to provide descriptions of PCK. For example, Lee and Luft (2008, p.1344) propose "the unique combination of content and pedagogical knowledge that helps transform science content into learning experiences for students". In a local study, Rollnick et al. (2008, p.1367) described PCK as "how teachers teach their subject by accessing what they know about the subject, the learners they teaching, the curriculum with which they are working and what they believe counts as good teaching in their context." In the US, the National Science Education Standards define PCK as: "special understandings and abilities that integrate teachers' knowledge of science content, curriculum, learning, teaching and students', allowing science teachers to tailor learning situations to the needs of individuals and groups" (National Research Council, 1996, p.62). The explanations given above demonstrate that PCK is not viewed as knowledge of one single entity in teaching, but rather a sound understanding of all types of knowledge that relate to how a subject is thought.

As Frykholm and Glasson (2005, p.128) have suggested, "How a person learns a particular set of knowledge and skills, and the situation in which a person learns, become a fundamental part of what is learned". Barnett and Hodson (2001) articulate a theoretical framework of what teachers know and how they use it to teach based on

PCK. The framework consisted of four overlapping dimensions: pedagogical content knowledge, professional knowledge, classroom knowledge, academic and research knowledge (Frykholm & Glasson, 2005). Pedagogical content knowledge and academic and research knowledge are known to be common frameworks for teacher development. The other two dimensions, professional and classroom knowledge are "emerging frameworks that embrace a situative lens for teacher development" (Frykholm & Glasson, 2005, p.129). It can be argued that the other knowledge types overlap with PCK (Brown & Borko, 1992; Frykholm, 1996; Hammrich, 1997; Lumpe, Haney, & Czemiak, 2000).

Two models, the integrative model and the transformative model, were introduced by Gess-Newsome (1999) to reflect the interaction between PCK and SMK. The integrative model was used in many studies to explain how new teachers explained concepts (Lee & Luft, 2008). The integrative model represents separate domains of knowledge of subject matter, pedagogy and context. In contrast the transformative model represents a synthesis of their different knowledge types. In a simplistic view beginning teachers would tend to have integrative PCK while experienced teaches tend towards the transformative model. In fact research of expert and novice teachers supports these models (Ball & Bass, 2000).

There are many studies done to explore the nature of PCK and how activities can be used to enhance PCK (Magnusson et al., 1994; Appleton & Kindt., 2000; Loughran et al., 2000; Usak, 2009.) The debate of PCK being the key to better science teaching continues. Appleton and Kindt argue that teachers who display poor PCK, lack confidence in teaching certain aspects of the content and they therefore postpone work that they are unsure about. Pardhan and Bano, (2001, p.302) "highlights the importance of content knowledge of teachers for confidence building". This implies that confidence plays an important role in the approach to teaching.

From personal experience I have also noticed that learners are aware of teachers' uncertainties in the classroom. Magnusson et al. (1994) argues that due to poor PCK, teachers cannot identify typical inaccurate responses and are not aware of why learners give these answers because they do not ask learners to explain how they understand it. Teachers themselves may also have misconceptions and poor understanding of the way learners could construct knowledge.

According to Lee and Luft (2008, p. 1345) two perceptions that were found by researchers, (Magnusson et al. 1999; van Driel et al. 2001; Gunstone et al. 2001; Loughran et al., 2004) are: (a) “PCK is the integrated set of knowledge, concepts, beliefs, and values that researchers develop in the context of the teaching situation.”, and (b) “PCK is the experiential knowledge and skills acquired through classroom experience”. This implies that researchers have alternative conceptualisation of PCK themselves. Relating to the two theories by Gess-Newsome (1999); the fundamentals to effective teaching lie in content or subject knowledge and pedagogical knowledge and experience. Lee and Luft (2008, p. 1360) found that, “teachers concurrently hold different forms of PCK, but the forms evolve differently at different points in their careers.” Therefore one can assume that experienced teachers have qualities that belong to both the integrative and the transformation models. “Despite the many calls for rich content and pedagogical content knowledge for teachers, there is a considerable body of research suggesting that novice teachers often do not possess the content and pedagogical knowledge to teach for understanding in their respective disciplines” (Frykholm & Glasson, 2005, p.130).

Veal & MaKinster (1999) developed a taxonomy of PCK consisting of three levels: general, domain-specific, and topic specific. General PCK refers to the PCK held by teachers in any discipline, e.g. History, Mathematics or Science. Domain specific PCK refers to the PCK held by teachers in different domains in a discipline, for example: Biology, Physics and Chemistry in the discipline of science. Topic specific PCK is the most specialized form of PCK, for example in the domain of physics, topic specific PCK refers to PCK in topics, e.g. electricity, heat and waves. Veal and MaKinster (1999) argue that all science teachers should hold general PCK and all beginning science teachers should hold domain specific PCK and experienced science teachers should hold topic specific PCK. Lee and Luft, (2008) describes PCK in terms of seven non-hierarchical components that they use as a basis for their research instruments: (1) Knowledge of science; (2) Knowledge of goals; (3) Knowledge of students; (4) Knowledge of curriculum organisation; (5) Knowledge of teaching; (6) Knowledge of assessment; (7) Knowledge of resources.

Mellado (1997) compares pre-service teachers’ conceptions of the learning and teaching of science with their classroom practice when teaching science lessons. Also drawing on the work of Shulman, he explains that teachers’ expectations have changed from a paradigm of technical rationality to "teacher thinking" whereby they have become constructivists. He is supported by Gunstone et al. (2009) who argue that what might be obvious to the teacher may not be obvious to the learner. Therefore, the knowledge that the teacher expects the learner to construct may differ from the knowledge that is actually constructed by the learner. Due to educational reforms, teachers do not merely apply instructions, but "process information, make decisions, generate routines and practical knowledge and beliefs that influence their professional activity" (Mellado, 1997, p197). Other researchers (Munby, 1982; Lederman, 1992) believe that the relationship between behaviour and thinking definitely plays a role in classroom practice. Teachers' classroom practices are consistent with their beliefs and values (Tobin & Espinet, 1989; Lorsbach, Tobin, Briscoc, & Lamaster 1992). McRobbie and Tobin (1995) explain how teachers create mental models of teaching and how their behaviour and values influence these models and therefore their teaching. A teacher's personal development has an impact on their acquisition of PCK. This type of constructivist viewpoint assumes or implies that many teachers inherit conceptual understanding of scientific terms from their own years of schooling. An interesting finding by Mellado (1997) is that "how teachers behave is influenced by how they think."

According to Hill, Ball and Shilling (2008), there is no evidence whether there is a relationship between a teachers' level of PCK and the effectiveness of student learning. In fact, the field has not been developed to assess programs designed to improve teachers' PCK. Hill et al. developed a frame of 'mathematical knowledge for teaching' shown in figure 3.1. This frame has been adopted for my study, focusing on science instead of mathematics. The frame identifies various knowledge strands within the domains of SMK and PCK. In particular, the strand knowledge of content and students (KCS) is a new construct which is useful in the area of misconceptions. The left hand side of the domain map, SMK, involves two new strands beyond Schulman's original SMK. While common content knowledge (CCK) corresponds to Schulman's SMK, knowledge at the horizon and specialised content knowledge (SCK) are added. The latter knowledge strand enables teachers to perform particular teaching tasks related to the specific topics in the subject. On the right hand side, PCK includes KCS, knowledge of content and teaching (KCT) and knowledge of curricula. While KCT corresponds to Schulman's original PCK, the added strand of KCS entails teachers' understanding of how students learn specific content independently of curricular knowledge. The frame is particularly suited to my research question, as teachers' understanding of learners' misconceptions clearly falls within the strand of KCS.

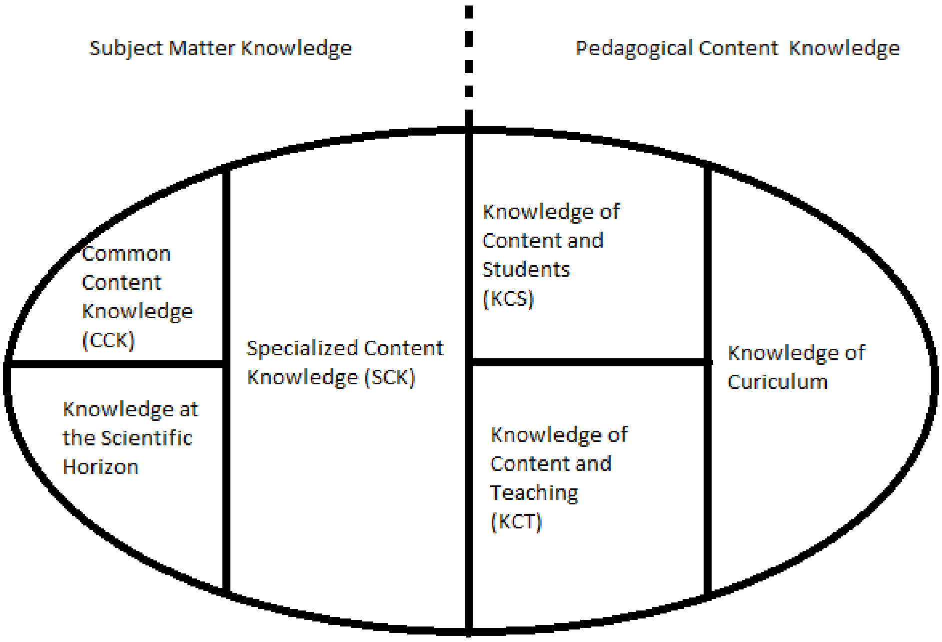


Figure 3.1: Domain map of scientific knowledge for teaching adapted from Hill et al. (2008)

Hill et al. (2008) investigated teachers' understanding of KCS and found that teachers have more control in the classrooms, and teaching methods changed after they studied specific material on KCS. This relates to the two theories by Gess-Newsome (1999) of how teachers explain concepts and how they teach these concepts. The knowledge that teachers have regarding the manner in which their students think is minimal (Hill et al., 2008). This links to the number of misconceptions in electric circuits, because it suggests that teachers may not be aware of the difficulties that their learners have in understanding the work. Teachers may identify the problem but may not understand why students have these problems. This leads us to the possibility that teachers may lack the core understanding of KCS. In terms of my study, KCS includes teachers' understanding of learners' misconceptions, therefore, the model of Hill et al. is a suitable conceptual framework for my study.

Chapter 4.

Research Methodology

4.1. Design

The study followed a qualitative approach in the interpretative paradigm. A multiple case study design was chosen because the study entails one phenomenon in a specific context dealing with different participants (Woolfolk, 2010). Each participant was treated as a separate case and compared during the data analysis. The researcher was subjective when choosing participants in the sense of purposeful sampling. There were specific criteria that were required for the participants to be chosen in order to collect the intended data. This was done so that the researcher could form a comparison between the responses when interpreting the data. Data was constructed through discussion and negotiation between participants and the researcher. The study had no intent of personal or professional ridicule. It did not aim to test the ability of a teacher to teach, or how knowledgeable a teacher is.

4.2. Sample

A purposeful and convenient sampling procedure was followed. Six teachers from different suburban government schools of convenient distance from the university were selected. The sample was based on the teachers' willingness to participate in this research. All participants were teachers that were not known to me and do not share a working relationship with me. The teachers were chosen according to experience, qualifications and school contexts. I decided to choose teachers that have five or more years of teaching because I believe that they would be able to share more information since they had taught electric circuits quite a number of times. Qualifications were also an important selection criterion because I wanted to use teachers with different qualifications to provide rich data. The school context was also considered because the context has a direct effect on the manner in which teaching and learning occurs, therefore I selected schools in different socio-economic settings.

4.3. Instruments

For this study, I adapted items from tests in the literature to cover specific misconceptions (Pesman & Eryilmaz, 2010; Engelhardt & Beichner, 2004). I have used two instruments namely: a questionnaire and an interview schedule to collect rich data and to enhance the trustworthiness of the data. I chose these instruments because I wish to gain an overall understanding of the perception that teachers have on how their learners understand electric circuits and to find out what methods they use to effectively teach electric circuits and ensure that their learners have the conceptual understanding to grasp complex aspects in electricity.

In developing the instruments for my research, I explored the misconception tests of previous researchers (Kucukozer & Kocakulah, 2007; Cohen et al, 1983; Chang et al., 1998). I found that most tests avoided potential difference. Looking at the test done by Kucukozer and Kocakulah (2007) and Cohen et al., (1983), I noticed that both tests involve cells in parallel and series, which is essential to explore the understanding of voltage. Chang et al. (1998) uses cells that are only in series and pays less attention to the effect on potential difference on the circuit. Kucukozer and Kocakulah (2007, p. 102) found that “concepts of potential difference, current and energy were used interchangeably as if they all are the same.” They were supported by Kärrqvist (1985); Shipstone et al., (1988) and Borges and Gilbert (1999). Based on this evidence, one can ask the question: Does a poor understanding of potential difference play a role in the misconceptions of electric circuits? Consequently I have included questions about potential difference in my instruments.

The questionnaire was designed for this study and was approved by two physics experts, enhancing the validity of the questionnaire. It is based on ten multiple choice items that have been adapted from tests by Pesman and Eryilmaz (2010), and Engelhardt and Beichner (2004). The format of the questionnaire can be described as ‘questions about questions’ where teachers are questioned about questions suitable for learners (van der Merwe & Gaigher, 2011). Each question starts with a multiple choice item suitable for a Grade 9 learner, with distracters based on misconceptions. The teacher is not required to answer this question. Instead the correct answer is provided and the teacher is asked about the incorrect options he/she expects his/her learners to choose. In this way, the teacher’s awareness of the learners’ misconceptions can be probed. Table 4.1 summarises misconceptions that were probed in the questionnaire. The questionnaire is given in the appendix.

It is possible that a teacher who knows the targeted misconception would think that his/her learners would not make that mistake. However, I argue that it is unlikely for a teacher to choose any other arbitrary incorrect answer. Therefore it will be assumed that if a teacher is aware if the relevant misconception he/she would choose that option as an expected wrong option.

The interview is designed to enquire about general matters regarding electric circuits, such as: teachers' views about misconceptions, learners' difficulties, practical work, the syllabus, and so on. The interview schedule comprised of six categories namely: teaching and learning, analogies, practical work, textbooks, syllabus and reference to questionnaire. Questions were formulated; however the interview was semi-structured to allow the researcher to probe for further information that may be relevant to the research. Audio tapes were used to record and transcribe interviews.

As with all instruments there are limitations. The limitations require a second instrument of some form of cross checking to enhance trustworthiness of data. All limitations to the instruments were kept in mind when data was interpreted and cross checked against each other. Table 4.2. summarises cross checking in the two instruments.

Table 4.1: Summary of misconceptions probed in the questionnaire.

Item	Misconception probed	Distracter representing the misconception
1	Unipolar or sink model	C
2	Attenuation model	B/E
3	Clashing current model	B
4	Empirical rule model	C/E
5	Superposition model	B
6	Short circuit model	E
7	Attenuation model	B/C

8	Voltage and current not distinguished	B
9	Sequential model	C
10	Power supply misconception or Parallel circuit misconception	B/C

Table 4.2: Cross checking of questionnaire answers with interview questions for trustworthiness.

Misconception	**Questionnaire item no:**	**Interview Question no:**
Unipolar or sink model	1	6.1.
Attenuation model	2	6.2.
Clashing current model	3	6.3.
Empirical rule model	4	6.4.
Superposition model	5	6.5.
Short circuit model	6	6.6.
Attenuation model	7	6.7.
Voltage and current not distinguished	8	6.8.
Sequential model	9	6.9.
Power supply misconception or Parallel circuit misconception	10	6.10.

4.4. Data Collection

Data was collected at a comfortable setting for the participant, which was either school or at the participant's home. Participants were visited on average about three times during the research process. The first visit was to inform the participants about what would be required of them, to explain the ethical constraints in the research, to give the participants clarity on the importance of the research and to brief them on what to expect during further visits and to give them the questionnaire to complete. In the second visit, the participants were interviewed and these interviews were recorded and transcribed the same evening to ensure that all the information had been recorded. During the third visit, the participants were allowed to view and amend the previous transcription to see if anything was unclear.

4.5. Data Analysis

Questionnaires were carefully analysed to establish each teacher's knowledge of typical mistakes, their understanding of the underlying misconception and their ideas about addressing the mistake. For each question, the teachers' responses are presented in a table, followed by a discussion of the responses. Recordings of interviews were transcribed and read thoroughly to get a sense of the information. The interview data is presented according to the predetermined categories from the interview schedule. Finally, the interview and questionnaire data were synthesized for each teacher. The ideas about teaching, have been grouped into two categories: ideas about content and ideas about method. The following aspects derived from the literature were used as key features in investigating what to teach: concepts and relationships, formulae and calculations, potential difference. The following aspects were investigated on how to teach: analogies, practical work, demonstrations, and explanations.

4.6. Methodological Norms

For a qualitative study the research should be trustworthy and confirmable. For purposes of trustworthiness data were enhanced by using two sources. Validity was enhanced by basing the questionnaire on instruments available in the literature (Engelhardt & Beichner, 2004; Pesman & Eryilmaz, 2010). Questionnaires were based on the known misconceptions from the literature, therefore the questionnaire can be regarded as a valid instrument and trustworthy. Furthermore, the interview questions were grouped into four sections allowing for repetition of ideas that could be compared to answers in the questionnaire. This allows for triangulation within the interview as well as between the interview and questionnaire. Triangulation is used for "crossvalidation among data sources, data collection strategies, time periods, and theoretical schemes" (McMillan & Schumacher, 2006, p.374). The data would be trustworthy if there is a pattern between, "solicited and unsolicited data, subtle influences among the people present in the setting, specific versus vague statements and accuracy of the sources" (McMillan & Schumacher, 2006, p. 374). Persistent observation of the manner in which participants answer questions and engage with the scope were taken into consideration when the data was analysed.

4.7. Ethics

Ethical procedures were followed via the University of Pretoria. Permission for ethical clearance was obtained prior to starting with the data collection process. Participants were informed about the procedures and were required to sign informed consent forms clearly indicating their role in the research. All data was treated confidentially and all reporting is anonymous. The participation was voluntary and the participant was free to leave or withdraw participation at any time during the data collection process. Interviews and questionnaires were conducted for the convenience of the participants at a place that is not harmful. No incentives were given to the participants as that may impact on the responses given by the participant. The research did not involve participants that are known to me in order to reduce possible bias.

4.8. Limitations

As mentioned in 4.3, the design of the questionnaire may place a limitation on the study, as it is possible that a teacher who knows the targeted misconception may choose another option. However, it was argued that there was no logical reason for the teacher to choose any other arbitrary wrong answer.

In the case of my research, no classroom visits were possible due to the number of hours that would be required. Therefore my research questions were designed not to involve classroom practice. This has thus limited my research instruments to interviews and questionnaires. Since I was using a small sample size, the data was specific to this research and will not reflect a generalization of South Africa itself.

Chapter 5

Data Analysis

5.1. Biographical Information

The teachers were selected from schools in the Pretoria area. Each teacher received a consent form and was asked to fill in the questionnaire upon the first visit. This gave me an idea of the biographical information in this study. Table 5.1 below illustrates the different schools' resources and the teachers' qualifications. For purposes of anonymity, pseudonyms have been used for each participant.

Table 5. 1: Reflection of the demographics of the schools used in this study and biographics of the teachers.

Teacher	Qualification	Institution Obtained	Years of Teaching Experience	Major Subjects	Year obtained	Schools' Resources
'Peter	B.Ed.	University	6	Physics; Chemistry; Mathematics	2007	Well resourced
Lee	D.Sc.	University	11	Physics	1977	Fairly resourced
Mike	M.Sc.	University	13	Physics; Mathematics	2012	Well resourced
Nick	B.Sc. Hons; HED	University	11	Biochemistry; Chemistry	1986	Fairly resourced
Olivia	Diploma in Education	College	8	Natural Science; Geography; Life Science	2003	Well resourced
Kate	Diploma in Education	College	6	Life Orientation; Life Science; Geography	2002	Under resourced

The bio graphics show that the teachers who were used in this study have different qualifications. Kate and Olivia have diplomas in teaching. Peter has a degree in science education, while Nick has degrees in science as well as a postgraduate teaching diploma. Lee and Mike have pure science qualifications but no qualifications in teaching. The teachers have between 6 and 13 years of experience and therefore are regarded as having sufficient experience for the purposes of this study. All the schools are suburban government schools and range from under-resourced to well-resourced.

Peter has a BEd (FET) qualification majoring in Physics and Mathematics. This suggests that he should have adequate PCK and SMK to teach the section of electricity to Grade 9 learners.

Lee holds a Doctorate in Physics. He therefore is well qualified to teach electricity but has no qualifications in education. He has specialised SMK but may have a lack of PCK because he has no formal training in teaching, only that which he has developed through experience. This PCK may be inadequate.

Mike has a Masters in Science majoring in Mathematics and Physics. He therefore should have proficient SMK but because he has no education qualifications, he may have limited PCK.

Nick has a BSc Honours in Biochemistry and Chemistry. A BSc degree ensures that students complete at least the first level of Physics. He therefore may have sufficient SMK. He also completed a postgraduate diploma in education, suggesting adequate PCK.

Olivia completed a Diploma in Education with the subject majors of Natural Science, Geography and Life Orientation. She is expected to have basic SMK and PCK. Her knowledge may be inadequate to teach the topic at Grade 9 level.

Kate's qualification reveals that she has an education diploma, but her major subjects are Life Science, Life Orientation and Geography, therefore she has no qualifications in Physics and Chemistry. This makes her inadequately qualified to teach the topic of electricity or electric circuits. She has a qualification in education, but not Science Education, suggesting that she may have some PCK in Life Science but not in Physical Science. She may have developed SMK through teaching experience but this may not be sufficient.

All the teachers are second language English speakers, teaching in English medium schools. This was not a selection criterion, however this is a reflection of the situation in many South African schools.

5.2. Analysis of Questionnaire

Each teacher was given a questionnaire to complete. This questionnaire was completed either in the teacher's classroom or at the teacher's home. Each question with the responses made by the teachers is shown below and a comparison between the responses is given. This comparison looked at aspects of the teacher's understanding of the learners' misconception and the different approaches taken to correct the learners understanding of the concept. It is important to notice that the design of the questionnaire does place a limitation on the validity of results. It may happen that a teacher knows a misconception but believes that his/her learners would not make such a mistake. In discussing the choices, it is assumed throughout that if a teacher is aware of the relevant misconception, he/she would choose that option as an expected wrong answer. It is argued that there is no logical reason for the teacher to choose any other arbitrary wrong answer.

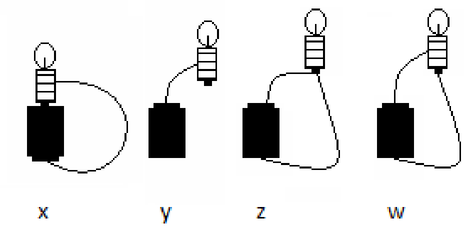
Table 5. 2: Analysis of Question 1 of the questionnaire

Question 1:

Which bulb/ bulbs will light?

- (A) x and w
- (B) w only
- (C) y
- (D) x, y, z, w

The correct answer is (A).



1.1. Which wrong option do you expect your learners to choose?
1.2. Why do you think they will choose this option?
1.3. How would you explain to learners why the chosen option is incorrect?

Peter	**Lee**	**Mike**	**Nick**	**Olivia**	**Kate**
1.1. B	1.1. C	1.1. D	1.1. B	1.1. D	1.1. D or C
1.2. They would/might think that to have a complete circuit, the components must be connected	1.2. Because they may think that one wire is enough for the current to flow. They may not realise that the	1.2. They will think that all of them will light since they are connected (bulb	1.2. It has two wires connecting the bulb and the cell.	1.2. Light bulb connected at both ends	1.2. D because z is in D. I have taught my learners that you need conducting wires from, the cell to the cell.

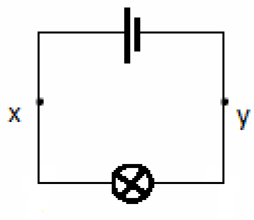
by a wire to complete a circuit.	circuit must be completed.	connected with cell).			
1.3. If the connection that completes the circuit is complete and potential difference is established, as in the case of bulb x and w, then current will flow	1.3. That the circuit is not completed and the current cannot flow into the light bulb and back to the cell. Explained using drawing of a cell and a battery.	1.3. Option D is incorrect because in fig. y, the circuit is not completed, and z the base of the bulb needs to be connected to the cell and the side of the bulb to the other side of the cell.	1.3. Two wires are connected to the light bulb at different positions, or one end of the bulb must be connected via a wire to the opposite pole. Two wires at one end-no light. One connection-no light. So bulbs that will light up is x and w, option A.	1.3. The light bulb needs to be connected to the positive and negative terminal of the cell, as well as the copper metal.	1.3. It has the conducting wires as I have taught them but it is connected wrong

Responses to question 1 are summarized in Table 5.2. The participants were probed on their knowledge of the misconception known as the Sink or Unipolar Model. Option C is a clear indication of the misconception and only Lee chose this option while the others chose B or D, meaning that they did not expect their learners to choose C. This is interpreted to mean that they are not aware of the "unipolar misconception". All the participants showed understanding of the scientific model. Shipstone (1985) found that the unipolar model is easily addressed. This may be the reason why the teachers in my sample have not encountered the misconception as they do not have experience of teaching primary school science. They all had a general understanding that learners do not understand that the position of the two connections on the light bulb was important in order for it to complete the circuit. It seems that they realize that learners may not understand the construction of the light bulb's connections.

Table 5. 3: Analysis of Question 2 of the questionnaire

<table>
<tr><td colspan="6">Question 2:

How do the currents at points x and y compare?

(A) x = y
(B) x > y
(C) y > x
(D) x=0
(E) y=0
The correct answer is (A).

</td></tr>
<tr><td colspan="6">2.1. Which wrong option do you expect your learners to choose?
2.2. Why do you think they will choose this option?
2.3. How would you explain to learners why the chosen option is incorrect?</td></tr>
<tr><td>Peter</td><td>Lee</td><td>Mike</td><td>Nick</td><td>Olivia</td><td>Kate</td></tr>
<tr><td>2.1. B</td><td>2.2. B</td><td>2.1.B</td><td>2.1. B</td><td>2.1. B</td><td>2.1. Between B or C</td></tr>
</table>

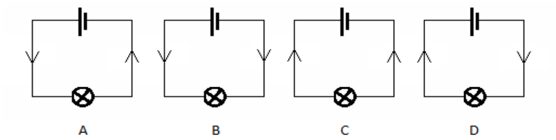
2.2. I think they'd probably confuse the potential difference across the bulb with the current. They'd think that as Potential energy decreases across the bulb, so would the ability of changes to move from one point to the other.	2.3. They would think that x is closer to the cell and the current flows through x firstly and that the light bulb y will be dimmer due to the dimmer light bulb.	2.2. They will think that after the current passes through the bulb, it will be used up.	2.2. They think that the current on one side of the bulb must be smaller than the other side, because the light bulb used current to light up.	2.2. Because the current flows from positive to negative	2.2. They are struggling to understand the concept that the current is the same throughout the circuit. The moment that you connect two ammeters it throws them off
2.3. I would use the analogy of a steering wheel: when one point of a steering wheel moves, all other points of the steering wheel move at the same instant.	2.3. If you put an ammeter in the position of x and y it should read the same. Demonstrate it practically. Also explain to them at electrical components like ammeters and points x and y and bulbs are all in series.	2.3. The chosen option is incorrect because x and y are in series, therefore when you place ammeters at each of these points, the current should be the same.	2.3. Current is the same everywhere. Use the example of a long string wound around a few objects that has different degrees of friction. The rope moves at the same speed at any time that it takes to complete a certain distance (measure how fast it goes).	2.3. Current in a circuit remains the same at any point in a circuit.	2.3. To tell and show them that the current is the same everywhere in an experiment.

Responses to question 2 are summarized in Table 5.3. The question was used to investigate the teachers' understanding of the misconception known as the Attenuation Model. This model is represented by option B and E, because it indicates that the learner believes that current is consumed by the electrical devices in the circuit. For this item, all participants recognised the misconception represented by option B. Kate and Lee would explain this practically by doing a demonstration. Nick and Peter would use analogies, and Mike and Olivia would explain the concept by telling the learners that the current stays the same throughout the circuit.

Table 5. 4: Analysis of Question 3 of the questionnaire

Question 3:

Which diagram correctly represents the flow of conventional current in the circuit?



The correct answer is (A).

3.1. Which wrong option do you expect your learners to choose?
3.2. Why do you think they will choose this option?
3.3. How would you explain to learners why the chosen option is incorrect?

Peter	**Lee**	**Mike**	**Nick**	**Olivia**	**Kate**
3.1.D	3.1. D	3.1. B	3.1. D and also B or C	3.1. D	3.1. D
3.2. Often kids struggle to understand with the idea of positive charges moving from one point to the other.	3.2. If they do not understand conventional current (+ to -) then they would choose D.	3.2. They think that current flows from the cell to the bulb.	3.2. D- don't know what side is + or – B or C- don't pay attention to both the arrows direction.	3.2. They always think positive is at the shorter end of the cell.	3.2. Learners are getting confused about which line of the symbol is positive and which one is negative although they know that the current flows from positive to negative.
3.3. Conventional current is movement of positive charges. Therefore, the have to move through the circuit to the negative terminal where there is less "concentration" of positive charges.	3.3. Define the word conventional current! Demonstrate the circuit with an ammeter and light bulb. Indicate which cell part is + and – and that current flows from + to -.	3.3. Is incorrect because, current might flow in a circle, that from one point (positive terminal) to the other point (negative terminal) to complete the circle. Also the flow of current is a result of the rate of flow of charges which is from the negative terminal to the positive terminal.	3.3. D- long line of symbol = + and short line = -. Conventional current flows from + to -. B or C- must pay attention to direction of both arrows because they are on opposite sides of the diagram, they will have opposite directions.	3.3. In a conventional current the charges flow from the positive (longer) to the negative (shorter).	3.3. I will tell then that they should think a lot about a subtraction (-) sign in any calculation. Subtraction sign is negative regarding taking away.

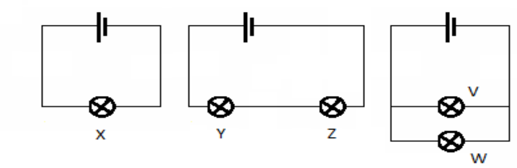
Responses to question 3 are summarized in Table 5.4. This question was intended to probe the teachers' awareness of the clashing current model. The option that indicates this misconception is option B. It is the misconception that current flows in two directions towards the bulb as opposed to circulating. Only Mike gave a clear indication and explanation of the clashing current model. Most responses emphasise the positive and negative sides of the cell, indicating that teachers focus on the concept of conventional current whilst teaching. As explained before, this is not sufficient evidence to prove that the other teachers are not aware of the misconception, it may mean that they expect their learners to know that current forms a closed loop. Mike and Nick are aware that learners do not understand that current flows in one direction or do not pay attention to the direction. However, Kate and Olivia believe that the learner is unsure of the symbol of a battery and confuses the positive and negative terminal when using a symbol, Peter and Lee showed understanding that learners do not understand conventional current. All participants stress the importance of explaining the concept of conventional current except for Kate and Olivia, who would emphasise that the short line is the negative terminal without an attempt to improve learners' conceptual understanding.

Table 5. 5: Analysis of Question 4 of the questionnaire

Question 4:

Which bulb or bulbs are the least bright?

(A) y ,z
(B) y, z, v, w
(C) w
(D) x
(E) z and w



The correct answer is (A).

4.1. Which wrong option do you expect your learners to choose?
4.2. Why do you think they will choose this option?
4.3. How would you explain to learners why the chosen option is incorrect?

Peter	**Lee**	**Mike**	**Nick**	**Olivia**	**Kate**
4.1. B	4.1. C	4.1. D	4.1. E	4.1. C	4.1. The option is not there in my opinion
4.2. Whenever two bulbs are connected in a circuit, the effect of bulbs on the total brightness is always smaller.	4.2. Learners must understand the difference between series and parallel connections. We tend to explain series resistance well but shy away from parallel resistance because of the math's involved. Because of the gap they tend to choose incorrectly.	4.2. They will think that it is only one bulb so it should be the least bright.	4.2. They think that energy is lost from one light bulb to the other. The one that receives energy "first" will then be the brightest.	4.2. Because it is parallel, therefore more resistance in the circuit.	4.2. -
4.3.	4.3.	4.3.	4.3.	4.3.	4.3.

Light bulbs are resistors. Therefore resistors connected in series increase resistance and those connected in parallel increase current, because total resistance decreases.	Demonstrate it using a series board and a parallel board. Firstly connecting V only and compare with Y and Z and then connecting W and explain again. Lastly by doing the two circuits mathematically.	Bulb X is getting the maximum energy from the cell while in the rest the energy is being shared.	The brightness of the bulbs depend on the potential difference across them. Identical bulbs in series will be of same brightness but dimmer than single bulb. In parallel the brightness will be the same.	Parallel connection. An equal amount of current flows through each light bulb.	-

Responses to question 4 are summarized in Table 5.5. This question was set to test the awareness of the Parallel Circuit Misconception (option B) and the Empirical Rule Model (option C or E). While acknowledging the limitation of the instrument, it seems that only Peter has understanding of the Parallel Circuit Misconception. Lee, Nick and Olivia have knowledge of the Empirical Rule Model misconception, but only Nick gives a clear indication that he understands it well. Lee demonstrates the concept practically and explains it mathematically, and also refers to the difficulties in explaining mathematically. Olivia would explain in terms of current only. Nick and Peter try to explain to improve conceptual understanding by referring to potential difference and resistance. Kate and Mike do not seem aware of the misconception. Only Nick refers to potential difference. It is possible that this is because he is the only one that believes this misconception is prevalent in his learners. There is no evidence to support this. Nobody tries to use an analogy to explain why resistance is less in parallel resistors. Mike's explanation seems to be explaining how the learners think instead of correcting the mistake.

Table 5. 6: Analysis of Question 5 of the questionnaire

Question 5:

Which bulb(s) are brightest?

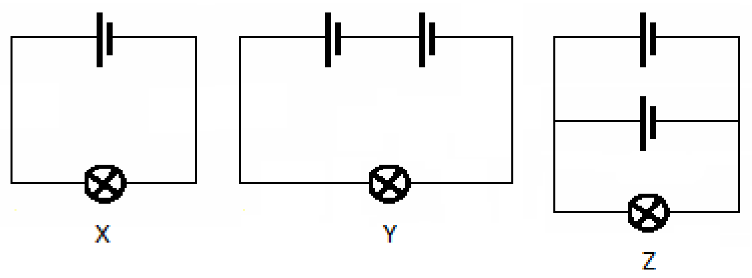
(A) y

(B) y and z

(C) z

(D) x

(E) x and y



The correct answer is (A).

5.1. Which wrong option do you expect your learners to choose?
5.2. Why do you think they will choose this option?

5.3. How would you explain to learners why the chosen option is incorrect?					
Peter	**Lee**	**Mike**	**Nick**	**Olivia**	**Kate**
5.1. B	5.1. C	5.1. B	5.1. C	5.1. B	5.1. C
5.2. Two or more cells increase current and energy of each charge, irrespective of the connection.	5.2. Learners must understand the addition of cells (total voltage) and the parallel connection of cells.	5.2. They will think that there are two cells in these circuits so they should the brightest.	5.2. Do not know/understand how series and parallel switching of cells work	5.2. There are more cells/batteries in the circuit.	5.2. They will think that cells connected in series and parallel will give the same brightness although they do not.
5.3. Cells that are connected in parallel offers the same current, for longer. They do not increase the energy of the circuit.	5.3. Using a series and parallel connected board and investigate the brightness of the bulb. Then explain why we see the difference. Series we add up and not with Z. By increasing one cell from Z we obtain the same brightness as with two or more.	5.3. Cells in series you add up their voltages but when cells are in parallel, their voltages don't add up and they last longer compared to those in series.	5.3. Series switching is like when you have two lorries switched to another with the ones front to the others rear. Together they have more power and will pull a heavy load at a faster speed than one lorry alone. Two cells in series has the same effect and the bulb will be brighter than with only one cell. The same two lorries hitched side to side will have the same power as one lorry, they will only be able to do more work with the same amount of diesel. So with parallel switched cells the light will be same brightness as with one cell, but will burn longer.	5.3. Z- the cells are connected in parallel thus the light will be bright but not as bright. Y- resistance is more.	5.3. Tell them and show them the difference between cells connected in series and parallel in an experiment.

Responses to question 5 are summarized in Table 5.6. This question investigates the teachers' awareness of the superposition model. An indication of this misconception is evident in option B. In this misconception, it is not understood that the physical arrangement of the cells determines the potential difference across the battery. Mike, Olivia and Peter are aware that learners think cells will produce the same potential difference either way because they believe the voltages must be added in the series as well as the parallel connection. Kate, Lee and Nick are also aware that the learners do not understand the difference between series and parallel cells however; they believe that the learners think parallel cells produce a larger voltage. Once again, Kate and Lee suggest demonstrating practically, but it seems that Kate would not try to explain. Kate simply says she would “tell them”. It seems that Kate resorts to demonstrations to compensate for her poor understanding. The others all explain by simply stating the rule, but no one actually refers to the meaning of voltage in terms of the battery. Nick explains by an analogy of the trucks which is not correct.

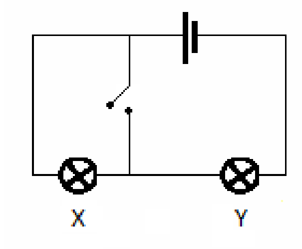
Table 5. 7: Analysis of Question 6 of the questionnaire

Question 6:

How does the brightness of the light bulbs change if the switch is closed?

(A) y brighter, x=0
(B) both brighter
(C) y=0, x=0
(D) x brighter, y=0
(E) no difference

The correct answer is (A).



6.1. Which wrong option do you expect your learners to choose?
6.2. Why do you think they will choose this option?
6.3. How would you explain to learners why the chosen option is incorrect?

Peter	Lee	Mike	Nick	Olivia	Kate
6.1. B	6.2. B	6.1. E	6.1. E	6.1. E	6.1. E
6.2. They’ll think that this connection will result in equal sharing of a current.	6.2. This question is some what advanced for grade 9. Learners will choose B because they do not understand the switch in the middle.	6.2. They will think that current will still pass through X and then continue to Y.	6.2. They don’t see the closing of the switch as creating a short circuit.	6.2. The switch is connected in parallel. There will be equal amount of charges flowing through each bulb.	6.2. They would say that the bulbs are connected series so they must shine equally bright.
6.3. Current takes the shortest path and the path of least resistance.	6.3. By demonstrating it practically and then explain why we see what happened.	6.3. Current will choose the shorter path.	6.3. Closing the switch gives the current an easier path to travel, so it will bypass bulb X. bulb Y will now get the full/higher current and will be brighter while bulb X will not shine at all.	6.3. There is more resistance in the circuit with two light bulbs.	6.3. By doing an experiment.

In question 6, summarized in Table 5.7, teachers’ awareness of the short circuit misconception is examined. The option that signifies a short circuit is option E. Kate, Mike, Nick and Olivia know of the misconception but only Mike and Nick’s explanation indicate understanding of short circuits and explain or demonstrate practically why the correct answer is A. Lee and Peter believe that the misconception lies in that the learner does not understand the purpose of the switch in the middle and may think that the bulbs are in series and the current is shared equally. Once again, Kate and

Lee say they will demonstrate, but Kate does not suggest that she would also explain. Mike refers to an easier path, only Nick refers to short circuits. Explanations by Nick, Mike and Peter indicate that they understand the concept of a short circuit by referring to "short circuit" or "shorter path" or "path of least resistance". Olivia gives an inappropriate explanation which shows that it is not clear if she herself understands.

Table 5. 8: Analysis of Question 7 of the questionnaire

Question 7: Why does a bulb light up when connected in a circuit? (A) electrical energy is converted to light (B) electrical charge is converted to light (C) electrical current is converted to light (D) all of the above The correct answer is (A).					
7.1. Which wrong option do you expect your learners to choose? 7.2. Why do you think they will choose this option? 7.3. How would you explain to learners why the chosen option is incorrect?					
Peter	**Lee**	**Mike**	**Nick**	**Olivia**	**Kate**
7.1. C	7.1. C	**7.1.** C	**7.1.** D	**7.1.** C	7.1. Any of the following B, C or D.
7.2. Current creates energy.	7.2. They would think that current and not charge is responsible for the light. They are confused between energy and current.	7.2. Learners are aware of current compared to energy and charge in electricity.	7.2. They don't always distinguish between energy, charge and current. They don't see light as energy and this may confuse them.	7.2. Because it says "current" and most teachers speak of an electric current.	7.2. Taught them that current is the flow of positive to negative charge, but do know the following conversion: Chemical Potential Energy →Electrical Energy → Heat and Light Energy.
7.3. For light bulb to light up charges must do work. Therefore, for work to be done energy must be used.	7.3. To explain that one energy is converted into another energy. This is conservation of energy. In current the word energy is not mentioned.	7.3. The rate of flow of charge constitutes current which is the electrical energy that is connected to light.	7.3. Electrical charge- the amount of electrons that are moving in a circuit. Electrical current- how fast the charges move in the circuit. Electrical energy- how strong the charge is and that is indicated by the voltage in the circuit. Light is energy, the brighter the light the higher its energy, Current and charge is not energy. Charge just	7.3. It is energy that flows as current through a circuit.	7.3. By doing revision every time about the work before every test and exam.

			counts electrons and current is dependent on energy. The only conversion is then electrical energy to light energy.		

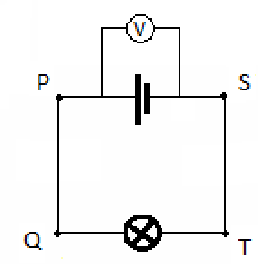
Responses to question 7 are summarized in Table 5.8. This question looks at the teachers' awareness of the Attenuation Model, but from a different perspective where the belief is that current instead of energy is converted to light. In this question, the understanding of the concepts involved such as current, charge and energy are emphasised. The option that indicates the misconception is C. All the participants except Nick expected option C, however Kate expected all possibilities. Peter, Kate, Nick and Lee believe that it is rather a confusion of concepts and terminology that may cause them to choose any option and would emphasise the difference between current and energy. Peter, Lee and Nick would attempt to explain to learners what is wrong with their reasoning. However, Olivia and Mike proposed incorrect explanations, suggesting that current is energy. Kate indicates that she would do revision, suggesting that she does not focus on the learners' particular problem.

Table 5. 9: Analysis of Question 8 of the questionnaire

Question 8:

A 6V battery is connected to a bulb as shown above in the diagram. A voltmeter is then connected between P and S. Next it is connected between P and Q, then Q and T and finally T and S. What are the voltmeter readings between the various points?

	PS	PQ	QT	TS
(A)	6	0	6	0
(B)	6	6	6	6
(C)	6	2	2	2
(D)	6	3	0	3



The correct answer is (A).

8.1. Which wrong option do you expect your learners to choose?
8.2. Why do you think they will choose this option?
8.3. How would you explain to learners why the chosen option is incorrect?

Peter	**Lee**	**Mike**	**Nick**	**Olivia**	**Kate**
8.1. C	8.1. B	8.1. B	8.1. B	8.1. B	8.1. B, C or D
8.2. V measures the potential difference across the battery and reading = 6V. However, since PQ, QT and ST	8.2. If they do not understand that Vpq and Vst have zero (or nearly zero resistance) resistance as indicated in the	8.2. No matter where the voltmeter is, it can still read the voltage of the cell.	8.2. They realise that the voltmeter must also be connected to the different poles of the cell, although not as directly as a resistor and that it measures	8.2. They will get confused between an ammeter and voltmeter, and think the current is the	8.2. Learners need to do the calculations first before answering otherwise they will

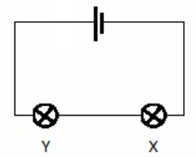
are equal in length, the resistance at each connection will also be equal.	problem, they will not know the answers.		a difference in potential energy.	same and not realise we are discussing potential difference.	just pick an answer.
8.3. Energy is used/ transferred at the light bulb. Negligible amount of energy is used in the conducting wire. Therefore no energy is transferred between connection P and Q between connection S and T.	8.3. By demonstrating it for the learners and then explain why we say that Vpq=Vst=0. Also explain that a voltmeter has a high resistance and needs only V and not I.	8.3. Between PS and QT, the voltmeter is across the battery and in parallel with the battery. But between PQ and ST, the voltmeter is in series with the cell/battery.	8.3. Between P and S and between Q and T we have a resistor (the cell and the bulb). The potential of the current to do work is higher before a resistor then after it because some energy was lost while the charges travelled through the resistor. The voltmeter to measures this energy. Connecting wires have no resistance (or very little) so there is no loss in potential to do work and the voltmeter will then have a zero reading.	8.3. A voltmeter measures the potential difference of the circuit, because there are no resistors between P and Q and S and T the reading will be zero.	8.3. By doing calculations with the learners.

Question 8, summarized in Table 5.9, examines the teachers' awareness of learners' poor distinction between voltage and current. The option that indicates the misconception is option B. All the participants are aware of the misconceptions but explain it in different ways. Kate does not make a choice of the more popular answer. She does not offer a conceptual explanation; she suggests that they should do calculations. She also does not mention understanding but just getting the right answer. It seems that she does not understand the problem herself. Lee suggests a demonstration with an explanation. Mike's explanation does not address what is wrong with option B. He focuses on how to connect the voltmeter to read potential of the cell. Olivia shows understanding by explaining work done in terms of resistance. Nick and Peter refer to resistance and energy, showing rich understanding. Nick says "the voltmeter measures this energy" and Peter says "no energy is transferred between connection P and Q between connection S and T." Peter explains the transfer of energy and the effect of the conducting wire in more detail to clarify why option A is correct.

Table 5. 10: Analysis of Question 9 of the questionnaire

Question 9:

What happens to the brightness of the bulbs X and Y if we add a resistor between them?



(A) X and Y both less bright
(B) X unchanged, Y less bright
(C) X less bright, Y unchanged
(D) X and Y both unchanged

The correct answer is (A).

9.1. Which wrong option do you expect your learners to choose?
9.2. Why do you think they will choose this option?
9.3. How would you explain to learners why the chosen option is incorrect?

Peter	Lee	Mike	Nick	Olivia	Kate
9.1. C	9.1. D	9.1. B	9.1. C	9.1. D	9.1. Any of the answers.
9.2. Charges that are passing through Y be experience no resistance	9.2. If they do not understand that connection in series as measured if another resistor is connected into the circuit. If they also do not understand Ohm's Law.	9.2. They will think the resistor will resist the current only after the current passes through Y.	9.2. Same as question 4. They think that energy is lost from one light bulb to the other. The one that receives energy "first" will then be the brightest.)	9.2. They will say it is because its in series so there is an amount of "light" flowing through each	9.2. Learners know that a bulb can also be a resistor.
9.3. Whenever light bulb are connected in series, and there is a change in the total resistance of the circuit, the resistance affect the flow of all charges.	9.3. By demonstrating practically with a circuit board. Place an ammeter also in the circuit and the Y only (read A) then X (read A) and then third resistor and read A.	9.3. The resistor is like opposition to the free flowing current so it opposes it in the entire circuit.	9.3. Same as question 4. (The brightness of the bulbs depend on the potential difference across them. Identical bulbs in series will be of same brightness but dimmer than single bulb. In parallel the brightness will be the same.)	9.3. The more resistors in series the weaker the current flow in the circuit, thus each light bulb will be less bright.	9.3. During an experiment regarding this matter.

Question 9, summarized in Table 5.10, investigates the teachers' awareness of the sequential model. The option that indicates this misconception is option C where learners believe that change in the circuit affects only parts "ahead" on the circuit but not "behind." Nick, Mike and Peter understand this misconception. Mike refers to electron current in his explanation showing understanding of the misconception. However Kate, Lee, and Olivia do not seem to know the misconception of sequential reasoning. Kate makes no specific choice and once again suggests doing an experiment without any explanation, suggesting lack of SMK. Lee and Olivia suggest that learners would not understand that the resistance of the circuit changes. Mike and Peter offer explanations addressing the circuit in total which does indicate that all charges are affected, not just some.

Table 5. 11: Analysis of Question 10 of the questionnaire

Question 10:

How do the readings on the ammeters X and Y change if the switch is closed?

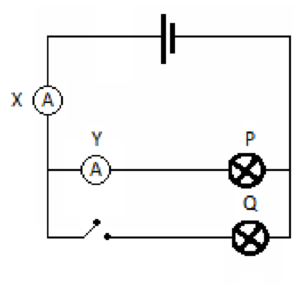
(A) X increases, Y unchanged

(B) X unchanged, Y decreases

(C) X decreases, Y decreases

(D) X increases, Y decreases

The correct answer is (A).



10.1. Which wrong option do you expect your learners to choose?
10.2. Why do you think they will choose this option?
10.3. How would you explain to learners why the chosen option is incorrect?

Peter	**Lee**	**Mike**	**Nick**	**Olivia**	**Kate**
10.1.C	10.1.C	10.1.D	10.1.B	10.1. D	10.1.C
10.2. Total resistance increases and thus decrease the total current of the circuit.	10.2. Because they do not understand parallel circuits.	10.2. They will think that the current will be divided at the junction towards the key to reduce the current that gets to Y.	10.2. Because bulb P and Q are now in parallel, the current will decrease. They don't take in consideration the effect and resistance and total current.	10.2. Learners will think that with Y closed there will be a current flowing through it.	10.2. Because the learners know that the current splits up.
10.3. Connection of resistors in parallel, decrease the total resistance and ultimately increase the total current, reflected at X. Current at Y stays the same because the resistance in that path is unchanged.	10.3. By demonstrating it practically for grade 9 and then explain it step by step what happens in the circuit. Firstly with series and then parallel connection.	10.3. The current in the circuit will choose the shortest path.	10.3. Bulbs are identical so in parallel the total resistance will half. This will have the effect that the ammeter Y register twice its former reading. But because the current is split evenly between the two parallel circuits, the reading on Y will stay the same.	10.3. The switch is connect to the series circuit so with the switch closed the current will now be able to flow through bulb Q=resistance will be more. The current on X will then increase	10.3. Doing an experiment.

Responses to question 10 are summarized in Table 5.11. This question examines the teachers' awareness of the power supply misconception and the parallel circuit misconception. The options that indicate the misconceptions are B and C respectively.

Mike and Olivia do not know these misconceptions. Kate, Lee and Peter chose C, which represents the parallel circuit misconception. However, Kate's explanation does not explain why learners would choose C and she once again suggests doing an experiment to demonstrate and explain. Peter correctly explains learners' reasoning and he gives a comprehensive explanation. Nick is the only one that chose option B, the constant power supply misconception, and gives a rich explanation to correct the misconception. Mike and Olivia chose D with inconsistent explanations.

The responses have to be compared and cross checked with the interview transcripts to ensure trustworthiness of the data obtained.

5.3. Analysis of Interviews

The interviews were voice recorded and transcribed for each participant. These interviews were used to extract teachers' ideas about content and method and also for triangulation with the questionnaire responses. Taking a closer look at the interview questions, we can see that there are some common ideas and common differences between participants.

Lee, Mike, and Peter feel that their studies prepared them to teach. Looking at the qualifications of the teachers, we can see these three teachers have majored in Physical Science. Kate, Nick and Olivia do not feel that their studies prepared them to teach. Nick's reaction is surprising because even though Nick majored in chemistry, his degree included university physics at first year level. Only Kate has no physical science qualification. Olivia studied Natural Science yet she also feels unprepared. Both Olivia and Nick have sufficient training to teach electricity at Grade 9 level. I conclude from Kate, Nick and Olivia's reaction that it appears to be necessary to have studied the content as a subject major in order to feel prepared to teach it.

All the teachers except for Peter find teaching electricity more difficult than other topics and ascribe it to cultural differences and that they feel that learners find it difficult to grasp concepts. Kate, Lee, Mike and Nick start the electricity concept by questioning learners and drawing from their knowledge. Olivia starts by doing a demonstration and Peter starts by explaining an analogy. Different methods of introducing the concept show that they attempt to capture learners' attention, though in different ways. Both

Lee and Mike in their interview explain that they use various teaching methods and choose methods that they believe their learners will understand best.

All of the participants believe that calculations should be taught, however, according to the CAPS document, calculations should not be taught at Grade 9 level. Lee specifies that these calculations should be basic. It appears that aspects of Ohm's Law, as mentioned by Lee and Mike, and possibly simple calculations of series and parallel resistors are used during explanations as an example of how the circuit works as a whole. Kate and Nick find calculations difficult to explain. This is a contradiction for Nick because he says he does not teach additional topics in electricity but calculations are an additional part to the prescribed syllabus. It is possible that Nick is not familiar with the requirements for CAPS.

Mike and Nick have observed learners' difficulty to understand series and parallel resistors, but Kate, Lee and Peter say learners find formulas difficult, even though at Grade 9 level learners should not be taught formulas. Lee, Mike, Olivia and Peter mention difficulty in conceptual understanding of work, energy, current and potential difference. This shows that they are aware of learners' poor conceptual understanding.

Kate is the only participant that says she does not use an analogy to teach electricity. Her response below shows that she does not seem to fully understand what an analogy is or perhaps is unfamiliar with the term/label "analogy."

Question: 2.1.

Interviewer: When you explain how a circuit works, which analogies do you use?

Interviewee: I normally have a cell in my class. I do not have a laboratory, so then I will just try and let them imagine how it works.

Practical work regarded as important ranges from series and parallel connections, use of ammeters and voltmeters and experiments to show Ohm's Law graphically. According to CAPS, only series and parallel connections are necessary for Grade 9. Yet again learners are taught sections of work, for example, Ohms Law, that is not part of the prescribed syllabus. It is possible that teachers are not familiar with the prescribed syllabus or are so used to teaching Ohm's Law and calculations that they are unaware that these sections are not necessary for this particular grade. All participants say they do experiments according to the class being taught in terms of time, class size, and cognitive ability or levels of the class. It appears that contextual factors have an impact on the experiments because even though all teachers feel that they are beneficial, hands-on and a visual method of teaching, they prefer to do demonstrations. They say that this is due to safety purposes, lack of resources, time saving and the type of learners in the class, although it may be that they do not know how to do these demonstrations.

The teachers' opinions of the importance of the concept of potential difference vary. All teachers believe that learners should be able to distinguish between potential difference and current. Mike points out that even though it is important to make this distinction, he doesn't think it is necessary for learners to know because they do not understand it. This can be seen in the interview:

Question: 5.6.

Interviewer: Do you think that the potential difference concept is important in teaching electricity in Grade 9?

Interviewee: I don't think so, because they don't understand it, it is difficult to explain it to them. I feel

Kate's response is particularly interesting because even though she feels potential difference is important, she explains the importance of current.

Question 5.6.

Interviewer: Do you think that the potential difference concept is important in teaching electricity in Grade 9?

Interviewee: Ya

Interviewer: Why?

Interviewee: Eeerrrmm…. Because it doesn't help if you have the content correct and give that through to them but they don't have the concept for example by visualizing or seeing a current, how a current works. It doesn't help to say you need 3 most important concepts of a circuit but you can't show them how it works.

Lee, Nick, Olivia and Peter believe that it is necessary for learners to understand the potential difference concept so that they will be prepared for future grades. It seems that they are more concerned about preparing learners for the next year than about understanding the concepts. In fact the grade 9 syllabus does not prescribe the understanding of potential difference. The curriculum prescribes measuring voltage across resistors and cells in series and parallel, but does not use the term potential difference or offer an explanation to relate it to energy. It seems that there is confusion amongst the participants about how much should be taught at Grade 9 level and to what depth. While not attempting to offer explanations about the meaning of potential difference they expect learners to do calculations involving voltage.

In terms of the syllabus and appropriate content, all teachers felt that the syllabus was not difficult for Grade 9 level and that they all taught more than was required by the syllabus though they seemed to be aware of it. All teachers felt that calculations specifically were important to be introduced in Grade 9 because learners who choose physical science in Grade 10 will have the basic understanding of calculations in electric circuits.

5.4. Comparison between the Responses from the Questionnaire, Interview and Scientific Model

Comparisons between the questionnaire and interview responses are made below. Each teacher is discussed separately to give an indication of their ideas on teaching and how these ideas are related to their awareness of misconceptions in teaching electric circuits.

Answers to the questionnaire show in many instances that the teachers do not explain why expected incorrect answers are wrong, but focus on the correct answer. This may mean that they only know the scientific model but not the misconception itself. It may also mean that a teacher also holds the misconception. The methods that they chose to correct the learners' misconceptions reveal how they represent content to their learners.

If we compare the awareness of misconceptions from the questionnaire to the ideas of teaching we can clearly see that the teachers that were aware of most misconceptions also have various teaching methods and various ideas of what should be taught. For example, Lee and Peter are well aware of what should be taught and how it should be taught and they use different methods to explain concepts and teach the content. It is important to note that although explanations are given by all the teachers, they are not all sufficient for conceptual understanding. e.g. Kate gave scientifically correct explanations though seemingly unaware of misconceptions. Also, even though Kate says she will do practical work, it is not certain if it is actually done.

To get a holistic understanding of each teacher's ideas of teaching and what influences these ideas, I have made a map of knowledge for each teacher. I aim to answer the research questions using these maps.

Peter:

Peter is well qualified and shows rich knowledge about electric circuits. He has a suitable B.Ed. qualification majoring in Physics, Chemistry and Mathematics. He is creative and uses various ways of teaching and explaining. The explanations given in the interview and questionnaire are long, descriptive and detailed. He shows sound SMK supporting his teaching. He seems to have a good understanding of the problems that his learners face in understanding the content.

Peter has a rigorous knowledge of the content and has suitable mechanisms to teach the topic of electricity. Peter believes that teaching content is not difficult but rather that it is the learners' attitude towards work that makes teaching difficult. He feels that his studies prepared him for the classroom and that practical work is beneficial to learners. He makes use of analogies and demonstrations to explain concepts. Peter shows excellent teaching capabilities with regard to PCK and SMK.

Peter does additional experiments, for example: Ohm's Law, to show that he finds experiments to be important and beneficial to learners. He mentions measuring current in series and parallel circuits and Ohm's Law as additional practical work. Peter teaches according to the type of learners he has in each class, accommodating different types of learning capabilities. He also mentions using different methods of teaching the same concept to cater for different learners. Peter relates the work to real life situations. With regard to practical work, he explains how certain learners are more "hands on" than others and how he accommodates for their different learning styles. This can be seen in his response to practical work and demonstration:

Question 3.4.

Interviewer: Do you sometimes prefer to demonstrate something rather than to have the students do practical work themselves?

Interviewee: I, it depends, I sometimes prefer them to do the practical and later then we try to explain the results of whatever they have been doing, or it's either way. It depends on the class as well. Because sometimes you get a not so hands on class and such that you will find that they will take forever to do an experiment, so it's better if you explain a concept and they would know what kind of experiment to do but if you find hands on okes then you can actually tell them what to do and then they will do it and then you will discuss the results later and then explain the entire concept

Peter is the only participant that finds textbooks to be confusing. He mentions that there is a textbook that is in fact good but has many terminology errors and would have been better if it was properly edited. To overcome this, Peter sets his own set of notes, showing confidence in the content and initiative of avoiding misconceptions. Peter follows a sequence of learning to avoid "disjointed segments of learning". He believes that learners build on conceptual knowledge and create understanding as they go on. He explains the importance of calculations and that they should be introduced, but at a very basic level.

Peter introduces the topic of electricity by using an analogy involving toll gates and ATM's which he seems to regard very effective because his explanation is very descriptive:

Question: 1.4.

Interviewer: How do you usually start the topic of electricity?

Interviewee: Well usually I'd start by using an analogy using an ATM for cells and I'd represent different components, the wire, the highway, the vehicles would represent the charge, and the toll gates or e-tolls would represent the resistors and the money that you have to pay would represent the energy *and and that way, it would make some sort of sense to them how the circuit actually works*

His response to most of the questions thereafter in his interview are in reference to this analogy. He is explicit in emphasising how the components of a circuit can be visualised as the components in the analogy. He is clear as to how each component in the circuit and in the analogy work together to produce electricity. He is able to integrate concepts well and teach for conceptual understanding, focusing on the process and not the product of the content.

Peter shows metacognition and excellent PCK, for example; thinking about a possible reason for the misconception in question 2 of the questionnaire. He explains the confusion that learners have between potential difference and current as follows:

> *I think they'd probably confuse the potential difference across the bulb with the current. They'd think that as potential energy decreases across the bulb, so would the ability of charges to move from one point to the other.*

Peter is the only participant who feels that language is not a problem in learning. He refers to his own experience in this regard:

Question: 4.2.

Interviewer: Do you feel that the language barrier causes any misunderstandings?

Interviewee: I'm not too sure, I'm not too sure because I'm a second language English speaking person and teaching to mostly firstly language English speaking boys so I don't really think that language is as such a problem to me and I hope not to them because I've never had a complaint about it and yeah I don't think language is such a problem

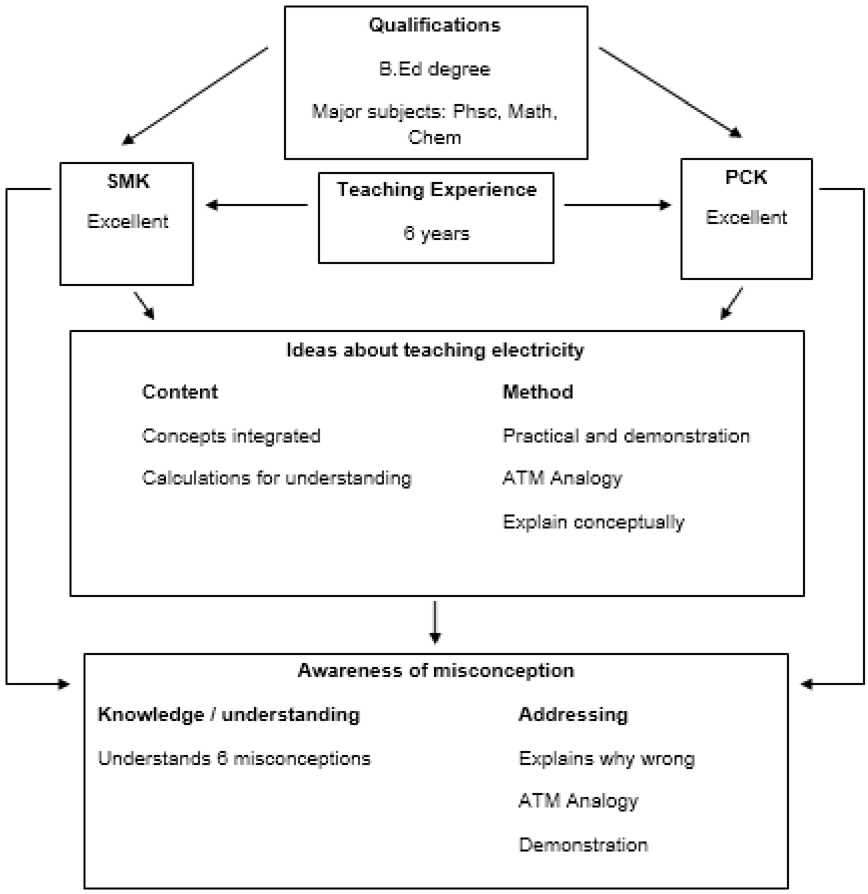


Figure 5.1: Knowledge Map of Peter

From Peter's knowledge map, shown in figure 5.1, we can see that his qualifications contribute to his excellent SMK and PCK. This influences his ideas of teaching and his awareness of misconceptions. His sound knowledge of the content and sufficient experience gives rise to various teaching methods. Peter is able to explain conceptually and integrate concepts while making use of various teaching methods focusing on the process rather than the product. Peter is aware of most misconceptions, understanding how learners think and giving comprehensive explanations aiming to correct mistakes. He gives detailed and lengthy explanations confirming sound SMK and PCK. He has knowledge and understanding of most of the misconceptions and he uses rich explanations to address and correct the misconceptions. He is able to explain the scientific model and correct misconceptions using analogies and demonstrations.

Lee:

Lee has a Doctorate in Science which suggests that his knowledge of science is very rich, but he has no education qualifications. He has depth in SMK, however his PCK has been developed due to class experience. Lee is aware that his PCK may be inadequate, as shown by the following remark: *"for me to understand there is no problem but I must explain it to them."*

He is aware of most misconceptions. Lee adapts his teaching according to the learners' needs, taking into account the knowledge that learners come with, and their backgrounds. These are all key factors in affective teaching and PCK. Lee is aware of the learners' background and therefore he uses limited explanations and he tries to use real life situations. For example, in question 6.6 Lee does in fact know what a short circuit is, but he says that it is difficult to explain to the learners properly. He therefore prefers to avoid it and assume they will not understand:

Question: 6.6.

Interviewer: How do you explain to learners what a short circuit is?

Interviewee: You must always think about their background and then explain to them, sometimes we have failure of light in this room and I explain to them that that can be due to a short circuit in other words there is a break in the line, causing an open circuit because it is difficult to explain to them that somebody maybe connected live to neutral together or something so I would just say we have an open circuit

Lee's studies prepared him to teach the content, but not how to teach. Lee speaks of lots of practical demonstrations but class size and time plays a role in the number of demonstrations. Lee talks of analogies in the interview when asked explicitly, but never uses it in any explanation in the rest of the interview and questionnaire. This can be seen in the following quote:

Question: 2.1.

Interviewer: When you explain how a circuit works, which analogies do you use?

Interviewee: The flowing of water in the pipe for example

Interviewer: Do you use only one analogy?

Interviewee: uhm, no I use one than one it depends in the situation it depends on the problem.

Interviewer: Which analogy works best for which concept?

Interviewee: For which concept? I will say the flow in the pipe for electron flow and then resistance is due to the flow of water in the pipe

Lee follows his “own” syllabus, to make the teaching and learning suitable for his learners. Lee believes that calculations are important in Grade 9 because the learners need to be exposed to it, however, these calculations need to be basic because their knowledge of mathematics has not yet been developed to that level. Lee makes reference to calculations in the interview a few times. He finds it to be very important for learners to understand the basic calculations of adding up resistance and then calculating current and voltage. He uses calculations in his teaching to explain concepts to the learners. Lee teaches the concept of Ohm’s Law even though it is not part of the syllabus. In question 6.4, Lee’s answers clearly show how he uses mathematics to aid explanation. He actually uses Ohm’s Law to explain mathematically, even though Ohm’s Law is not part of the syllabus. This shows that he has a strong algebraic approach:

Question: 6.4.

Interviewer: a) How do you explain that adding light bulbs in series decreases the brightness?

Interviewee: Because each one of those ones, alright I’ll explain each one of those has a certain resistance and if you add up each once resistance the resistance becomes more and if go then to ohms law you see it well

Interviewer: b) How do you explain that adding light bulbs in parallel does not affect the brightness?

Interviewee: After I demonstrate the fact, then I will say to them the only way to explain to them properly is to do it mathematically after I’ve demonstrated it and then show them that actually your resistance goes down

In question 3, Lee also mentions that the confusion lies in the direction of the current but does not mention the misconception of the clashing current model. He is aware that there is confusion and gives a good explanation to help correct it. He also thinks that the concept of a short circuit is too advanced for Grade 9. He believes that learners will not grasp the concept and he concurs with this in his interview by explaining that he takes into consideration the background of the learner and explains the concept as a real life situation, but very briefly. Lee explains parallel circuits and involves resistance, not just current. He offers rich explanations that voltage “adds up” but not in parallel circuits. He is aware of the parallel circuit misconception but his explanation is not clear as to why learners have this misconception.

Lee says that he does not teach any additional topics in electricity but his explanations include aspects of Ohm’s Law and calculations that are not in the prescribed syllabus. He does however explain that he follows his own syllabus as long as he has covered what is in the prescribed syllabus.

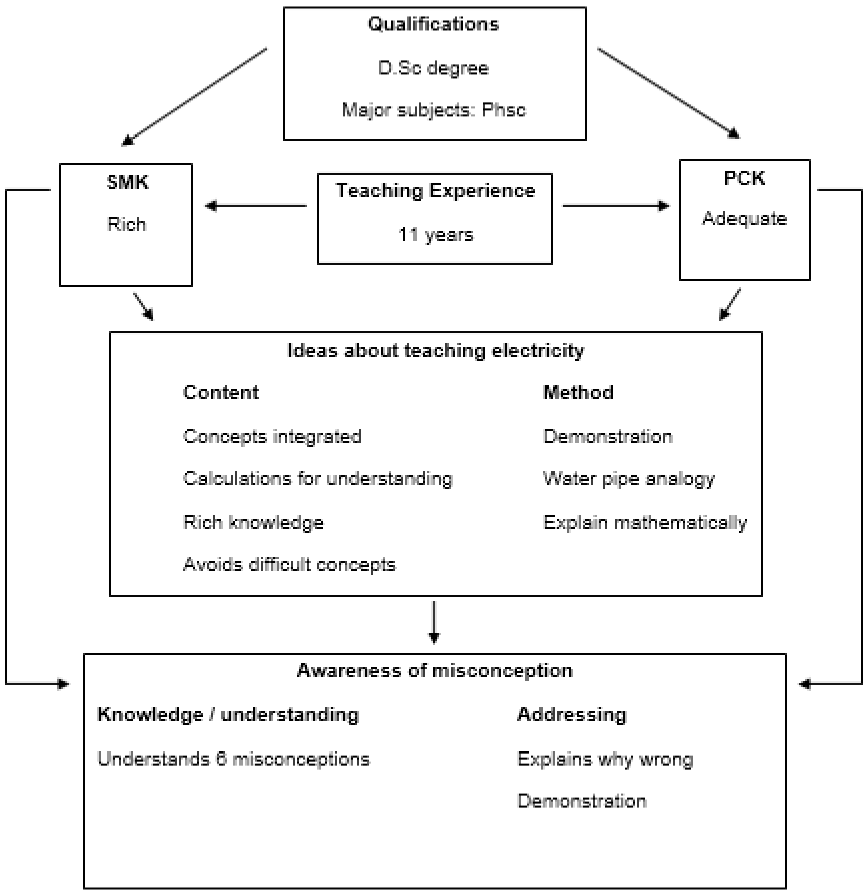


Figure 5.2: Knowledge Map of Lee

Through his several years of teaching experience, Lee is well aware of the misconceptions and has a great deal of understanding of how learners think. Prior to his involvement in science education, Lee did work in a different field. His ideas of teaching show various different strategies and awareness of learning styles even though he has no education qualifications. He makes frequent use of demonstrations combined with explanations focused on the learners' ideas. Even though he thinks practical work is beneficial, he finds class sizes to be a limitation. He makes use of the water pipe analogy whilst teaching to explain electron flow. Lee constantly mentions the background that the learners come from and how he tries to explain concepts using everyday examples that they are familiar with. This links to the domain map by Hill et al. (2008), where KCS is a key factor in PCK. His explanations are sufficient and take into consideration the background that the learners come from. This is a major contribution to their understanding. He teaches additional topics of Ohm's Law and calculations as part of his explanation of concepts.

Lee's map (see figure 5.2.) demonstrates rich SMK and adequate PCK which enables him to teach integrated concepts. Lee can be described as "mathematical scientist" because he demonstrates practically and explains mathematically, but not conceptually. His ideas of teaching electricity are practical and mathematical. He has the ability to integrate concepts because of adequate SMK and PCK, which he has gained through experience, but difficult concepts are avoided. Lee has understanding of most misconceptions but does not address it on a conceptual level because he thinks that learners would not understand.

Mike:

Mike has a Master's degree in Science and he does teach to cater to the learners in his class, taking into consideration their backgrounds and the knowledge they bring with them to class. Mike's SMK and PCK are sufficient because his studies have covered the content and his years of experience have developed his PCK. Mike is confident, well qualified and seems to have good knowledge of the content; however he does not answer how he will explain the concepts around the underlying misconceptions very clearly. Mike believes that his studies prepared him for the classroom and that the language barrier causes confusion for learners. Mike mentions that the prescribed syllabus is not difficult but, "*challenging for them to understand*".

Mike does not mention practical work in response to the interview questions or in the questionnaire regarding how the concepts are explained. Mike does talk about practical work as being beneficial and hands-on, especially about Ohm's Law, but due to lack of time and equipment, he says he demonstrates it. Mike uses the blood circulation analogy and feels that calculations are necessary; however, does not mention using this to explain the concepts. He regards the visual impact of the brightness of bulbs as important in concept formation:

Question: 5.2.

Interviewer: Do you think it is sufficient to observe brightness of bulbs to understand circuits, or do you think that measurements of current and potential difference are important for Grade 9 learners?

Interviewee: I think the brightness of bulbs is for me, better than using measurements potential difference and current

Interviewer: Why do you think so?

Interviewee: I think so because when they see that let's say you have one cell in a circuit and then you add another one and the bulb, it glows brighter in a series circuit for instance. And you do a similar example with the cells now in parallel and there is no change in the brightness of the bulb, then they see it and it starts sticking to their memory better than if you measure voltages and current, they don't usually understand what a voltage and current and what is the difference, but when they see the brightness increase, they understand better.

Mike emphasises that learners need to distinguish between voltage and current yet they do not understand what voltage is. He explains resistance as "barriers" showing that he understands that they are hindrances to the flow or charge and are not consuming the charge. It seems that Mike regards observations to be more important and effective than explanations. It can be seen here that he understands the current consumption misconception and has found a way to prevent it. He also shows awareness of the difficulty that his learners have in grasping the concepts of parallel cells, as shown by the following answer:

Question: 1.6.

Interviewer: Are there any specific concepts that your learners find difficult to understand in electricity?

Interviewee: Ya, they are challenges with the, if cells are in series, their voltages are put together, therefore makes the bulb brighter, but if they are in parallel their voltages are not put together to make the bulbs brighter. They have difficulties in understanding that.

Mike contradicts himself in questions 5.4, 5.6 and 5.7. He says that potential difference is not an important concept to be taught, but mentions that learners should be taught parallel cells and how to distinguish between potential difference and current.

He makes use of the blood circulating analogy to explain electron flow. He does focus on Ohm's law even though it is not prescribed in the Grade 9 CAPS syllabus. He feels that learners find it challenging to understand concepts and that they understand better when they see numerical values. He teaches calculations and does not believe that learners need to have a conceptual understanding of potential difference because it is too complex for them. This can be seen in his response below:

Question: 5.5.

Interviewer: Do you think that Grade 9 learners should do calculations in electricity?

Interviewee: yes

Interviewer: Why?

Interviewee: If you just tell them current, voltage and brightness and parallel and series they should see the calculation part of it, to be able to see that if you are talking about cells in series and the voltages increases to make the bulb brighter they should see it in numbers.

Mike seems to have a sound knowledge of misconceptions and the scientific knowledge. His explanations do correspond with his interview answers although they are not always clear. In question 4, the empirical rule misconception was tested and Mike chose option D. This suggests that he is not aware of the misconception but he does have knowledge of the scientific model and gives a fair explanation.

Mike is the only teacher who mentions using computer simulations as part of his teaching methods. When asked how he would explain a short circuit in the questionnaire, Mike explains:

"A short circuit is when the, when the circuit is bridged and what I do is I normally use a computer simulation to show them. I connect the circuit for them to see then I just pull one side and connected it to another and the bulb blows up and they can see that it's a short circuit"

This shows Mike's awareness of new teaching methods and how they can be beneficial if used together with practical work or demonstration.

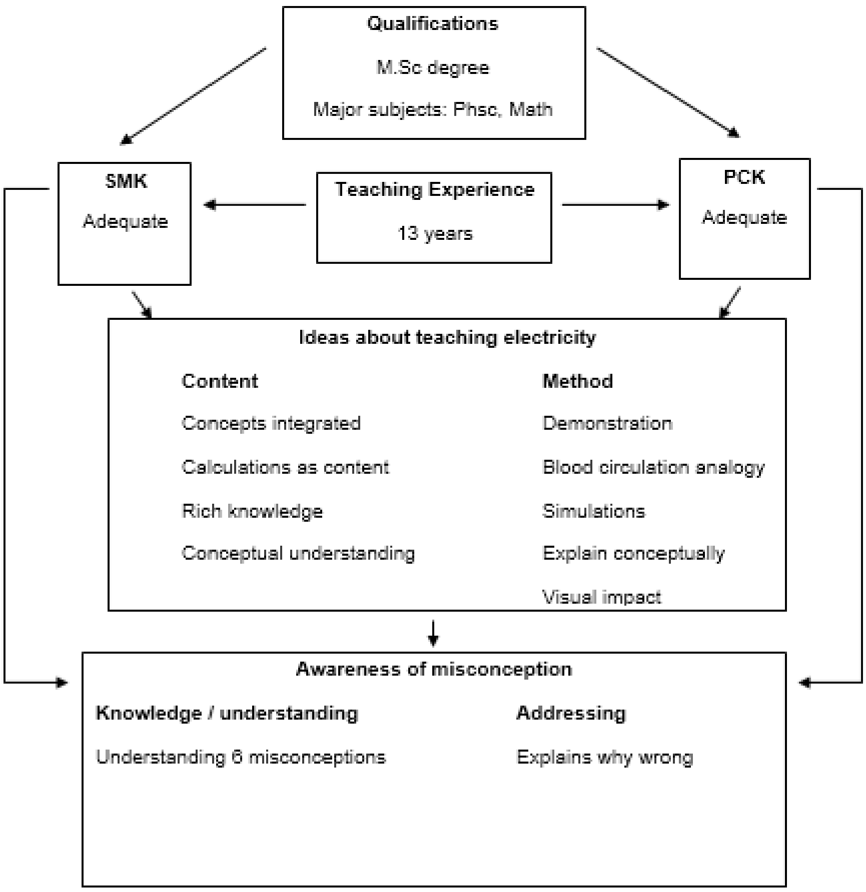


Figure 5.3: Knowledge Map of Mike

Mike does practical demonstrations to cover the syllabus because he feels that there is not enough time for group activities and he says that they lack the equipment to do it. He follows the syllabus as a guideline to teaching. Mike demonstrates sufficient knowledge in all aspects, but he regards his learners as limited by their background.

He does mention the use of computer simulations to show learners certain aspects within the topic. Mike does mention that the language barrier does play a major role in the understanding of the content. Learners battle to understand terminology and create conceptual understanding. The context of the school influences the teaching methods and the background of the learners limits their understanding. To overcome the possibility of misconceptions, he uses a variety of teaching methods. He uses practical demonstrations, computer simulations, calculations, analogies and explanations to teach his learners. This reflects in his awareness of misconceptions amongst his learners.

From Mike's map, shown in figure 5.3, we can see that he has adequate PCK and rich SMK. His ideas of teaching electricity are of a conceptual nature whereby he aims to create understanding and integrate concepts. He has sufficient teaching experience from which he has developed a range of different teaching methods to teach different concepts. His explanations are rich and he shows awareness and understanding of misconceptions, and his explanations are sufficient in correcting and addressing misconceptions.

Nick:

Nick's qualifications are sufficient for teaching Physical Science because a BSc (Hons) degree in chemistry does include undergraduate modules in physics. He seems well qualified, academically (SMK) and professionally (PCK), but still feels poorly prepared. He mentions having no problems with content except for "maybe the geography component" of Natural Science. It seems his unpreparedness refers to dealing with learners themselves.

Nick follows the syllabus as prescribed by the department because he feels it is necessary if the students are going to write the district or provincial exam. Nick finds it difficult to explain to the learners content that he understands, "you can't see why the pupil can't understand something that is clear to you".

Nick explains Grade 9 as the stage when the learners learn the basics of electricity. He teaches calculations even though this is not part of the syllabus. "*if you do not teach calculations when they get to grade 10 they don't know how to calculate these things. They didn't have the basic education on how to look at these sums or these* *questions"*. Nick does not mention using calculations in any of his explanations, but rather analogies.

Nick finds it difficult to explain concepts with regard to energy and resistance, and to do calculations. Nick does experiments according to the class and finds them to be "hands on" and beneficial. He seems to have a sound understanding of the concepts and has found ways to explain it to the learners. Nick uses many analogies (Tunnel, water pipes, lorries, trucks, rubber bands) to teach concepts and seems to cover sufficient content to avoid misconceptions. Nick believes that the language barrier causes confusion of concepts in learners.

In question 3 of the questionnaire he ascribes wrong answers to learners not paying attention to arrows, rather than an incorrect understanding or misconception.

Nick talks of difficulties in calculations and understanding of formulas, which is not part of the Grade 9 syllabus. He claims to follow the syllabus. He adds to the syllabus and justifies that he regards calculation as a basic skill needed in Grade 10. This is again revealed in question 5.2 where he again mentions measurements needed to be done for higher grades:

Question:5.2.

Interviewer: Do you think it is sufficient to observe brightness of bulbs to understand circuits, or do you think that measurements of current and potential difference are important for Grade 9 learners?

Interviewee: In a way it is sufficient to look at the brightness of bulbs, but to prepare them for further, a further studies in science you must go to the measurements

Nick seems to understand most of the misconceptions. This could be as a result of his number of years of experience. He gives very detailed answers in both the questionnaire and interview to explicitly show his knowledge and understanding of the scientific model and how he teaches these aspects to his learners. He seems to emphasize conceptual understanding in all his explanations and does not merely state the scientific model.

An interesting aspect that Nick mentions is that he does experiments according to the cognitive ability of the class. This is an indication of the knowledge of the student and content and teaching as emphasised by Hill et al. (2008). Nick says he prefers to do practical work in the form of a demonstration and mentions that it is dependent on the way in which "the class handles itself". This is indicative of possible behaviour or discipline problems that may affect the ability to teach effectively.

Nick mentions that the language barrier is a problem in conceptual understanding because the learners do not always have a vocabulary of scientific words in their language so there is no way of explaining it to them. This was also found by Tallant (1993) in the literature. It is important to note that Nick talks of incorrect terminology, but he uses casual terminology in his questionnaire when explaining how energy is transferred to the circuit, he says it is "lost". When saying lost it may be misunderstood by the learners. It is casual language to refer to energy as being "lost" meaning transferred to another form.

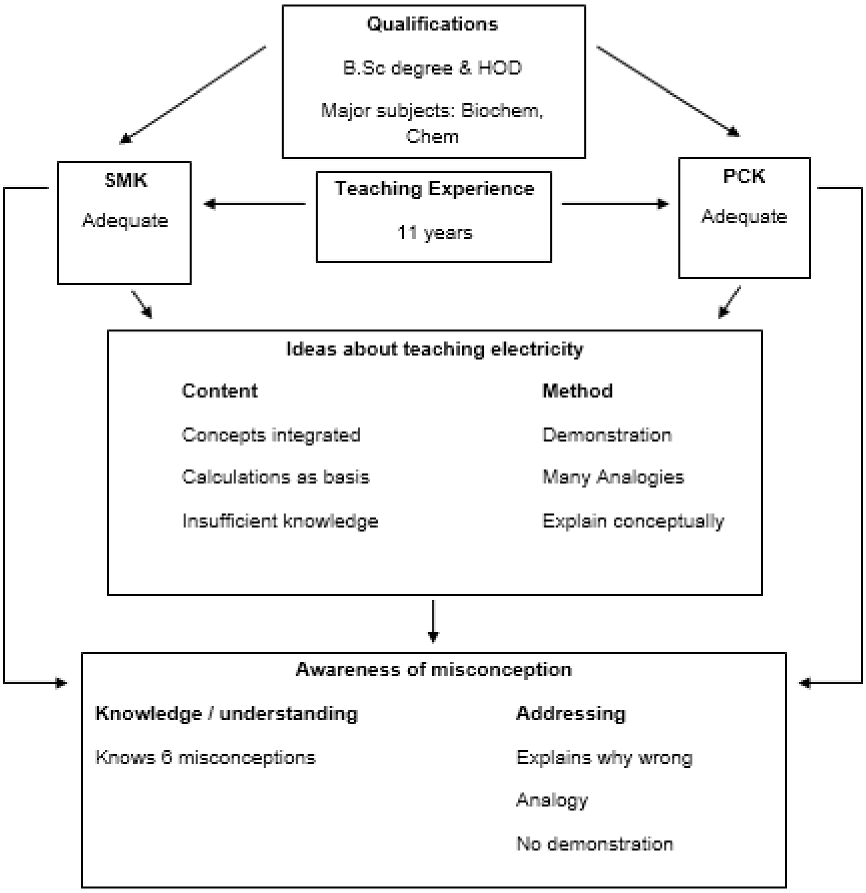


Figure 5.4: Knowledge Map of Nick

Nick shows efforts of using different teaching strategies to accommodate the learners that he teaches. He shows experience and fair knowledge of the content and syllabus. What he says he will do in the questionnaire is not always in agreement with what he says in the interview. He mentions practical work in the questionnaire, but not in the interview. Even though he understands the importance of practical work, he demonstrates and uses analogies to teach because he finds it most suitable for the learners that he teaches. The language barrier in Nick's case is difficult for him and the learners because he uses casual language and both Nick and his learners speak a different first language whilst the medium of instruction is English.

From Nick's knowledge map, shown in figure 5.4, we can conclude that he has adequate PCK and SMK. His ideas of teaching electricity are conceptual and he makes use of various analogies. He has understanding of most misconceptions. He can integrate concepts whilst teaching and not just give factual information. Analogies and explanations are used to address misconceptions.

Olivia:

Olivia believes that her studies did not prepare her for the physical and cultural differences in the classroom, even though she studied Natural Science for her Teaching Diploma. Even though she has done certain modules in Natural Science, her content knowledge seems to be insufficient to teach or understand misconceptions that her learners have. This is evident in her response to the interview questions and the questionnaire answers. She focuses on the correct model without confronting the misconception. Olivia shows factual knowledge but a lack of understanding of the section herself. Her explanations are factual and do not link concepts to facilitate conceptual understanding. She mentions that cultural differences are a problem in teaching, but has no compensation or ideas of misconceptions. She knows five misconceptions but she only understands three of these.

Olivia says she does experiments on the concepts that learners find difficult in the classroom, however, she does not mention any experiment in the explanation of concepts. She does not specify which experiments she does in class but says she discusses the expected outcome of what she would like the learners to achieve. One could say that she is aware of the outcomes but does not know how to achieve them, suggesting poor PCK. Olivia has an idea of how she thinks the learners will understand a specific concept. She claims that learners can understand by simply doing an experiment. She says that they will see the experiment and then realise "oh, this is how it works". She does not indicate that some discussion should follow to link concepts to observations to ensure that learners understand the concept after demonstration. It is possible for them to become even more confused. She speaks of practical work but limits it to demonstrations due to "time saving".

Olivia appears to be very confused about the electricity content and seems to have some misconceptions herself. These misconceptions may be taught to the learners. When probed about sequential reasoning, her answer actually reflects the empirical rule model:

Interviewer: 6.9. How do you explain that adding a resistor affects the components in front and behind in a circuit?

Interviewee: Well the components in front will receive charges and some of the energy will be lost and by the time it gets to the last let's say light bulb for example that light bulb will be dimmer because it already went through two components lost, well, not lost but some of the energy was converted leaving lesser energy for the third one

Olivia struggles to explain the work to the learners and seems to have very poor PCK. She claims to do demonstrations but does not mention any suitable explanations or questions that go with it. It seems that she lacks SMK. This is evident in question 6.2:

Interviewer: 6.2. How do you explain to a learner that the current in a series circuit stays the same throughout?

Interviewee: Because it does. I cannot explain it.

Olivia seems to avoid explaining abstract concepts such as potential difference and resistance and instead presents the scientific model factually. In question 1 it is clear from her response in her questionnaire and the response in the interview that she struggles to explain what a closed circuit is. She immediately speaks about series and parallel circuits and how they differ, but avoids the actual question. In her interview she is not able to give an answer for the meaning of conventional current and asks to come back to the question so as to give her time to think of a possible answer. The reluctance shown by this answer shows a lack of confidence and SMK. This indicates that Olivia is aware of isolated aspects of the scientific model but may not understand it clearly herself. Olivia is aware that her learners find it difficult to understand the difference in potential difference and current, but her explanation is very vague:

Question: 6.8.

Interviewer: How do you explain the difference between current and potential difference?

Interviewee: The current is the charges that flow throughout the circuit the potential difference is the amount of energy supplied to the components on a specific circuit, not necessarily the whole circuit itself, for example a light bulb and resistor, you able to get the potential difference of each…

Olivia speaks mostly of current rather than potential difference in both question 6.4b and 6.10; yet in question 6.8, she correctly explains potential difference in terms of energy transfer, however, this concept is not used in her answers to potential difference. She has factual knowledge of what potential difference is but cannot apply her understanding of it. She says she finds it difficult to explain how potential difference and current differ, yet in question 6.8 she does give a factual explanation of the difference. She shows factual knowledge but lacks understanding.

She follows the textbook as a guideline to her teaching and thinks that the “graph of potential difference versus current” is important. This is Ohm’s Law which is not part of the Grade 9 syllabus. Olivia shows a lack of conceptual understanding of circuits. In the question about a short circuit her response is completely unscientific:

Question: 6.6.

Interviewer: How do you explain to learners what a short circuit is?

Interviewee: When there is too much components and not enough energy to supply the components with, it kicks out or it shorters

Olivia shows limited use of analogies in her teaching. She also says she uses an analogy of lighting of houses and streets. This is, however, not an analogy. Her response to the type of analogies reveals that she does not create a clear image or picture for learners to understand the cause-effect relationship between potential difference and current.

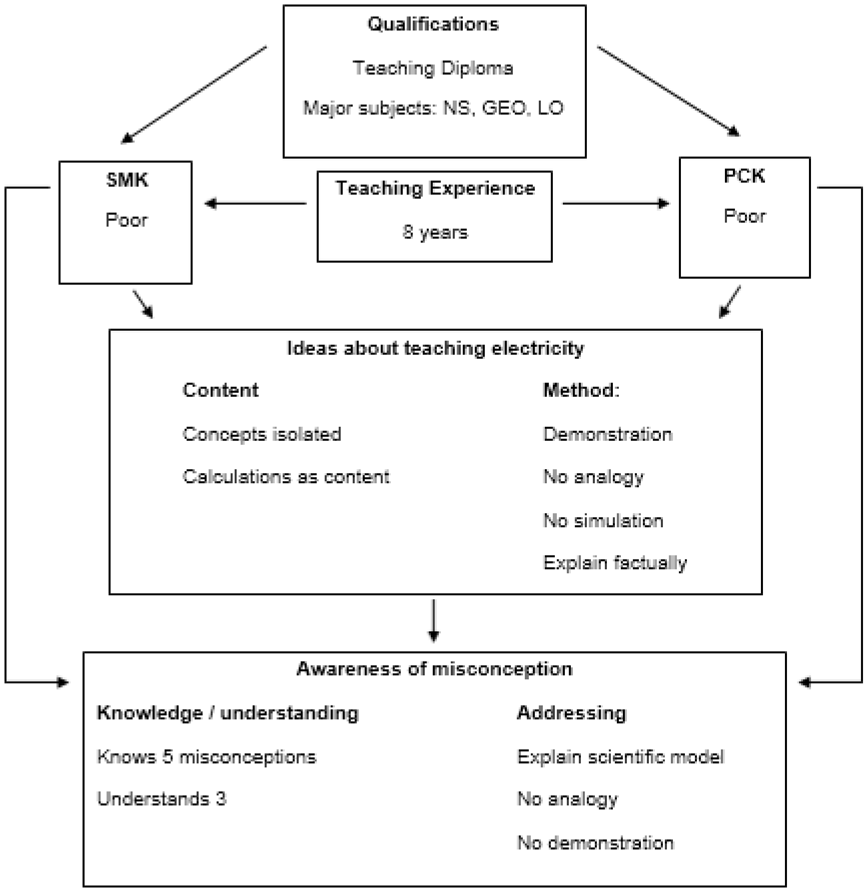


Figure 5.5: Knowledge Map of Olivia

Olivia's PCK and SMK are insufficient to teach electricity at Grade 9 level. She has poor understanding of misconceptions, so to avoid or overcome these misconceptions is not possible. She speaks of practical work but shows no evidence of it in her explanations. She finds calculations important and the graph of potential difference and current to be important. This suggests that she does teach certain aspects of Ohms Law. She is not confident in her responses and avoids answering the question when she is not sure. Olivia assumes that her learners learn in a certain way and that they as teachers are expected to achieve the desired outcome that they believe they are aiming to teach these learners.

Olivia's knowledge map (see figure 5.5.) shows that she teaches concepts in isolation. She has mostly factual knowledge and struggles to explain how the different concepts are linked. She shows poor SMK and PCK even though she does have formal training in Natural Science and Education. Her responses are vague and her teaching is focused on isolated facts and not understanding the relationships and processes.

Kate:

Kate's SMK seems to be insufficient for the topic of electricity and she does say that her studies did not prepare her for classroom practice and would have preferred to know more physical sciences, especially the chemistry aspect. Kate seems to have problems explaining the knowledge that she has to the learners and she tends to use the wrong terminology whilst teaching, which may cause misconceptions and/or confusion in her learners. During the interview, she seems to have misunderstood a question and gives an answer that reveals very poor understanding, as shown below:

Question: 6.10.

Interviewer: How do you explain that a battery produces more current when bulbs are added in parallel?

Interviewee: Because a battery consists out of two or more cells which is connected, so that's actually quite obvious. It's like a container

This answer seems to indicate that she understands the question by referring to cells in series, instead of bulbs in parallel. She makes the statement "it's actually quite obvious." One can pose the question: Is it in fact obvious to the learner? This may be an attempt to conceal her own poor understanding.

When questioned about the sequence she follows, Kate clearly is unaware of whether she follows the syllabus or the textbook. The hesitant response before answering "content" does not answer the question. She seems to have no knowledge of analogies. She describes the demonstration of a cell when questioned on which analogies she uses in class.

Kate tends to teach isolated concepts and does not seem to be able to integrate the concepts. This is why she is able to give the scientific model but struggles to explain further. This can be linked to literature by Tiberghien (2000), whereby she discusses the two domains of knowledge and practical work. Kate is not able to make the link between the domain of knowledge and the domain of practical work. Therefore, she teaches isolated concepts and her practical work is not integrated into the syllabus. Kate claims to do many practical experiments but she does not seem to be able to explain the theory behind the experiment. In the questionnaire, for most questions she suggests doing experiments without explaining. She omits any information of what experiment to do and how it is linked to the concept discussed in the question.

Her questionnaire responses reflect the scientific model factually, but offer no conceptual understanding. In question 3, we are testing the clashing current model. She chose option D, which suggests that learners are confused with the direction in which current flows. This shows that she may not be aware of the misconception of learners believing that current flows from both directions. She then explains option D by teaching the learners the symbol of a battery. This explanation is different to the one given in the interview where she gives the scientific model of current flowing from positive to negative. One can assume that she is aware of the scientific model but it is not possible to conclude whether she knows the learner misconception of the clashing currents. Nevertheless, she attempts to explain the incorrect answer that she expects from her learners.

In the interview, Kate claims that potential difference is an important concept as shown by the following quote:

In question 5.6.

Interviewer: Do you think that the potential difference concept is important in teaching electricity in Grade 9?

Interviewee: Ya

Interviewer: Why?

Interviewee: Eeerrrmm…. Because it doesn't help if you have the content correct and give that through to them but they don't have the concept for example by visualizing or seeing a current, how a current works. It doesn't help to say you need 3 most important concepts of a circuit but you can't show them how it works.

However, her answer reveals a lack of conceptual understanding. Once again she uses inappropriate terminology by referring to a current instead of a circuit showing isolated thinking about concepts. In question 10 of the questionnaire she also only talks about the current splitting, with no reference to the voltage.

In question 5 of the questionnaire we are testing the superposition model. Kate explains correctly that her learners may not realise that the arrangement of the cells changes the brightness of the bulb, although her choice, option C, is not in agreement with her explanation. Her interview and questionnaire responses are very similar in terms of explanation, however, the explanations show knowledge but do not show understanding.

In question 4, 7, 8 and 9 of the questionnaire she does not make a choice. This shows that she is unaware of the misconceptions. She also says she will do an experiment but does not say what experiment. It is possible to assume that she does not understand the misconception herself. There is inconsistency in the answers in the questionnaire and in the interview. Her education qualifications suggest general PCK but no training in science methodology, therefore her SMK is poor.

It is important to note that Kate says that she does a lot of practical work particularly in response to the questionnaire; however, under the practical section of the interview she only mentions the series and parallel connections and the usage of voltmeters and ammeters. It is questionable if these practicals are being done or are just a mere answer of what could be done. Kate says she demonstrates most practicals due to safety purposes.

Kate finds calculations to be important and thinks it should be done for those learners that take physical science in Grade 10. She believes that it will allow them to, *"have the basic background of calculations"*. It is not clear as to what the basic "background to calculations" is. She teaches calculations for the sake of doing it as content to make sure that learners "can do" them, but not to support their understanding. Kate does not mention teaching according to the background of her learners and it is possible that her poor SMK influences her motivation to support her learners, unlike the other teachers. Her teaching methods seem to be inefficient due to poor understanding of content.

If we make a comparison between Kate's responses in the questionnaire and interview, we can see that she knows few of the misconceptions. She only knows three misconceptions: the attenuation model, short circuit misconception and the parallel circuit misconception. In all three cases, it is unclear if she really understands it. She addresses misconceptions by "doing experiments" and gives factual explanations of the correct answer.

A comparison between the questionnaire answers and the interview questions show that the explanations given around each misconception are limited. Kate does not have sufficient SMK to explain further than the scientific model. In question 6 of the interview Kate is asked:

Interviewer: 6.6. How do you explain to learners what a short circuit is?

Interviewee: There I would just tell them, the 3 main eerrr… components of a circuit, energy source, conducting wires and a light bulb

This illustrates that Kate does not know what a short circuit is. She avoids answering the question, giving a vague, inadequate answer that illustrates a lack of SMK.

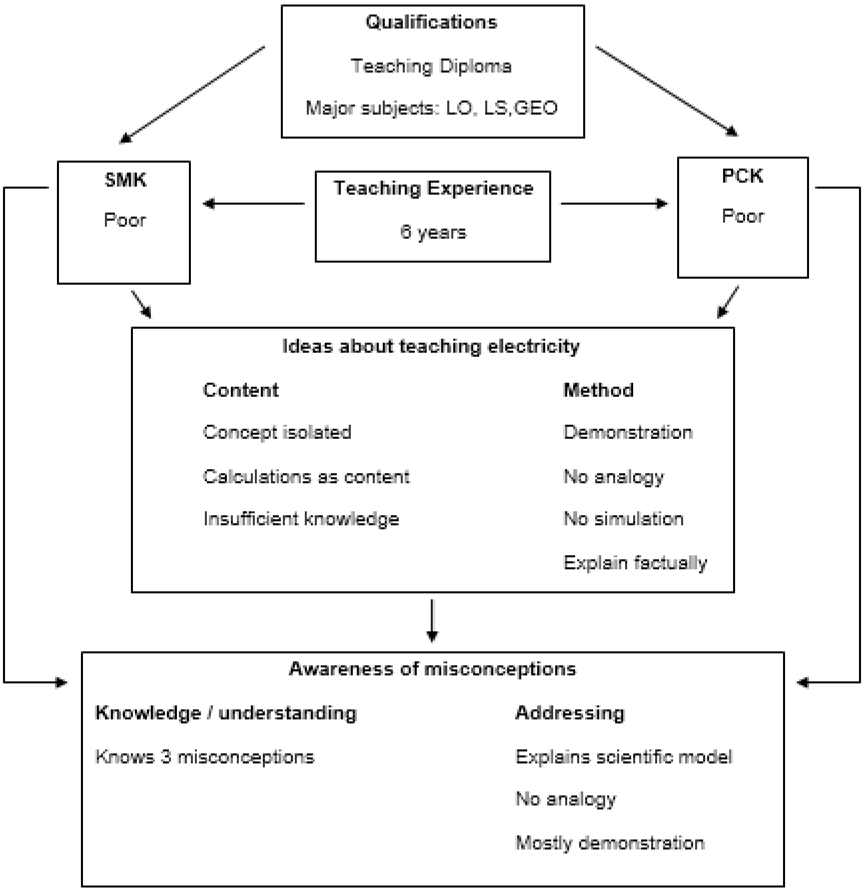


Figure 5.6: Knowledge Map of Kate

From Kate's knowledge map (see figure 5.6), we can deduce that her qualifications have a great impact on her teaching ability. Kate's qualifications are inadequate to teach the Grade 9 Natural Sciences syllabus. There is no evidence indicating knowledge in physics or chemistry. Due to inadequate qualifications, her PCK and SMK are limited. Even though she knows some of the misconceptions through experience, her poor understanding of the misconceptions influences her methods of teaching. She is therefore unable, or has not found methods, to alleviate these misconceptions. Her teaching methods show poor effort of practical and demonstration work. This contradicts her response to practical work being beneficial as she clearly states that she will "show them".

Kate's interview seems to be more trustworthy than her questionnaire, because her interview is internally consistent, but not in agreement with her questionnaire. For example there are two ideas supporting one another. She mentions demonstrations twice in the interview, but in the questionnaire she mentions practical work only once.

It is possible that she does not really involve learners in practical work, but only does demonstrations herself. Nevertheless, both instruments reveal poor SMK and PCK.

In conclusion, Kate's ideas about teaching electricity are limited to the transfer of isolated facts and demonstration of effects without regard for conceptual understanding. These ideas are reflected in her lack of understanding and addressing learners' misconceptions on a conceptual level.

5.5. Understanding of Short Circuits

Results about the misconception about short circuits is of particular value as there is a dearth of research reported on this misconception. The short circuit model has not been investigated in many studies, however, it is appealing to see the different responses from the interview.

Table 5.12: Comparison of short circuit explanation

6.6. How do you explain to the learners what a short circuit is?					
Peter: I use the parallel circuit. The parallel connection of cells in parallel, and just connect one opposite positive to an positive and I ask them for the current direction. Where does it go? And they'll tell you from a positive to negative and then another negative to positive instead of going through the external circuit and that basically a short circuit.	Lee: You must always think about their background and then explain to them, sometimes we have failure of light in this room and I explain to them that that can be due to a short circuit in other words there is a break in the line, causing an open circuit because it is difficult to explain to them that somebody maybe connected live to neutral together or something so I would just say we have an open circuit	Mike: A short circuit is when the, when the circuit is bridged and what I do is I normally use a computer simulation to show them. I connect the circuit for them to see then I just pull one side and connected it to another and the bulb blows up and they can see that it's a short circuit	Nick: That I always is when you give the current an easier way to travel, its like when you have to travel over a hill, with all the stones in it, or they make a tunnel through the hill, you will take the tunnel through the hill because it is easier the current will do the same thing so you will bypass all those other resistors in your way	Olivia: When there is too much components and not enough energy to supply the components with, it kicks out or it shorters	Kate: There I would just tell them, the 3 main eerrr… components of a circuit, energy source, conducting wires and a light bulb

All the teachers have completely different methods of explaining the concept of a short circuit. According to the scientific model, a short circuit is a path without resistance that bypasses resistors. If a battery is shorted, other devices will receive no current while the current in the wire and battery will become very large because current takes the way of least resistance. The wires will become very hot and may melt, and the battery will overheat and become exhausted. Only Nick and Mike seems to have adequate understanding of the concept. My results suggest that many teachers, themselves, in South Africa may have misconceptions regarding the short circuit. It is possible that they may propagate this misconception in their teaching.

In analysing the data, I was able to extract the key findings of this research showing the link between teachers' ideas of teaching electricity and their awareness of learner misconceptions. These findings will be discussed in detail in the next chapter.

Chapter 6.
Conclusions

This final chapter of the dissertation starts by interpreting the results of the study so as to answer the research question. Next, a revision of the model of Hill, Ball and Schilling (2008) is proposed to represent the hierarchical nature of PCK which crystallised from the results. This is followed by a discussion of the findings. Finally, the chapter is concluded by discussing limitations, implications and recommendations following from this study.

6.1. Findings from the Questionnaire and Interviews

This study explored the relationship between teachers' ideas of teaching electric circuits and their awareness of learner misconceptions. As explained in chapter 1, teachers' ideas about teaching electricity refer to the opinions, views and beliefs held by teachers about the content and method that should be used to teach the topic of electricity.Their awareness of misconceptions refers to their knowledge of typical mistakes, understanding of misconceptions leading to these mistakes, and ways of addressing misconceptions. I can now make the link between teachers' ideas of teaching and their awareness of misconceptions by drawing on the data from the questionnaire, interview and literature, and consolidating insights gained from this study by using the conceptual framework.

The data shows that these teachers' ideas about teaching electricity are linked with their awareness of misconceptions. It is not clear as to what comes first in terms of the idea or the awareness. In fact, I propose that these two constructs work cooperatively in teaching. It is not simply a cause and effect relationship, but rather a cyclical relationship, the one shaping the other. Peter, Mike, Lee and Nick are aware of most of the misconceptions and they also use a variety of teaching methods to improve learners' conceptual understanding. These teachers understand how their learners think and this contributes to their ideas about the interrelatedness of concepts. Also, addressing these misconceptions contribute to their ideas about effective teaching methods. Conversely, their ideas about content contribute to their understanding of the learners' mistakes, and their ideas about how to teach contribute to the ways to address misconceptions. These four teachers' interlinked ideas about concepts and methods are associated with adequate SMK and PCK. The other two teachers, Olivia and Kate, consider limited teaching methods such as demonstrating and presenting factual information as sufficient. Their limited ideas about how concepts are linked do not support understanding learners' mistakes. Although they know about some typical mistakes, they do not understand the misconceptions leading to these mistakes. They propose to address mistakes by doing demonstrations or by giving factual information, reinforcing their ideas that content can be transferred without offering interpretation. These ideas about isolated concepts and knowledge transmission are related to inadequate SMK and limited PCK.

In this study teachers' ideas of teaching were used as manifestation of their PCK. During the study strengths and weaknesses in their SMK were revealed. From the map constructed for each teacher, it is clear that qualifications play a vital role in their SMK. The four teachers holding university degrees demonstrated rich SMK, being able to discuss relationships between concepts. Furthermore, their awareness of misconceptions and variety of teaching methods demonstrate adequate PCK, in particular KCS, knowing how their learners think. On the other hand, the two teachers holding college diplomas in teaching demonstrated poor SMK, evidenced by factual answers about concepts and resorting to demonstrations without explanations. Such demonstrations reflect limited, generic PCK that do not aid conceptual development. PCK is strongly dependent on SMK because even with experience, teachers need to know beyond what they have to teach in order to notice misconceptions in their learners. This is evident in the number of misconceptions that teachers are aware of and how many of these misconceptions they actually understand. If they do not understand the misconception they struggle to address it.

Peter is the most capable participant in this study. He has only a few years of experience and rich SMK and PCK to teach effectively. The questionnaire data show that he has sound knowledge of the misconceptions and he understands how his learners think. He is able to explain in great detail using various teaching methods to enable all learners to understand. Peter's awareness of misconceptions may have shaped his ideas of teaching and encouraged him to use different analogies, hands on practical work and demonstrations to allow the learners to visualise the concepts. He focuses on the syllabus as a guideline and focuses on concepts rather than calculations. Peter is the only participant that does not find the language barrier to be a problem in teaching and learning, and he uses himself as an example in the interview. However, Peter teaches learners that are mostly first language English speakers, which may explain why they do not experience language problems

Lee shows rich SMK. His questionnaire responses indicate that he is able to notice a pattern of mistakes and understands how his learners learn and understand the content, which suggests adequate PCK, specifically KCS. Lee mentions more than once that many of the learners lived in poverty, and that he takes their background into consideration when explaining, for example:

> "*Not…From the children's aspect maybe because they not exposed or so much exposed as they should be and because they come from a background where maybe they do not have experience with it, so it mean that one must start with very basic and connect it with their every lives where you can....for me to understand there is no problem but I must explain it to them."*

This has shaped Lee's ideas of teaching and we can see from the map that he is aware of misconceptions, but does not bother to explain to the learners why they are incorrect. He simply believes that they will not understand and therefore omits the explanation. This is evident in his response to short circuits. He is aware of what it is but refrains from explaining it to them because his believes that they would not understand:

Interviewer: 6.6. How do you explain to learners what a short circuit is?

Interviewee: You must always think about their background and then explain to them, sometimes we have failure of light in this room and I explain to them that that can be due to a short circuit in other words there is a break in the line, causing an open circuit because it is difficult to explain to them that somebody maybe connected live to neutral together or something so I would just say we have an open circuit

I can conclude that Lee has excellent SMK and very good PCK, but his ideas about contextual factors limit his teaching. Chui (2005) emphasises how learners can have different understandings of the truth and how they make sense of concepts. Lee believes his learners understand the concepts around electric circuits differently because they have different backgrounds and therefore he adjusts his teaching. However, his ideas are not beneficial to the learners as he teaches incorrect concepts when he thinks it is too difficult for them to understand.

Mike’s interview shows sufficient SMK and PCK. His map indicates that though he does not have training in education, his SMK together with his experience in teaching enables him to convey the content knowledge to the learners using various strategies. This indicates that his PCK developed from his teaching experience. Mike mentions showing learners computer simulations to teach certain concepts because they can see what he is trying to explain to them. He also mentions the background of learners and the language barrier that learners have when trying to create conceptual understanding. His ideas of teaching are also shaped by the learners he teaches, their backgrounds and the contextual factors such as class size and lack of resources. He has found methods or teaching strategies to work around this such as his computer simulations. He uses computer simulations together with explanations to help learners construct knowledge. He is aware of the misconceptions that his learners make and gives sufficient explanations to elucidate them.

Nick’s training ensured sufficient SMK and PCK. He gives detailed explanations to all the questionnaire and interview questions. Nick has a sound knowledge of the content and the syllabus and has many years of teaching experience. Nick uses various analogies to explain concepts in order to give learners an idea of what he is trying to explain. Nick is aware of the misconceptions that his learners have and he tries to adapt his teaching methods to relate the work in such a way that the learners will grasp the concepts and understand what he is trying to teach. Nick is aware of various possible reasons as to why his learners could be confused and this is evident in his questionnaire responses. He has sound knowledge of the scientific model and emphasises it in his explanations. He gives very detailed and descriptive answers in the interview and questionnaire, but in one case he used an analogy incorrectly. This is aimed at creating a picture in the learners’ minds as to what is actually happening. This is a clear indication of how his ideas of teaching have been shaped by his awareness of misconceptions

Although Olivia studied Natural Science for her teaching diploma, she demonstrates poor SMK and PCK and this is evident in her questionnaire and her response to the interview questions. The map created for Olivia shows that her lack of SMK and her inability to convey the knowledge to the learners in a manner that they will understand has influenced her ideas of teaching electric circuits. Olivia knows typical mistakes, but in most cases she is unaware of the misconceptions leading to these mistakes; this shows poor KCS. Even though she has knowledge of the scientific model, she cannot explain how concepts are related. Her brief responses and hesitant responses show lack of confidence within the section. Olivia is the only participant that mentions using a graph to explain the relationship between current and potential difference even though it is not included in the grade 9 syllabus. This shows that she also has a poor knowledge of the syllabus. Olivia's limited knowledge is reflected in poor awareness of misconceptions and fragmented ideas of teaching. She mentions the importance of practical work and contextual factors, but these ideas are not useful if not supported by SMK. She follows the textbook rather than the syllabus, therefore teaching learners inappropriate content for that specific grade and omitting important and necessary conceptual understanding.

Kate shows a lack of SMK in that her claims of what is important to teach and her responses to various questions in the interview and the questionnaire are vague and show poor explanation. This is evident in the responses that she gives in the analysis of the questionnaire, which emphasises the link between ideas of teaching and awareness of misconceptions. Her ideas of teaching influence the way in which she interprets how her learners think, and therefore shows that she does not notice the misconceptions because she has poor SMK and does not reflect on her learners mistakes. She does not understand that mistakes are not random, but are based on a pattern of incorrect reasoning or understanding. Drawing from the analysis of the interview, the map shows a clear indication that SMK is missing and this influences her ideas on teaching. She teaches the scientific model in a factual way, without linking concepts. We can conclude that she assumes that knowledge can be transmitted without explanation; in fact she remarked that certain things are "obvious", revealing fragmented ideas about teaching the topic of electricity. Kate seems to prefer demonstrating rather than explaining. This is in agreement with McNeil (1983), who states that demonstrations are used as "defensive teaching". When teachers do not understand the topic themselves, they sometimes use demonstrations without explanation to teach the concepts. This shows a lack of SMK, and fragmented PCK.

When discussing ideas about what content is suitable to teach in Grade 9 electricity, all the teachers believed that calculations of resistance and Ohm's Law should be taught, even though it is not part of the syllabus. This is a clear indication of emphasising calculations and leaving out conceptual understanding as found by Anderson and Mitchener (1979) and Mulhall (2001), and seems to be a prominent problem in science teaching. In some cases, it is possible that they avoid teaching conceptually by focusing on calculations because they may not fully understand the concepts themselves. Lee seems to think in terms of mathematics rather than in words. He often uses a mathematical approach, explaining concepts in terms of values and calculations. This was evident in his answers from the questionnaire whereby he assigned values to the ammeters and voltmeters prior to explaining the misconception, rather than explaining conceptually.

All the teachers regard practical work as beneficial, yet they tend to shy away from it due to large class sizes, safety reasons and discipline, as explained by Lee, Nick, and Mike. Even though Olivia and Kate mention the use of practical work several times, it is not evident as to whether these practical's are actually done in reality. It is questionable as to whether the outcome of the practical is successfully achieved.

Teachers sometimes use incorrect terminology whilst explaining concepts and this may lead to poor understanding and may contribute to misconceptions. This may have been influenced by all participants being second language English speakers teaching in English medium schools. This was not a sample selection criterion, but rather a consequence of South Africa being a multilingual country. Nick, for example, speaks of energy "lost". Olivia explains the importance of potential difference and is able to define it showing factual knowledge but struggles to express her understanding of it, because she constantly makes reference to current. This indicates isolation of concepts and poor SMK leading to ineffective PCK.

A common error expected by all the teachers relates to the direction of current, however, it was clear that the teachers do not have knowledge of the Clashing Current Model but have experience of learners' incorrect ideas about current direction. This mistake is not regarded as a misconception as current direction is a convention rather than a concept. .

The data received on the awareness of the Short Circuit Model is of particular interest because it seems that only one participant out of the six could express his understanding of the misconception and how it could be corrected. This misconception, as found in the literature, has not been researched in great detail and could serve as valuable research for the future.

Having looked at all the participants in the study, I can conclude that the ideas about teaching do in fact shape teachers' awareness of misconceptions, and that the awareness of misconceptions contribute to their ideas about teaching the topic. Furthermore, teachers' ideas as well as awareness about misconceptions are founded primarily by their own SMK.

6.2. A Hierarchical Model of PCK

Teachers' awareness of misconceptions is part of their PCK, specifically KCS and KCT. The foundation aspect, which is of importance, is that of content knowledge which is SMK. One method of understanding how teachers develop PCK is by creating a step by step link of different types of knowledge as it is constructed by teachers. The teacher needs to understand the cognitive and academic levels of the learners to teach accordingly. The teacher should have KCS to support the development of KCT. It is imperative for a teacher to understand the context in which his/her learners are found, in order to choose the most suitable teaching strategies and methods. Furthermore, a teacher should be aware of the content that needs to be taught, relevant study material and resources that are available, which is KC. The teacher needs to understand students and their individual needs with regard to learning specific content and have knowledge about misconceptions. This is different for all learners and it is necessary to teach in a manner that the learner will understand. The final knowledge level to develop is the KCT - the actual knowledge about teaching the content which includes how to address specific misconceptions. Whilst these knowledge's develop as a hierarchy, there is a cyclic relationship between all knowledge implying that all of these aspects of PCK grow together to enable teaching and learning.

From the results of my study, I propose to adapt the PCK model of Hill, Ball and Shilling, to show the hierarchy and layered structure of teacher knowledge. The new model is simpler than the hierarchical model proposed earlier by Veal and MaKinster (1999). It may seem that the Hill, Ball and Schilling PCK model in Figure 3.1, is simplistic because it does not emphasise the importance of hierarchy of how knowledge types develop. The pyramid shown in figure 6 represents the development of knowledge hierarchy of PCK that enables teachers to teach. The knowledge that teachers have about content and teaching (KCT) is supported by their knowledge and understanding of the subject (SMK), their understanding and knowledge of the curriculum (KC) and their understanding and knowledge of the student (KCS). When a teacher has poor SMK, inadequate KC and KCS develops, which ultimately results in poor KCT.

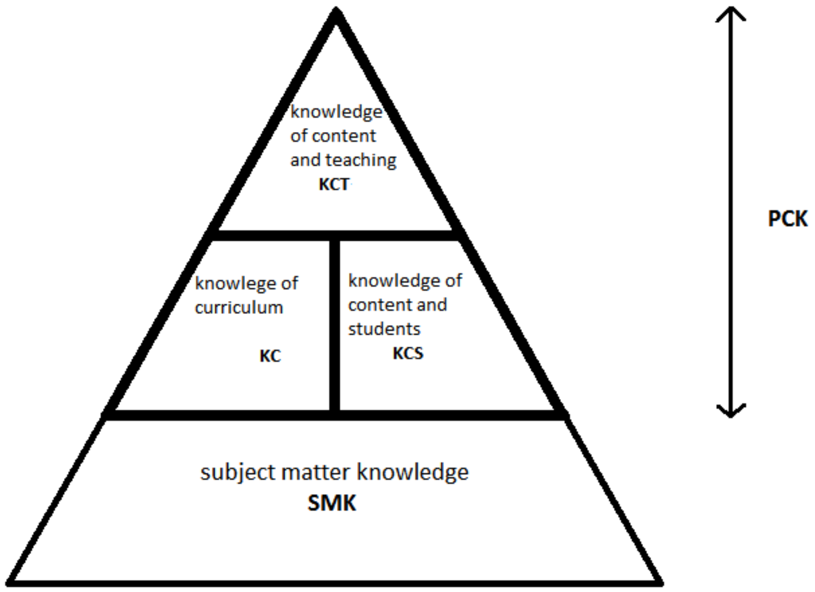


Figure 6. A new hierarchical model of PCK

Effective teaching cannot exist as isolated skills and fragmented concepts. Using the PCK pyramid we can see that Lee, Mike, Nick and Peter have good SMK supporting their PCK. Now we understand why they have better PCK, because it is based on strong SMK. This leads to good understanding of the syllabus and how their learners understand concepts. Mike and Peter both mention how they teach according to the learners that are in their class adapting the lessons for them to grasp the concepts. They are therefore able to then notice misconceptions more easily and find ways of overcoming them. Kate and Olivia have very poor SMK and struggle to teach the learners even if they use demonstrations, because they have not acquired sufficient

SMK in their qualifications to explain concepts further than presenting the scientific model factually.

6.3. Revisiting the Research Questions

From this study, I found that the teachers' ideas about teaching electricity and their awareness of misconceptions are highly dependent on both their PCK and SMK. Even when teachers have knowledge of misconceptions, they are not able to help their learners overcome these misconceptions if they do not understand learners' thinking. It is possible that time, contextual factors and the background of learners play a role in this, but it is poor SMK that allows the continuation of learners' misunderstandings.

In answering my research questions I can conclude that teachers' ideas of teaching electricity and their awareness of learners' misconceptions are interdependent, each shaping the other. Their ideas of aspects that are regarded as important contribute to the content they teach to their learners and the understanding they expect the learners to develop. The relationship between their ideas and their awareness of misconceptions develop through experience and knowledge of the content and student (KCS), knowledge of the curriculum (KC), and knowledge of the content and teaching (KCT). The basis of this knowledge is SMK which is based on having the appropriate qualifications. Due to the lack of SMK, some teachers do not view conceptual understanding as essential and instead focus on the scientific model, calculations and demonstrations. Teachers who have sufficient SMK are more aware of their learners' misconceptions because they have rich understanding of the concepts and are able to use various methods and teaching strategies to overcome and avoid these misconceptions. Teachers who lack SMK tend to be less aware and unable to explain or rectify misconceptions that their learners have. They avoid explaining conceptually and teach the scientific model without having a clear understanding themselves. The new hierarchical PCK model emphasises the dependence of PCK on SMK. This model explains how teachers' ideas of what should be taught and how it should be taught influences their awareness of learner misconceptions. The better SMK and PCK that a teacher has, and the more aware they become of their learner misconceptions, the more their ideas about electricity develop towards well integrated concepts and effective teaching.

6.4. Limitations, Implications and Recommendations

Being a teacher myself, time was a limitation to this research. Due to my own teaching duties, I was unable to do class visits to check if the teachers actually did what they said they would in class. However, the study was designed to avoid this problem by making use of two data collection strategies to enhance trustworthiness. Furthermore, being a case study, results cannot be generalized to other teachers and other countries.

With all instruments there are limitations. As discussed in chapter 4, the design of the questionnaire may place a limitation on the study. However, it was argued that there is no logical reason for the teacher to choose any other arbitrary wrong answer. Furthermore, the interview results support the questionnaire data. Therefore, I argue that the limitation of the questionnaire design did not influence the results of this study.

In this study I have concluded that SMK is a prerequisite for effective PCK. In South Africa, policy documents such as the RNCS and CAPS provide knowledge of the curriculum to improve the quality of PCK in classrooms. Furthermore, teachers' personal and professional development is assessed by an Integrated Quality Management System (IQMS). However, the effectiveness of these measures are not guaranteed, while many science teachers lack SMK resulting from inadequate initial teacher training.

Finally, I recommend that scientific content knowledge should be addressed thoroughly in initial teacher training programs to enable teachers to understand misconceptions and being able to address it at a conceptual level. Another recommendation from the research is that misconceptions should be explicitly addressed in teacher training programmes. This may develop both SMK and PCK in a mutually supporting way.

7. Reference List:

Abrahams, I., & Millar, R. (2008). Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science. *International Journal of Science Education 20*(14) p. 1945-1969.

Adams, P. E., & Krockover, G. H. (1997). Concerns and perceptions of beginning secondary science and mathematics teachers. *Science Education. 81(1),* 29-50.

Allan, Isaacs. (2000). A Dictionary of Physics. Oxford University Press.

Ameh, C., & Gunstone, R. (1985). Teachers' concepts in science. *Research in Science Education*, *15*, 151–157.

Anamuah-Mensah, J., Otuka, J. O. E., & Mensah, F. (2001). Developing a remedial method of teaching electric circuits in secondary schools. *African Journal of Educational Studies in Mathematics and Science. 1*, 31-42.

Anderson, R. D., & Mitchener, C. P. (1994). Research in science teacher education. In D. L. Gabel (ed), *Handbook of research on science teaching and learning*. pp. 2-44. New York: Macmillan.

Appleton, K., & Kindt, V. (2000). How do Beginning Elementary Teachers Cope with Science: Development of Pedagogical Content Knowledge in Science. Report: ED448998.

Ausubel, D. P. (1968). *Educational psychology:* A *cognitive view.* New York: Holt, Rinehart, and Winston.

Ball, D. L. (1990a). Prospective elementary and secondary teachers' understanding of division, yoi/rna/ *for Research in Mathematics Education. 21,* 132-144.

Ball, D. L. & Bass, H. (2000). Interweaving content an pedagogy in teaching and learning to teach: Knowing and using mathematics. In J. Boaler (Ed.), *Multiple perspectives on the teaching and learning of mathematics* (pp. 83-104). Westport, CT: Ablex.

Bamett, J., & Hodson, D. (2001). Pedagogical context knowledge: Toward a fuller understanding of what good science teachers know. *Science Education 55*(4), 426-453.

Bar, V. (1989). Children's views about the water cycle. *Science Education, 73*, 481 –500.

Bar, V., & Travis, A. S. (1991). Children's views concerning phase changes. *Journal of Research in Science Teaching*, *28*, 363–382.

Bar, V., Zinn, B., Goldmuntz, R., & Sneider, C. (1994). Children's concepts about weight and free fall. *Science Education, 78*, 149–169.

Barbas, A., & Psillos, D. (1997). Causal reasoning as a base for advancing a systemic approach to simple electrical circuits. *Research in Science Education, 27*(3), 445-459.

Beaty, W. J. (1996). "What is Electicity?" Bill B's SCIENCE HOBBYIST website. Retreived from: www.eskimo.com/~**bill**b/miscon/whatis.html

Benson, D. L., Wittrock, M. C., & Baur, M. E. (1993). Students' preconceptions of the nature of gases. *Journal of Research in Science Teaching*, 30, 587–597.

Borges, A. T., & Gilbert, J. K. (1999). Mental models of electricity. *International Journal of Science Education*, *21*(1), 95-117.

Borko, H. (2004, April). *Teacher learning and professional development: Mapping the terrain.* Presidential Address delivered at the annual meeting of the American Educational Research Association, San Diego, CA.

Brown, C. A., & Borko, H. (1992). Becoming a mathematics teacher. In D. A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning.* (pp.165-194). New York: Macmillan.

Cerini, B., Murray, I., & Reiss, M. (2003). Students review of science curriculum. Major findings. London: Planet Science/Institute of Education, University of London/

Science Museum. Retrieved from http.//www.planet-science.com/sciteach/review.

Carlsen, D., & Andre, T. (1992). Use of a microcomputer simulation and conceptual change text to overcome student misconceptions about electric circuits*. Journal of Computer-Based Instruction, 19*, 105–109.

Chabay, R., & Sherwood, B. (2005). Restructuring the introductory electricity and magnetism course. *American Journal of Physics*, *74*(4), 329-336.

Chambers, S. K., & Andre, T. (1997). Gender, prior knowledge, interest and experience in electricity and conceptual change text manipulations in learning about direct current. *Journal of Research in Science Teaching, 34,* 107-123.

Chang, K., Liu, S., & Chen, S. (1998). A testing system for diagnosing misconceptions in DC electric circuits. *Computers & Education, 31*(2), 195-195-210.

Chi, M. T. H. (1992). Conceptual change within and across ontological categories: Examples from learning and discovery in science. In R. Giere (Ed.), *Cognitive models of science* (pp.129-186). Minneapolis, MN: Minnesota Press.

Chi, M. T. H., & Roscoe, R. D. (2002). The processes and challenges of conceptual change. In M. Limon & L. Mason (Eds.), *Reconsidering conceptual change: Issues in theory and practice* (pp. 3–27). Dordrecht: Kluwer.

Chi, M. T. H. (2008). Three types of conceptual change: Belief revision, mental model transformation, and categorical shift. In S. Vosniadou (Ed.), *Handbook of research on conceptual change* (pp. 61–82). Hillsdale, NJ: Erlbaum.

Chinn, C. A., & Brewer, W. F. (1993). The role of anomalous data in knowledge acquisition: A theoretical framework and implications for science instruction. *Review of Educational Research, 63*, 1–49.

Chiu, M. H., & Lin, J. W. (2005). Promoting fourth graders' conceptual change of their understanding of electric current via multiple analogies. *Journal of Research in Science Teaching, 42*, 429–464.

Classen, C. (1998). Outcomes-based education: some insights from complexity theory. *South African Journal of Higher Education, 12*(2), 34-40.

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

Collins English Dictionary. (2003). Glasgow: Harper Collins Publishers.

Cosgrove, M. (1995). A study of science-in-the-making as students generate an analogy for electricity. *International Journal of Science Education, 17*(3), 295-310.

Cosgrove, M., Osborne, R., & Carr, M. (1995). Children's intuitive ideas on electric current and the modification of those ideas. In R. Duit, W. Jung, & C. von Rhöneck (Eds.), *Aspects of understanding electricity*. Keil, Germany: Schmidt & Klaunig.

Cummings, K., Laws, P.W., Reddish, E.F., Cooney, P.J. (2004). *Understanding Physics*. New York: John Wiley & Sons Inc.

Dagher, Z. R. (1994). Does the use of analogies contribute to conceptual change? *Science Education, 78*, 601–614.

de Jong, T. (2006). Computer simulations: Technological advances in inquiry learning. *Science, 312*, 532–533.

Department of Education (2003). *Revised National Curriculum Statement.* Grade R-9 (Schools) Natural Science. Pretoria, Department of Education.

Department of Basic Education (2011). *Curriculum and Assessment Policy Statement*. South Africa.

Dickinson, V. L., & Flick, L. B. (1997). Children's ideas in science: How do student and teacher perspectives coincide? Report: ED405215.33pp.Mar 1997

Dictionary of the English Language. (2009). *The American Heritage*. Brazil. Houghton Miffin Company, fourth edition.

Driver, R., Easley, J. (1973). Pupils and paradigms: A review of literature related to concept development in adolescent science students. *Studies in Science Education, 5*, 61-84.

Dowker, A. (2005). *Individual differences in arithmetic.* Hove, UK: Psychology Press.

Dunbar, K. (1993). Concept discovery in a scientific domain. *Cognitive Science, 17*, 397–434.

Dupin, J. J., & Joshua, S. (1987). Conceptions of French pupils concerning electric circuits: structure and evolution. *Journal of Research in Science Teaching, 24*, 791–806.

Eggen, P., & Kauchak, D. (2004). *Educational Psychology: Windows, Classrooms*. Upper Saddle River: Pearson Prentice Hall.

Engelhardt, P. V., & Beichner, R. J. (2004). Students' understanding of direct current resistive electrical circuits. *American Journal of Physics, 72*(1), 99-115.

Eryilmaz, A. (2002). Effects of conceptual assignments and conceptual change discussions on students' misconceptions and achievement regarding force and motion. *Journal of* Research *in Science Teaching, 39*, 1001–1015.

Eylon, B. S., & Ganiel, U. (1990). Macro-micro relationships: the missing link between electrostatics and electrodynamics in student reasoning. *International Journal of Science Education, 12,* 79–94.

Farlex. (2010). Free Online Dictionary by Farlex. Retrieved from: http://www.thefreedictionary.com/idea Random House Kernerman Webster's College Dictionary, © 2010 K Dictionaries Ltd. Copyright Random House, Inc.

Finkelstein, N. D., Adams, W. K., Keller, C.J., Kohl, P.B., Perkins, K.K., Podolefsky, N. S., Reid, S., & LeMaster, R. (2005). When learning about the real world is better done virtually: A study of substituting computer simulations for laboratory equipment. *Physical Review Special Topics—Physics Education Research, 1*, 010103.

Frederiksen, J. R., White, B. Y., & Gutwill, J. (1999). Dynamic mental models in learning science: The importance of constructing derivational linkages among models. *Journal of Research in Science Teaching, 36*, 806–836.

Fredette, N. H., & Clement, J. J. (1981). Student misconceptions of an electric circuit: What do they mean? *Journal of College Science Teaching, 10,* 280-285.

Free Online Dictionary. Retrieved from dictionary.reference.com/browse/**idea** from learning and discovery in science. In R. Giere (Ed.), *Cognitive models of science* (pp.129-186). Minneapolis, MN: Minnesota Press.

Frykholm, J. A. (1996). Pre-service teachers in mathematics: Struggling with the standards. *Teaching and Teacher Education, 2*(1), 665-682.

Frykholm, J. A. & Glasson, G. (2005). Connecting science and mathematics instruction: Pedagogical context knowledge for teachers. *School Science and Mathematics, 105*(3), 127-127.

Gabel, D. L., Stockton, J. D., Monaghan, D. L., & MaKinster, J. G. (2001). Changing children's conceptions of burning. *School Science and Mathematics, 101*, 439–451.

Glauert, E. B. (2009). How young children understand electric circuits: Prediction, explanation and exploration. *International Journal of Science Education, 31*(8), 1025–1047.

Gee, J. C., Boberg, W. S., & Gabel, D. L. (1996). Preservice Elementary Teachers: Their Science Content Knowledge, Pedagogical Knowledge and Pedagogical Content Knowledge. Report: ED393702.23pp.Apr 1996.

Gess-Newsome, J. (1999). Secondary teachers' knowledge and beliefs about subject matter and their impact on instruction. In J. Gess-Newsome & Lederman (Eds.), *Examining pedagogical content knowledge* (pp.51-94). Dordrecht, the Netherlands: Kluwer.

Gentner, D., & Gentner, D. (1983). Flowing waters or teeming crowds: Mental models of electricity. In D. Gentner & A. L. Stevens (Eds.), *Mental models* (pp. 99–129). Hillsdale, NJ: Lawrence Erlbaum.

Gilbert, J. K., & Watts, D. M. (1983). Concepts, misconceptions and alternative conceptions: changing perspectives in Science Education. *Studies in Science Education, 10*, 61-98.

Glynn, S. M. (1989). The teaching with analogies model: Explaining concepts in expository texts. In K.D. Muth (Ed*.), Children's comprehension of narrative and expository text: Research into practice* (pp. 185–204). Newark, DE: International Reading Association.

Greeno, J. G. & Hall, R. P. (1997). Practicing Representation Learning with and About Representational Forms. *Phi Delta Kappan, 78* (5), pp 361-366.

Gunstone, R. (1994). *The Content of Science: A Constructivist Approach to its Teaching and Learning*. Bristol, PA: Falmer Press.

Gunstone, R., Mulhall, P., & McKittrick, B. (2009). Physics teachers' perceptions of the difficulty of teaching electricity. *Research in Science Education, 39*(4), 515-538.

Halim, L., & Meerah, S. M. (2002). Science trainee teachers' pedagogical content knowledge and its influence on physics teaching. *Research in Science & Technological Education, 20*, 215–225.

Hammrich, P. L. (1997). Teaching for excellence in K-8 science education: Using Project 2061 bench marks for more effective science instruction. *Journal of Teacher Education, 48(3),* 222-232.

Hanuscin, D. (2001). Misconceptions in Science, E328: Elementary Methods. Retrieved from: http://www.indiana.edu/~w505a/studwork/deborah/.

Harrison, A. G., & Treagust, D. F. (1993). Teaching with analogy: A case study in grade-10 optics. *Journal of Research in Science Teaching*, *30*, 1291–1307.

Hart, C. (2008). Models in physics, models for physics learning, and why the distinction may matter in the case of electric circuits. *Research in Science Education, 30*, 529–544.

Heller, P. M., & Finley, F. N. (1992). Variable uses of alternative conceptions: A case study in current electricity. *Journal of Research in Science Teaching, 29*, 259-275.

Hennessy, S., Deaney, R., & Ruthven, K. (2006). Situated expertise in integrating use of multimedia simulation into secondary science teaching. *International Journal of Science Education, 28*(7), 701–732.

Hesse, J., & Anderson, C. (1992). Students' conceptions of chemical change. *Journal of Research in Science Teaching, 29*, 277–299.

Hewson, M., & Hewson, P. W. (2003). Effect of instruction using students' prior knowledge and conceptual change strategies on science learning. *Journal of Research in Science Teaching, 40*, S86–S98.

Hill H. C., Ball, D. L., & Shilling, S. G (2008). Unpacking Pedagogical Content Knowledge: Conceptualizing and Measuring Teachers' Topic-Specific Knowledge of Students*. Journal of Research in Mathematics Education. 39*(4), 372-400.

Hodson, D. (1991). Practical work in science: Time for a reappraisal. *Studies in Science Education, 19*, 175-184.

Horner, M., Williams, H., Toerien, R., Maharaj, J. S. K., Masemula, M., Jones, E., Reddy. K., Diergaardt, M., & Visser. W. (2011). Siyavula: Grade 10 Physical science. Free High School Science Texts Project. pp.275, 277, 283.

House of Commons Science and Technology Committee. (2002). *Third report. science education from 14 to 19.* London: HMSO. Retrieved from: http://www.publications.parliament.uk/pa/cm200102/cmselect/cmsctech/508/50802.htm.

Hudson, P (2007). Examining mentors' practices for enhancing pre-service teachers' pedagogical development in mathematics and science. *Mentoring & Tutoring: Partnership in Learning, 15*(2), 201-201-217.

Hudson, P. B., & Kidman, G. C. (2008) Making a difference in secondary science education. In T, Aspland, Eds. Proceedings Australian Teacher Education Association (ATEA) Conference 2008, Sunshine Coast, Queensland.

Jaakkola, T., & Nurmi, S. (2008). Fostering elementary school students' understanding of simple electricity by combining simulation and laboratory activities. *Journal of Computer Assisted Learning, 24*(4), 271–283.

Jaakkola, T., Nurmi, S., & Veermans, K. (2011). A Comparison of Students' Conceptual Understanding of Electric Circuits in Simulation Only and Simulation-Laboratory Contexts. *Journal of Research in Science Teaching, 48*(1), 71-93.

Johnson-Laird, P. N. (1983). *Mental models: Towards a cognitive science of language, inference, and consciousness*. Cambridge, MA: Harvard University Press.

Jones, M. G., Carter, G., & Rua, J. M. (1999). *Children's Concepts: Tools for Transforming Science Teachers' Knowledge*. University of North Carolina: John Wiley & Sons, Inc.

Jones, R., & Berens, N. (2008). *Physical science explained. Grade 11 Learner's book*. South Africa. Juta Gariep, p 377.

Karrqvist, C. (1985). The development of concepts by means of dialogued centred on experiments. In: R.Duit, W. Jung, C. von Rhoneck (Eds), *Aspects of understanding electricity*, *Proceedings of an international workshop* (pp. 73-83). Kiel: IPN.

Kerr, K., Beggs, J., & Murphy, C. (2006). Comparing children's and student teachers' ideas about science concepts. *Irish Educational Studies, 25*(3), 289-302.

Kind, V. (2009). Pedagogical content knowledge in science education: perspectives and potential for progress. *Studies in Science Education, 45*(2), 169-204.

Klahr, D., Triona, L. M., & Williams, C. (2007). Hands on what? The relative effectiveness of physical vs. virtual materials in an engineering design project by middle school children. *Journal of Research in Science Teaching, 44*, 183–203.

Klein, M. (1972). The use and abuse of historical teaching in physics. In S. Brush, & A. King (Eds.), *History in the teaching of physics* (pp. 12–18). Hanover, NH: University Press of New England.

Kriek, J., & Kapartzianis, A. S. (2011). The perceptions of Cypriot secondary Technical and Vocational Eduaction students about simple electric circuits. Presented at the International Conference of Science, Mathematics and Technology Education. Published by Unisa Press, 215- 229.

Kriek, J., Khwanda, M., Basson, I., & Lemmer, M. (2011). An investigation of pre-service teachers' conceptual understanding of basic DC circuits. Presented at the International Conference of Science, Mathematics and Technology Education. Published by Unisa Press, 294-308.

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

Kucukozer, H., & Demirci, N. (2006). High School Physics teachers' forms of thought about simple electric circuits. Retrieved from: w3.balikesir.edu.tr/~demirci/mugla3.pdf Accessed on 16 August 2013.

Kucukozer, H., & Demirci, N. (2008). Pre-service and in-service physic teachers' ideas about simple electric circuits. *EURASIA Journal of Mathematics, Science & Technology Education, 4*(3), 303-311.

Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching, 29,* 331-359.

Lee, E., & Luft, J. A. (2008). Experienced secondary science teachers' representation of pedagogical content knowledge. *International Journal of Science Education, 30*(10), 1343-1363.

Lee, Y., & Law, N. (2001). Explorations in promoting conceptual change in electrical concepts via ontological category shift. *International Journal of Science Education, 23*(2), 111–149.

Licht, P. (1991). Teaching electrical energy, voltage and current: an alternative approach. HOP publishing Ltd. *Physic Education 26*, 272-277.

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

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

Lorsbach, A. W., Tobin. K., Briscoc, C., & Lamaster, S.U. (1992). An interpretation of assessment methods in middle school science. *International Journal of Science Education, 14*, 305-317.

Loughran, J., Gunstone, R., Berry, A., Milroy, P., Mulhall, P. (2000). Science Cases in Action: Developing a Understanding of Science Teachers' Pedagogical Content Knowledge. Report: ED442630.

Loughran, J., Milroy, P., Berry, A., Gunstone, R., & Mulhall, P. (2001). Documenting science teachers pedagogical content knowledge through PaP-eRs. *Research in Science Education, 31*, 289-307.

Loughran, J., Mulhall, P., & Berry, A. (2004). In search of a pedagogical content knowledge in science: Developing ways of articulating and documenting professional practice. *Journal of Research in Science Teaching, 41(*4*),* 370-391.

Lunetta, V. N., & Tamir, P. (1979). Matching lab activities with teaching goals. *The Science Teacher, 46*(5), 22-24.

Lumpe, A. T., Haney, J., & Czemiak, C. (2000). Assessing teachers' beliefs about their science teaching context. *Journal of Research in Science Teaching 37*(3), 123-145.

Mackay, J, & Hobden, P. (2012). Using circuit and wiring diagrams to identify students preconceived ideas about basic electric circuits. *African Journal of Research in MST Education. 16*(2), 131-144.

Magnusson, S., Borko, H., & Krajcik, J. S. (1994) Teaching Complex Subject Matter in Science: Insights from an Analysis of Pedagogical Content Knowledge. Report: ED390715. 27pp.Mar 1994.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N.G. Lederman (Eds.), *Examining pedagogical content knowledge*: *PCK and science education.* (pp. 633-635). Dordrecht, the Netherlands: Kluwer.

Martin, R., Sexton, C., & Gerlovich, J. (2002) *Teaching Science for all Children: Methods for Constructing Understanding*. Boston: Allyn and Bacon.

McDermott, L. C., & Shaffer, P. S. (1992). Research as a guide for curriculum development: An example from introductory electricity. Part I: Investigation of student understanding. *American Journal of Physics, 60*(11), 994–1013.

McMillan, J. H., & Schumacher, I. S. (2006). *Research in Education: Evidence Based Enquiry*. 6th Edition. Pearson Education, Inc.

McNeil, L. M. (1983). Defensive teaching and classroom control. In Apple, M.W. & Weis, L. *Ideology and practice in schooling.* Philadelphia: Temple University Press, 114-143.

McRobbie, C., & Tobin, K. (1995). Restraints to reform: The congruence of teacher and student actions in chemistry classroom. *Journal of Research in Science Teaching. 32*, 373-385.

Meece, J. L. (2003). Applying learner-centred principles to middle school education. *Theory into Practice, 42*(2), 109-116.

Mellado, V. (1997). The classroom practice of pre-service teachers and their conceptions of teaching and learning science. *Science Teacher Education*. 198-214.

Meriam Webster free online dictionary. Britannica company. Retrieved from: http://www.merriam-webster.com/dictionary/analogy

Millar, R., Le Maréchal, J., & Tiberghien, A. (1999). Mapping the domain. Varieties of practical work. In Leach, J. & Paulsen, A. (Eds). *Practical work in Science Education.* (pp.60-74*).* Dordrecht: Kluwer.

Minsky, M. (1985, 1986). *The Socity of Mind*. New York: Simon & Schuster.

Mulhall, P., McKittrick, B., & Gunstone, R. (2001). A perspective on the resolution of confusions in the teaching of electricity. *Research in Science Education, 31,* 575-587.

Munby. H. (1982). This place of teachers' beliefs in research on teacher thinking and decision making, and an alternative methodology. *Instructional Science*, *11,* 201-225.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.

National Science Teachers Association (NSTA) (2007). *NSTA position statement: The integral role of laboratory investigations in science instruction.* National Science Teachers Association.

Nkopane, L., Kriek, J., Basson, I., & Lemmer, M. (2011). Alternative conceptions about simple electric circuits amongst high school FET band learners. *Proceedings of the International Conference of Science, Mathematics and Technology Education held at Kruger Park, October 2011.* Unisa Press, 339-353.

Olivier, A. (2012). *Physical Science theory and workbook Grade 11*. Protea Park, South Africa: Reivilo publishers

Osborne, R. J. (1981). *The Framework: towards action research. Learning in science project, working paper no: 28*. Hamilton (NA): University of Waikato.

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

Pardhan, H., & Bano, Y. (2001). Science teachers' alternate conceptions about direct currents. *International Journal of Science Education, 23*(3), 301-318.

Park, S., Jang, J., Chen, Y., & Jung, J. (2011). Is pedagogical content knowledge (PCK) necessary for reformed science teaching?: Evidence from an empirical study. *Research in Science Education, 41*(2), 245-245-260.

Pesman, H., & Eryilmaz, A. (2010). Development of a three-tier test to assess misconceptions about simple electric circuits. *Journal of Educational Research, 103*(3), 208-222.

Pine, K., Messer, D., & St. John, K. (2001). Children's misconceptions in primary science: A survey of teachers' views. *Research in Science and Technological Education, 19*, 79–96.

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

Psillos, D., Koumaras, P. & Valassiades, O. (1987). Pupils' representations of electric current before, during and after instruction on DC circuits. *Research in Science and Technological Education, 5*(2), 185-185-199.

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

Putnam, R., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher leaming? *Educational Researcher, 29*(1), 4-15.

Reiner, M., Slotta, J. D., Chi, M. T. H., & Resnick, L. B. (2000). Naıve physics reasoning: A commitment to substance based conceptions. *Cognition and Instruction, 18*(1), 1–34.

Riley, M. S., Bee, N. V., & Mokwa, J. J. (1981). Representations in Early Learning: The Acquisition of Problem-solving Strategies in Basic Electricity/Electronics in: *Proc. Int. Workshop on problems concerning students' representations of physics* *and chemistry knowledge, Ludwigsburg* (Ludwigsburg, West Germany: Pädagogische Hochschule) 107-73.

Rogan, J. (2004). Out of the frying pan …? Case studies of the implementation of curriculum 2005 in some science classrooms. *African Journal of Research in Maths, Science & Technology Education, 8*, 165-179.

Rollnick, M., Bennett, J., Rhemtula, M., Dharsey, N., & Ndlovu, T. (2008). The place of subject matter knowledge in pedagogical content knowledge: A case study of South African teachers teaching the amount of substance and chemical equilibrium. *International Journal of Science Education, 30*(10), 1365-1387.

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

Sadiku, A. (2009*). Fundamentals of Electric circuits*. Cleveland University: McGrawHill International, 4th edition. pp6.

Scheckler, R. K. (2003).Virtual labs: A substitute for traditional labs? *International Journal of Developmental Biology, 47*, 231–236.

Schmidt, H. (1997). Students' misconceptions: Looking for a pattern. Science Education, 81, 123–135. In Aspland, Tanya, Eds. Proceedings Australian Teacher Education Association (ATEA) Conference 2008, Sunshine Coast, Queensland.

Sebastia, J.M. (1993). " Cognitive mediators and interpretations of electric circuits," *in Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics* (Misconceptions Trust), Ithaca, New York.

Sencar, S., & Eryilmaz, A. (2004). Factors mediating the effect of gender on ninth-grade turkish students' misconceptions concerning electric circuits. *Journal of Research in Science Teaching, 41*(6), 603-616.

Sequeira, M., & Leite, L. (1991). Alternative conceptions and history of science in physics teacher education. *Science Education, 75*, 45–56.

Shaffer, P., & McDermott, L. (1992). Research as a guide for curriculum development: An example from current electricity. Part II: Design of instructional strategies. *American Journal of Physics*, *60*, 1003–1013.

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

Shipstone, D. M. (1985). Electricity in simple circuits. In: R. Driver, E. Guesne and A. Tiberghien (Eds.), *Children's Ideas in Science* (pp. 32-50). Milton Keynes: Open University Press.

Shipstone, D. M. (1988). Pupils' understanding of simple electrical circuits. Some implications for instruction. *Journal of Physics Education, 23*, 92-96.

Shipstone. D. M., von Rhoneck, C., Kärrqvist, C., Dupin, J., Joshua, S., & Licht, P. (1988). A study of student' understanding of electricity in five European countries. *International Journal of Science Education*, *10* (3), 303-316.

Shulman, L. (1986a).Those who understand: A conception of teacher knowledge. *American Educator, 10*(1), 9-15, 43-44.

Shulman, L. (1986b). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14.

Shulman, L. (1987). Knowledge and teaching: Foundations of the New Reform. *Harvard Educational Review, 57*(1), 1-22.

Shymansky, J. A., & Penick, J. E. (1981). Teacher behavior makes a difference in hands-on science classrooms. *School Science and Mathematics, 81,* 412–422.

Smith, J. J. A., & Nel, S. J. (1997). Perceptions of models of electric current held by physical science teachers in South Africa. *South African Journal of Science, 93*(5), 202-205.

Sneider, C., & Ohadi, M. (1998). Unraveling students' misconceptions about the Earth's shape and gravity. *Science Education, 82*, 265–284.

Solomonidou, C., & Kakana, D. M. (2000). Preschool children's conceptions about the electric current and the functioning of electric appliances. *European Early Childhood Education Research Journal, 8*(1), 95–111.

Southerland, S., Abrams, E., Cummins, C., & Anzelmo, J. (2001). Understanding students' explanations of biological phenomena: Conceptual frameworks or p-prims? *Science Education, 85*, 328–348.

Stocklmayer, S., & Treagust, D. (1996). Images of electricity: how do novices and experts model electric current. *International Journal of Science Education, 18*, 163–178.

Tallant, D. P. (1993) A Review of Misconceptions of electricity and electric circuits. The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Misconceptions Trust: Ithaca, NY.

Tao, P., & Gunstone, R. (1999). The process of conceptual change in force and motion during computer supported physics instruction. *Journal of Research in Science Teaching, 36*, 859–882.

Tiberghien, A. (2000). Designing teaching situations in the secondary school. In: R Millar, j. Leach & J. Osborne (Eds.), *Improving science education: The contribution of research* (pp.27-47). Buckingham, UK: Open University Press.

Tobin, K., & Espinet, M. (1989). Impediments to change: Applications to coaching in high school science teaching. *Journal of Research in Science Teaching, 26*, 105-120.

Toerien, R., Clitheroe, F., & Dilley, L. (2006). *Head Start Natural Science Learners book. Grade: 8*. England: Oxford University Press. p42.

Treagust, D. F. (2006). Conceptual change as a viable approach to understanding student learning in science. In K.G. Tobin (Ed.) *Teaching and Learning Science, A Handbook* (pp. 25-32). Westport, Connecticut: Praeger.

Trend, R. D. (2001). Deep time framework: A preliminary study. *Journal of Research in Science Teaching, 38*, 191–221.

Triona, L. M., & Klahr, D. (2003). Point and click or grab and heft: Comparing the influence of physical and virtual instructional materials on elementary school students' ability to design experiments. *Cognition and Instruction, 21*, 149–173.

Triona, L. M., & Willaims, C. (2007). Hands on what? The relative effectiveness of physical versus virtual materials in an engineering design project by middle school children. *Journal of Research in Science Teaching 44*(1), 183–203.

Usak, M. (2009). Pre-service Science and Technology Teachers' Pedagogical Content Knowledge on Cell Topics. *Educational Sciences: Theory and Practices*. *9*(4), 2033-2046.

Van der Merwe, O.R. & Gaigher, E. (2011). Teachers' awareness of learners' misconceptions about simple circuits. *Proceedings of the International Conference of Science, Mathematics and Technology Education held at Kruger Park, October 2011.* Unisa Press, 181-190.

Van Driel, J. H., Beijaard, D., & Verloop, N. (2001). Professional development and reform in science education: The role of teachers' practical knowledge. *Journal of Research in Science Teaching, 38*(2), 137-158.

Van Zee, E. H., Evans, J., Greenberg, D. W., & McDermott, L. C. (1982). Student conceptual difficulty with current electricity. Paper presented at National Meeting of the American Association of Physics Teachers, San Francisco.

Veal, R. W. & MaKinster, J. G., (1999). The TTF model to explain PCK in teacher development. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Boston, Massachusetts, USA.

Viennot, L., & Rainson, S. (1992). Students' reasoning about the superposition of electric fields. *International Journal of Science Education, 14*, 475–487.

Vosniadou, S. (2002). On the nature of naive physics. In M. Limon & L. Mason (Eds.), *Reconsidering Conceptual Change: Issues in Theory and Practice* (pp. 61–76). Dordrecht: Kluwer.

Vosniadou, S., & Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology, 24*, 535–585.

Wieman, C. E., Adams, W. K., & Perkins, K. K. (2008). PhET: Simulations that enhance learning. *Science, 322*, 682–683.

Wong, E. D. (1993). Understanding the generative capacity of analogies as a tool for explanation. *Journal of Research in Science Teaching*, *30*, 1273–1290.

Woolfolk. A. (2010). *Educational Psychology*. Pearson Education International. Eleventh edition.

Wright, J. D., & Hounshell, P. B. (1981). A survey of interest in science for participants in a junior science and humanities symposium. *School Science and Mathematics, 81,* 378– 382.

Yerrick, R. K., Doster, E., Nugent, J. S., Parke, H. M., & Crawley, F. E. (2003). Social interaction and the use of analogy: An analysis of preservice teachers' talk during physics inquiry lessons. *Journal of Research in Science Teaching, 40*(5), 443-463.

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

Zohar, A., & Schwartzer, N. (2005). Assessing teachers' pedagogical knowledge in the context of teaching higher-order thinking. *International Journal of Science Education, 27*(13), 1595-1620.

Zwiep, G. S. (2008). Elementary teachers' understanding of students' science misconceptions: implications for practice and teacher education. *Journal of Teacher Education, 19,* 437-454.

Appendix 1

Biographical information

1. Complete the table below

Year degree was obtained:	Qualification:	Institution:	Major Subjects:	Other subjects:

2. How many years have you been teaching science?

____

3. What type of school do you teach at? (i.e. private, ex model c, rural?)

____

4. What is the annual school fee at your school?

____

5. How would you rate your school in terms of resources? Tick (□) the appropriate answer.

Under resourced	Fairly resourced	Well resourced

Appendix 2

Questionnaire

- Every question starts by a typical test item for learners given in a box
- You are not required to answer the items in the box
- You are required to answer the questions following the boxed items
- Note that the correct option of each item is given
- You are required to think about mistakes that your learners would make had they been given these test items

Question 1:

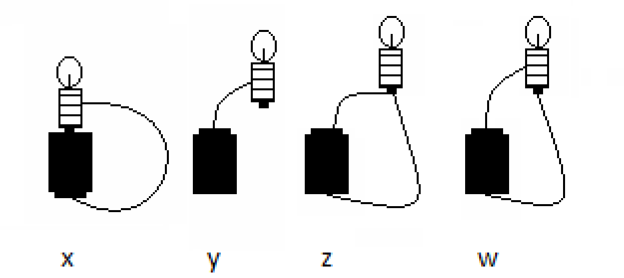
Which bulb/ bulbs will light?

(A) x and w

(B) w only

(C) y

(D) x, y, z, w



The correct answer is (A).

1.1 Which wrong option do you expect your learners to choose?

____

1.2 Why do you think they will choose this option?

____

____

____

____

____

1.3 How would you explain to learners why the chosen option is incorrect?

____

____

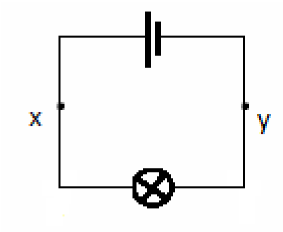
____

____

____

Question 2:

How do the currents at points x and y compare?



(A) x = y

(B) x > y

(C) y > x

(D) x=0

(E) y=0

The correct answer is (A).

2.1. Which wrong option do you expect your learners to choose?

____

2.2. Why do you think they will choose this option?

____

____

____

____

____

2.3. How would you explain to your learners why the chosen option is incorrect?

____

____

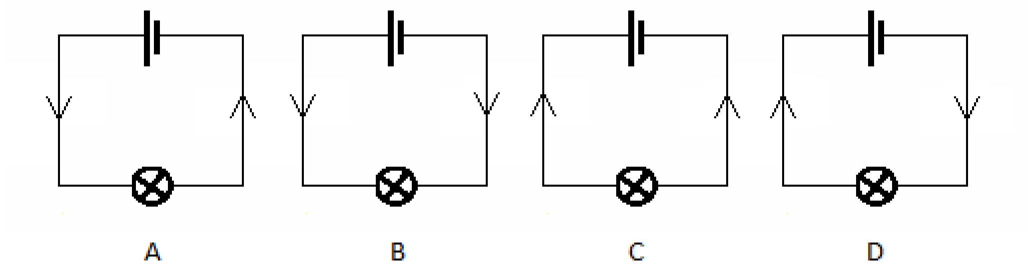
____

____

____

Question 3:

Which diagram correctly represents the flow of conventional current in the circuit?



The correct answer is (A).

3.1. Which wrong option do you expect your learners to choose?

____

3.2. Why do you think they will choose this option?

____

____

____

____

____

3.3. How would you explain to your learners why the chosen option is incorrect?

____

____

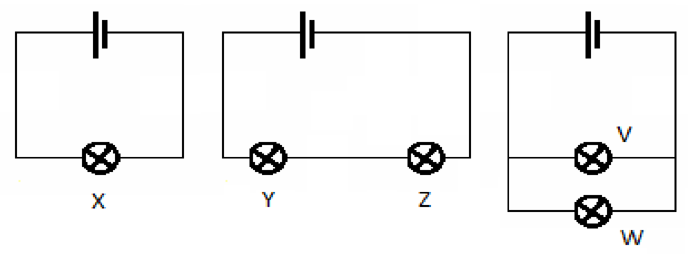
____

____

____

Question 4:

Which bulb or bulbs are the least bright?



(A) y ,z

(B) y, z, v, w

(C) w

(D) x

(E) z and w

The correct answer is (A).

4.1. Which wrong option do you expect your learners to choose?

____

4.2. Why do you think they will choose this option?

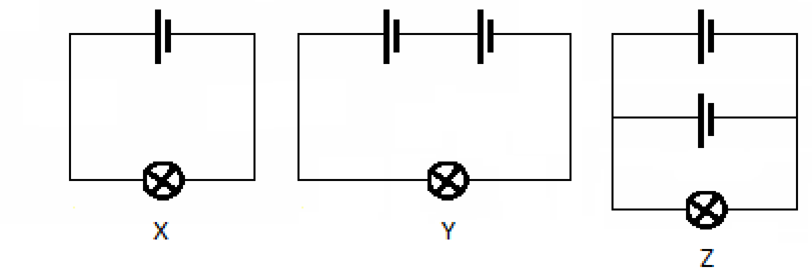
____
____
____
____
____

4.3. How would you explain to your learners why the chosen option is incorrect?

____
____
____
____
____

Question 5:

Which bulb(s) are brightest?



(A) y

(B) y and z

(C) z

(D) x

(E) x and y

The correct answer is (A).

5.1. Which wrong option do you expect your learners to choose?

____

5.2. Why do you think they will choose this option?

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5.3. How would you explain to your learners the why chosen option is incorrect?

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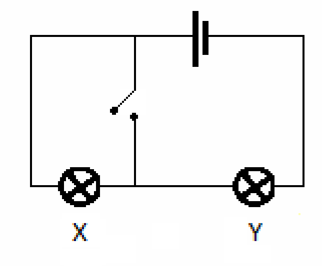
Question 6:

How does the brightness of the light bulbs change if the switch is closed?



(A) y brighter, x=0

(B) both brighter

(C) y=0, x=0

(D) x brighter, y=0

(E) no difference

The correct answer is (A).

6.1. Which wrong option do you expect your learners to choose?

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6.2. Why do you think they will choose this option?

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6.3. How would you explain to your learners why the chosen option is incorrect?

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Question 7:

Why does a bulb light up when connected in a circuit?

(A) electrical energy is converted to light

(B) electrical charge is converted to light

(C) electrical current is converted to light

(D) all of the above

The correct answer is (A).

7.1. Which wrong option do you expect your learners to choose?

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7.2. Why do you think they will choose this option?

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7.3. How would you explain to your learners why the chosen option is incorrect?

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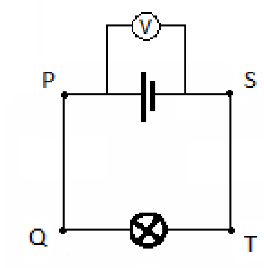
Question 8:

A 6V battery is connected to a bulb as shown above in the diagram. A voltmeter is then connected between P and S. Next it is connected between P and Q, then Q and T and finally T and S. What are the voltmeter readings between the various points?



	PS	PQ	QT	TS
(A)	6	0	6	0
(B)	6	6	6	6
(C)	6	2	2	2
(D)	6	3	0	3

The correct answer is (A).

8.1. Which wrong option do you expect your learners to choose?

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8.2. Why do you think they will choose this option?

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8.3. How would you explain to your learners why the chosen option is incorrect?

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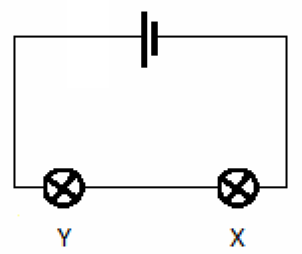
Question 9:

What happens to the brightness of the bulbs X and Y if we add a resistor between them?



(A) X and Y both less bright

(B) X unchanged, Y less bright

(C) X less bright, Y unchanged

(D) X and Y both unchanged

The correct answer is (A).

9.1. Which wrong option do you expect your learners to choose?

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9.2. Why do you think they will choose this option?

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9.3. How would you explain to your learners why the chosen option is incorrect?

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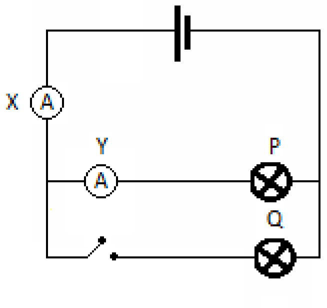
Question 10:

How do the readings on the ammeters X and Y change if the switch is closed?



(A) X increases, Y unchanged

(B) X unchanged, Y decreases

(C) X decreases, Y decreases

(D) X increases, Y decreases

The correct answer is (A).

10.1. Which wrong option do you expect your learners to choose?

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10.2. Why do you think they will choose this option?

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10.3. How would you explain to your learners why the chosen option is incorrect?

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Appendix 3

Interview Schedule

Question 1: Teaching and learning

1.1. Do you feel that your studies prepared you for your classroom practice? If not, which topic would you prefer to know better?

1.2. Do you find it easy or difficult to explain things that you understand?

1.3. Do you find teaching electricity more difficult than other subjects?

1.4. How do you usually start the topic of electricity?

1.5. What do you find most difficult to explain to your learners about electricity?

1.6. Are there any specific concepts that your learners find difficult to understand in electricity?

Question 2: Analogies

2.1. When you explain how a circuit works, which analogies (eg water pipes, people queuing, traffic) do you use? Do you use only one analogy? Which? Otherwise, which analogy works best for which concept? [Interviewer should not suggest any specific concepts!]

Question 3: Practical work

3.1. Which experiments do you think are most important for electric circuits?

3.2. It is difficult to do all the experiments. How do you decide which experiments should be done?

3.3. Do you think students benefit from practical work? How?

3.4. Do you sometimes prefer to demonstrate something rather than to have the students do practical work themselves? In what way do you find it easier to demonstrate?

Question 4: Textbooks

4.1. Do you feel that textbooks sometimes cause confusion of concepts? Can you give examples?

4.2. Do you feel that the language barrier causes any misunderstandings? Can you give examples?

4.3. If the textbook and syllabus differ in terms of sequence and content, which do you follow?

Question 5: Syllabus

5.1. Is there any of the prescribed electricity content for Grade 9 that you think is too difficult? Which, why?

5.2. Do you think it is sufficient to observe brightness of bulbs to understand circuits, or do you think that measurements of current and potential difference are important for Grade 9 learners? Why do you think so?

5.3. Do you teach additional topics that are not prescribed for Grade 9? Which, why?

5.4. Do you think that Grade 9 learners need to distinguish between voltage and current when learning about circuits?

5.5. Do you think that Grade 9 learners should do calculations in electricity? Why? / Why not?

5.6. Do you think that the potential difference concept is important in teaching electricity in Grade 9? Why?

5.7. The CAPS document for Grade 9 prescribes series and parallel connections of bulbs but not of cells. Do you think it should be taught? Why? Why not? Do you think it may cause problems?

Question 6: Reference to questionnaire

6.1. How do you explain to learners the need for a closed circuit?

6.2. How do you explain to a learner that the current in a series circuit stays the same throughout?

6.3. How do you explain the meaning of conventional current to your learners?

6.4. a) How do you explain that adding light bulbs in series decreases the brightness?

b) How do you explain that adding light bulbs in parallel does not affect the brightness?

6.5. How do you explain that connecting cells in series increases the brightness of the bulb, but when you connect cells in parallel the brightness of the bulb is not affected?

6.6. How do you explain to learners what a short circuit is?

6.7. How do you explain what makes a bulb light up in a circuit?

6.8. How do you explain the difference between current and potential difference?

6.9. How do you explain that adding a resistor affects the components in front and behind in a circuit?

6.10. How do you explain that a battery produces more current when bulbs are added in parallel?

Appendix 4 – Interview Transcripts

Interview Transcript: Peter

Interviewer: Interview with participant F

Interviewee: I consent to this interview and I am aware that the data obtained from this interview will be used for research.

Interviewer: 1.1. Do you feel that your studies prepared you for your classroom practice?

Interviewee: At varsity, yes I think they did adequately. Yes especially for physics and not so much about chemistry but yeah

Interviewer: 1.2. Do you find it easy or difficult to explain things that you understand?

Interviewee: I find it easy, I find it easy, if its something that I really understand then its much easier for me to explain, yeah

Interviewer: 1.3. Do you find teaching electricity more difficult than other subjects?

Interviewee: No, I actually have devised a strategy, that and I think it is working for me and I find it more enjoyable in fact to teach electricity because there are more intricate subjects that kids don't understand as such, as such and it gives me a pleasure to teach a subject that they don't really understand, yeah

Interviewer: 1.4. How do you usually start the topic of electricity?

Interviewee: Well usually I'd start by using an analogy using an atm for cells and I'd represent different components, the wire, the highway, the vehicles would represent the charge, and the toll gates or e-tolls would represent the resistors and the money that you have to pay would represent the energy and and that way, it would make some sort of sense to them how the circuit actually works

Interviewer: 1.5. What do you find most difficult to explain to your learners about electricity?

Interviewee: I think the most difficult concept, it's when you actually have to, when I explain to them there is a split of current the potential difference remains the same and and I think that they find much more difficult and they find it even harder later when they have to reapply the concept

Interviewer: 1.6. Are there any specific concepts that your learners find difficult to understand in electricity?

Interviewee: I think application of the formulas. They have problems with application of the formulas especially when you suddenly have a parallel combination with another series resistor and then they have to apply all these sorts of formulas. They seem to battle a lot often with those

Interviewer: 2.1. When you explain how a circuit works, which analogies do you use?

Interviewee: I use the atm, the road as would represent the conductors, the atm would represent the cell, and the e-tolls or toll gates would represent the resistors, and the money that they would have withdraw from the atm would represent the energy, something that allows them or enables them to cross from one point to another because they would have to pay the e-tolls. That basically what I use

Interviewer: Do you use only one analogy?

Interviewee: At times not, sometimes I have to use red bulls for instance you know sometimes some kids don't really understand it. But I find that the e-toll analogy works perfectly in fact they keep on reminding themselves using that analogy how certain things work

Interviewer: 3.1. Which experiments do you think are most important for electric circuits?

Interviewee: The experiment, I think to demonstrate that current stays constant, and demonstrate that the current splits when resistors are connected in parallel, and the previous one that it stays constant when resistors are connected in series and the Ohms Law. The Ohms Law. I think it's important although you may not actually cover Ohms Law at grade 9 I think it's important for FET just so that they know what you do and and so when you speak of Ohms Law it's nothing strange, yeah

Interviewer: 3.2. It is difficult to do all the experiments. How do you decide which experiments should be done?

Interviewee: I think it depends on the difficulty of the concept as I said the concept that I've explained that they find most difficult the most that's the ones that I'd usually do experiments on. That actually do hands on and see an actual results and that way I think most boys will actually remember the entire concept

Interviewer: 3.3. Do you think students benefit from practical work?

Interviewee: I think they do, they do a lot 'cause it helps them to remember, it helps them to see the real life situation, the real things that they happen, not just some theory or some analogy that suppose to make sense to them

Interviewer: 3.4. Do you sometimes prefer to demonstrate something rather than to have the students do practical work themselves?

Interviewee: I, it depends, I sometimes prefer them to do the practical and later then we try to explain the results of whatever they have been doing, or it's either way. It depends on the class as well. Because sometimes you get a not so hands on class and such that you will find that they will take forever to do an experiment, so its better if you explain a concept and they would know what kind of experiment to do but if you find hands on oaks then you can actually tell them what to do and then they will do it and then you will discuss the results later and then explain the entire concept

Interviewer: 4.1. Do you feel that textbooks sometimes cause confusion of concepts?

Interviewee: I do yes, that's why I actually prefer setting my own set of notes and using different types of textbooks

Interviewer: Can you give examples?

Interviewee: of a textbook? There is one by, there is one textbook, which actually, well I think its good if it would have been properly edited and yes, because the language itself sometimes it's wrong in the textbook, the connection, then it will tell you something is joined instead of connected and, ya, I think the language in most of the textbook is wrong particularly because it confuses the science concepts

Interviewer: 4.2. Do you feel that the language barrier causes any misunderstandings?

Interviewee: I'm not too sure, I'm not too sure because I'm a second language English speaking person and teaching to mostly firstly language English speaking boys so I don't really think that language is as such a problem to me and I hope not to them because I've never had a complaint about it and yeah I don't think language is such a problem

Interviewer: 4.3. If the textbook and syllabus differ in terms of sequence and content, which do you follow?

Interviewee: If it differs in terms of sequence..?

Interviewer: content

Interviewee: And content. I'd follow the sequence.

Interviewer: Why?

Interviewee: I think it's more fair to the kids to actually build a concept and make and understanding and it's actually easier to move from one concept to the other instead of having a disjointed segments of learning, because when you try to refer to something that you have studied a month or two months ago or even three weeks ago, its sometimes hard for these youngsters to actually remember those concepts so I prefer sequence because it makes a lot of sense to them and it actually makes a lot of sense scientifically speaking to have a particular sequence to draw out a particular theory or a particular concept more.

Interviewer: 5.1. Is there any of the prescribed electricity content for Grade 9 that you think is too difficult?

Interviewee: No, I don't, I think the most challenging thing is that most of the kids they think that its easy as you explain it and they think its going to be even easier if he studies it at 2 for a test and if he gets all the answers from a teacher and then it will be, it'l make he's life easy and they don't practice the work. Most often they don't really practice. Often enough they will do homework just so they avoid to be punished and not actually, do the actual work to understand the concept.

Interviewer: 5.2. Do you think it is sufficient to observe brightness of bulbs to understand circuits, or do you think that measurements of current and potential difference are important for Grade 9 learners?

Interviewee: A combination of both I think, you know sometimes its easier if, sometimes the readings may not be enough for these kids and when they see the brightness and then it actually becomes dimmer and dimmer as you connect them series or it becomes brighter as you connect one in parallel, I think, I think a combination of both numbers and brightness

Interviewer: 5.3. Do you teach additional topics that are not prescribed for Grade 9?

Interviewee: Basically what happens is we we we do, like chemistry, we try to teach the most basic chemistry

Interviewer: Specifically to electricity?

Interviewee: Specifically to electricity, No

Interviewer: 5.4. Do you think that Grade 9 learners need to distinguish between voltage and current when learning about circuits?

Interviewee: I think its very important that they actually get the concept right, what is potential difference and what is current and know distinctly the difference between the two and that way they will know the definition, they will know the formulas, and they will no the application of work as you apply all those different definitions

Interviewer: 5.5. Do you think that Grade 9 learners should do calculations in electricity?

Interviewee: Yes, it is important that they do calculations because it helps them with the cognitive ability and it actually makes the understanding of the concept of electricity much easier when there are calculations involved. They could actually see some, those who are clever enough can actually see where they have gone wrong with calculations rather than with theoretical work

Interviewer: 5.6. Do you think that the potential difference concept is important in teaching electricity in Grade 9?

Interviewee: I think it is, I actually teach the potential difference concept what it is, how it works and etcetera . I think it is very important that they understand it

Interviewer: Why?

Interviewee: Because I believe if you don't teach something well , then later you try to rectify yourself then its going to be harder so atleast if you teach it properly at the beginning and tell then that potential difference is the work done by unit charge, then in that way it makes sense because you give them formulas and you give them a definition and they understand the whole concept. I think its important that you don't get them to pass, but you get them to pass and understand it's a science concept

Interviewer: 5.7. The CAPS document for Grade 9 prescribes series and parallel connections of bulbs but not of cells. Do you think it should be taught?

Interviewee: The cells. Yes I think it should be taught

Interviewer: Why?

Interviewee: Because it explains, they have their own different phenomenon that they explain and at grade 9 I think it is only fair and just that they understand they connection of cells in series and in parallel the effect they have on current and potential difference etcetera

Interviewer: Do you think it may cause problems later on if they don't learn it?

Interviewee: Its not going to be a train smash as such, if they don't learn it, it's not going to be a train smash, but if you have the time to teach I mean its going to take literally less than a period to teach that simple concepts so I don't see why should you leave it for later

Interviewer: 6.1. How do you explain to learners the need for a closed circuit?

Interviewee: The need for a closed circuit, what you mean?

Interviewer: Why is a closed circuit necessary? Why should we have a closed circuit?

Interviewee: Oh, to explain the current you mean.

Interviewer: Yes

Interviewee: Its actually for me, because they have to know, because electricity is something that they use everyday, they have to know when they turn on the switch what actually happens or when they switch it off what actually happens or what doesn't happen and why is it important to have a closed circuit and why sometimes it is important to have an open circuit

Interviewer: 6.2. How do you explain to a learner that the current in a series circuit stays the same throughout?

Interviewee: Basically as I told you about my analogy, now the ammeter would be represented by the guy who counts the number of cars on the highway, so now I would have one on the one point and the other on the other point so merely it would be you and I driving two cars so the one guy would count two cars and that would make it two amperes and the other guy on the other side, after passing many toll gates what ever he will still count a total of two vehicles and that will make two amperes as well, so that's how I actually teach it and they actually see the numbers and then they actually draw up a conclusion that current one this side is the same and the current on the other side is the same

Interviewer: 6.3. How do you explain the meaning of conventional current to your learners?

Interviewee: Well conventional current, I use I use different points like I'll put about four boys or five of them and then move one from his same. I'll put them close together and then move one from his space and then now the absence, each boy would represent an electron and if I remove one then we have an absence of electron and that is a positive charge and a positive charge attracts a negative charge and then the negative charge as it moves its space it would move backwards and there will be positive charges moving in a different directions and that how I actually explain it because every time a boy shifts to the right the space shifts to the left and when one boy shifts even further to the right the space shifts even further to the left

Interviewer: You teach this to grade 9's?

Interviewee: Yes, I teach this to grade 9's

Interviewer: 6.4. a) How do you explain that adding light bulbs in series decreases the brightness?

Interviewee: I usually give them I connect the circuit diagram and I literally put one and look at the brightness and use the ammeter and I put in the second light bulb and they would see that the ammeter reading keeps dropping and that he brightness also drops and then I'll put the third one and then they will see that actually as we put more light bulbs the current decreases as well as the brightness

Interviewer: b) How do you explain that adding light bulbs in parallel does not affect the brightness?

Interviewee: What I do is on my analogy, what happens is, obviously the current will split, but then each car that has withdrawn money from an atm has its own money to pay at the toll gate and the toll gate would be the light bulbs, and so now you would have the same amount of money on one side and the same amount of money on the other side then off obviously inevitably they should be the same brightness the same energy the same work same potential difference and same current for either of the two cars

Interviewer: 6.5. How do you explain that connecting cells in series increases the brightness of the bulb, but when you connect cells in parallel the brightness of the bulb is not affected?

Interviewee: How do I explain increasing?

Interviewer: How do you explain that connecting cells in series increases the brightness of the bulb, but when you connect cells in parallel the brightness of the bulb is not affected?

Interviewee: I still use the same analogy as well. If different cars are leaving two different atm's and they'd have a little amount compared to each other if the resistors, cells are connected in parallel, however if you have a series of cells connected and you withdraw money from each you a gonna leave the entire circuit with a large amount of money compared to when you had them in parallel which means you still have less amount of money

Interviewer: 6.6. How do you explain to learners what a short circuit is?

Interviewee: I use the parallel circuit. The parallel connection of cells in parallel, and just connect one opposite positive to an positive and I ask them for the current direction. Where does it go? And they'll tell you from a positive to negative and then another negative to positive instead of going through the external circuit and that basically a short circuit.

Interviewer: 6.7. How do you explain what makes a bulb light up in a circuit?

Interviewee: What makes a?

Interviewer: Light bulb light up in a circuit?

Interviewee: I never really gone through that. They have never asked me that really. But, all I would do is I'd tell then that obviously a light bulb is a resistance and as such as I told you, you would need to pay in order to get through now the only way that they pay, they use the energy, now the light bulb uses, converts the electrical energy in to light

Interviewer: 6.8. How do you explain the difference between current and potential difference?

Interviewee: Difference between current. Current is the flow of charge and the potential difference is the work done so basically as the vehicles are flowing through the highway they represent current. How many vehicles, each would represent a charge and their flow would represent the current. Now the amount of money that they pay or the amount of energy that they use to go over a hump or the money that they pay for a toll gate that would represent the energy that they use, which is the energy actually need to know how much he had before the toll gate and how much he had after the toll gate and that will be the potential difference and that is why he to go back to the atm to get more money or go back to the store to get more energy and then do the same trip again

Interviewer: 6.9. How do you explain that adding a resistor affects the components in front and behind in a circuit?

Interviewee: Alright that one, obviously I tell them that if you have a resistor alright and you have to pay off on of the resistors obviously you would need to go through the other ones and in fact they need to understand that as one charge moves its not that in the circuit there is only one charge moving that's making the circuit, its actually a series of charges that are moving so they need to understand that the moment there is and effect, the one charge experiences an effect it will effect the other charge, because its further away from it

Interviewer: 6.10. How do you explain that a battery produces more current when bulbs are added in parallel?

Interviewee: Battery produces more current when bulbs are added in parallel. Obviously as they split if you add the two addition would actually mean that its greater than subtracting, and that how I actually tell them if you have two cars and they split one plus one will give you two

Interviewer: Thank you for your time.

Interviewee: Thank you. I wished to have demonstrated some of these things

Interview transcript: Lee

Interviewer: Interview with participant 1

Interviewee: I consent to this interview and I am aware that the data obtained from this interview will be used for research.

Interviewer: 1.1. Do you feel that your studies prepared you for your classroom practice?

Interviewee: Yes

Interviewer: 1.2. Do you find it easy or difficult to explain things that you understand?

Interviewee: Easy

Interviewer: Why?

Interviewee: Because I'm am very well rehearsed in my subject and I have a very a very intense knowledge

Interviewer: 1.3. Do you find teaching electricity more difficult than other subjects?

Interviewee: Not…From the children's aspect maybe because they not exposed or so much exposed as they should be and because they come from a background where maybe they do not have experience with it, so it mean that one must start with very basic and connect it with their every lives where you can....for me to understand there is no problem but I must explain it to them.

Interviewer: 1.4. How do you usually start the topic of electricity?

Interviewee: How do I?

Interviewer: How do you usually start the topic of electricity?

Interviewee: I will connect it with the basic usage or where they stay now, I'm talking for example lighting that they have, lighting of the school and then remember they already have the basic knowledge of some basic understanding that they have a specific view due to electron flow and so on. So I'm going to then take it then step by step to explain to them

Interviewer: 1.5. What do you find most difficult to explain to your learners about electricity?

Interviewee: I think concepts like work done, maybe energy, not that I find difficult I understand fully but to explain it to them with their poor background, to explain to them concepts like that and you must really explain start basics step by step, to explain what is meant by work done? What is meant by energy, that sorts.

Interviewer: 1.6. Are there any specific concepts that your learners find difficult to understand in electricity?

Interviewee: I will say yes, parallel connection is one example in grade 9 if you go to the mathematically part, some of their mathematics is not up to date yet, so to explain to them that when you connect two in series and two in parallel for example that the resistance really becomes smaller and its really important

Interviewer: 2.1. When you explain how a circuit works, which analogies do you use?

Interviewee: The flowing of water in the pipe for example

Interviewer: Do you use only one analogy?

Interviewee: uhm, no I use one than one it depends in the situation it depends on the problem.

Interviewer: Which analogy works best for which concept?

Interviewee: For which concept? I will say the flow in the pipe for electron flow and then resistance is due to the flow of water in the pipe

Interruption by intercom

Interviewer: 3.1. Which experiments do you think are most important for electric circuits?

Interviewee: I think first the basic circuit, okay the basic circuit for er.. to show that when you have a battery and a little light in there and a switch and so on or a cell that there is a current flowing in there and then from there go to series resistance and from there then to parallel resistance

Interviewer: 3.2. It is difficult to do all the experiments. How do you decide which experiments should be done?

Interviewee: uhm, it depends ion the time available in a class. I will do all those basics definitely

Interviewer: 3.3. Do you think students benefit from practical work?

Interviewee: Yes

Interviewer: How?

Interviewee: Because its visual and its hand on and its concrete. Its not abstract

Interviewer: 3.4. Do you sometimes prefer to demonstrate something rather than to have the students do practical work themselves?

Interviewee: I would actually prefer the students to do the practical work after I demonstrate something but then in a class of 40 its not so easy so in many of the cases I demonstrate and then I work I walk around

Interviewer: 4.1. Do you feel that textbooks sometimes cause confusion of concepts?

Interviewee: It could be the case but I haven't experienced one yet, we use we use a prescribed one and er… that one we did not have any problems textbook and we haven't had any problems and we do not have several prescribed ones we have on prescribed one and that one we havnt got any problems

Interviewer: 4.2. Do you feel that the language barrier causes any misunderstandings?

Interviewee: That can happen ja

Interviewer: Can you give examples?

Interviewee: It is these learners come from several different languages and er… so I would think that concept of energy the concept of current so I don't even know if they got those words in their languages for them so it can be strange to them and it can cause confusion.

Interviewer: 4.3. If the textbook and syllabus differ in terms of sequence and content, which do you follow?

Interviewee: So long as I do the prescribed contents I can follow my syllabus which I think is preferably for the learners I teaching

Interviewer: 5.1. Is there any of the prescribed electricity content for Grade 9 that you think is too difficult?

Interviewee: No

Interviewer: 5.2. Do you think it is sufficient to observe brightness of bulbs to understand circuits, or do you think that measurements of current and potential difference are important for Grade 9 learners?

Interviewee: I think they must be exposed to it already because when they go to grade 10 they should know the basics some basics of it so they don't get confused

Interviewer: 5.3. Do you teach additional topics that are not prescribed for Grade 9?

Interviewee: I did, Ya not in electricity but more in mechanics

Interviewer: 5.4. Do you think that Grade 9 learners need to distinguish between voltage and current when learning about circuits?

Interviewee: yes

Interviewer: 5.5. Do you think that Grade 9 learners should do calculations in electricity?

Interviewee: very basics ones. By adding up series resistance and so on and learning how to calculate current and volts

Interviewer: Why?

Interviewee: Because then they are exposed, I think learners that go from grade 9 to grade 10 in science they are already exposed

Interviewer: 5.6. Do you think that the potential difference concept is important in teaching electricity in Grade 9?

Interviewee: Yes I think they should be exposed to that

Interviewer: Why?

Interviewee: Because then they have that basic information and when they go to grade 10 they already know what we talking about, although we will tend to speak only about voltage, the voltage measure and we wont mention the potential difference

Interviewer: 5.7. The CAPS document for Grade 9 prescribes series and parallel connections of bulbs but not of cells. Do you think it should be taught?

Interviewee: Yes I think it should be taught

Interviewer: Why?

Interviewee: Because when you work with series cells you just add them up, so we tend to talk about a battery and a battery is two or more cells and so when we gonna talk about the battery, so the moment we talk about the battery we gonna talk about series connections of cells

Interviewer: Do you think it may cause problems in the future if they are not taught series and parallel cells?

Interviewee: No, but I think they should be exposed to it

Interviewer: 6.1. How do you explain to learners the need for a closed circuit?

Interviewee: Well we teach them what's a closed circuit and what's a closed circuit. In an open circuit there is no current flow and a closed circuit you have a flow, so if they have an open circuit a flash light for example, there will be no flash light. If theres an open circuit in the kitchen they will have no electricity. So a closed circuit is very important

Interviewer: 6.2. How do you explain to a learner that the current in a series circuit stays the same throughout?

Interviewee: Well the easiest way there is to explain to them that there is no additional part for the current to flow. In other words if there is only one path for the current to flow through in the circuit and for that it means that all places is the same. If you have a parallel circuit then you don't have it the same

Interviewer: 6.3. How do you explain the meaning of conventional current to your learners?

Interviewee: I always go out the stand point that many many years ago, 30 odd years ago when people didn't know what electron flow is and so they observe, they had their man made batteries or cells, so they observe flow so they accepted that its from positive to negative and that's how we see it even today

Interviewer: 6.4. a) How do you explain that adding light bulbs in series decreases the brightness?

Interviewee: Because each one of those ones, alright I'll explain each one of those has a certain resistance and if you add up each once resistance the resistance becomes more and if go then to ohms law you see it well

Interviewer: b) How do you explain that adding light bulbs in parallel does not affect the brightness?

Interviewee: After I demonstrate the fact, then I will say to them the only way to explain to them properly is to do it mathematically after I've demonstrated it and then show them that actually your resistance goes down

Interviewer: 6.5. How do you explain that connecting cells in series increases the brightness of the bulb, but when you connect cells in parallel the brightness of the bulb is not affected?

Interviewee: When we look at parallel, when we look at series connection we can clearly see that we add up the cells but in parallel connection cells there is no add up and for that therefore the voltage doesn't go up

Interviewer: 6.6. How do you explain to learners what a short circuit is?

Interviewee: You must always think about their background and then explain to them, sometimes we have failure of light in this room and I explain to them that that can be due to a short circuit in other words there is a break in the line, causing an open circuit because it is difficult to explain to them that somebody maybe connected live to neutral together or something so I would just say we have an open circuit

Interviewer: 6.7. How do you explain what makes a bulb light up in a circuit?

Interviewee: okay, I would say that, now to go from a stand point that some on them have electricity and they have their electric stove and they switch it on and they know that current goes to through plate and the plate becomes red hot and I will explain that now I will explain that a light bulb works with a similar process and that due to the high resistance that you have in that little filament inside that you have a big build up of resistance and the current wants to go through and therefore there is much work to be done and heats up and then you see the light

Interviewer: 6.8. How do you explain the difference between current and potential difference?

Interviewee: I try to explain it in terms of maybe talk about the ammeter and the voltmeter and so I say an ammeter is always in series and an ammeter reads only current and the voltmeter reads only the voltage across the bulbs and so on and it does not read current at all, so its always connected in parallel and the other one is always connected in series

Interviewer: 6.9. How do you explain that adding a resistor affects the components in front and behind in a circuit?

Interviewee: I will say if you have a little light bulb and a current and a resistor connected after it and so on, it will affect the current flow and therefore, let me see, it will affect the current flow yes, and therefore if you haven't got a resistor in you have got a current flowing and if you have resistors in then the current will come down and then the bulb wont burn so bright if its connected in series

Interviewer: 6.10. How do you explain that a battery produces more current when bulbs are added in parallel?

Interviewee: Because the resistance goes down, when the bulbs are connected in parallel then the resistance goes down.

Interviewer: Thank you for your time

Interview transcript: Mike

Interviewer: Interview with participant C

Interviewee: I consent to this interview and I am aware that the data obtained from this interview will be used for research.

Interviewer: 1.1. Do you feel that your studies prepared you for your classroom practice?

Interviewee: Yes

Interviewer: In what way?

Interviewee: I think I acquire knowledge and the skills to be able to manage my classroom situation and then to impart the knowledge to my learners

Interviewer: 1.2. Do you find it easy or difficult to explain things that you understand?

Interviewee: I don't find it difficult to explain things that I understand

Interviewer: 1.3. Do you find teaching electricity more difficult than other subjects?

Interviewee: yes, than some subjects, than some topics in physics, yes

Interviewer: 1.4. How do you usually start the topic of electricity?

Interviewee: Usually I start by, asking them questions, I do not particular remember the questions, but I start by asking them questions that will bring, you know, issues of light, bulbs, batteries, cells then we build on from there.

Interviewer: 1.5. What do you find most difficult to explain to your learners about electricity?

Interviewee: The most difficult part of electricity for me is the circuit diagram and how to locate when there are diversions in current, you know, when there are branches in the current, for instance coming from the battery, the cell, the battery, and then there is ammeter A there is B, Ya that

Interviewer: 1.6. Are there any specific concepts that your learners find difficult to understand in electricity?

Interviewee: Ya, they are challenges with the, if cells are in series, their voltages are put together, therefore makes the bulb brighter, but if they are in parallel their voltages are not put together to make the bulbs brighter. They have difficulties in understanding that.

Interviewer: 2.1. Okay, when you explain how a circuit works, which analogies do you use?

Interviewee: how a circuit works…

Interviewer: for example: water pipes, people queuing, traffic

Interviewee: oooh… I normally use the blood circulating in the body

Interviewer: Do you use only one analogy?

Interviewee: no, I don't use only one

Interviewer: So you feel the blood circulation analogy works the best?

Interviewee: Yes

Interviewer: 3.1. Which experiments do you think are most important for electric circuits?

Interviewee: Ohms Law, The ohms law experiment. The experiment to verify ohms law

Interviewer: 3.2. It is difficult to do all the experiments. How do you decide which experiments should be done?

Interviewee: I usually choose ohms law, because its the more commonly required for them

Interviewer: 3.3. Do you think students benefit from practical work and how?

Interviewee: I think they benefit from practical work because they experience the experience the theory hands on and I think they are able to remember when questions are asked if they practically did it

Interviewer: 3.4. Do you sometimes prefer to demonstrate something rather than to have the students do practical work themselves?

Interviewee: Yes I sometimes prefer to demonstrate the practical work compared to the students doing it, for maybe sometimes lack of time, or lack of equipment

Interviewer: 4.1. Do you feel that textbooks sometimes cause confusion of concepts?

Interviewee: yes

Interviewer: Can you give examples?

Interviewee: Yes eeer… sometimes textbooks explain one particular concept in different ways making it confusing for students to choose which one of the concepts to use.

Interviewer: 4.2. Do you feel that the language barrier causes any misunderstandings?

Interviewee: yes, I think so

Interviewer: Can you give examples?

Interviewee: If the student doesn't understand the language of instruction then it becomes difficult for that learner to understand the detailed explanation because the language, they can not actually understand fully, obviously.

Interviewer: 4.3. If the textbook and syllabus differ in terms of sequence and content, which do you follow?

Interviewee: The syllabus

Interviewer: 5.1. Is there any of the prescribed electricity content for Grade 9 that you think is too difficult?

Interviewee: Electricity content of grade 9, I wouldn't say its too difficult, I would think it is challenging for them to understand, because some do understand. And its this concept of cells in series and cells in parallel, and then bulbs in series and bulbs in parallel.

Interviewer: 5.2. Do you think it is sufficient to observe brightness of bulbs to understand circuits, or do you think that measurements of current and potential difference are important for Grade 9 learners?

Interviewee: Come again

Interviewer: Do you think it is sufficient to observe brightness of bulbs to understand circuits, or do you think that measurements of current and potential difference are important for Grade 9 learners?

Interviewee: I think the brightness of bulbs is for me, better than using measurements potential difference and current

Interviewer: Why do you think so?

Interviewee: I think so because when they see that lets say you have one cell in a circuit and then you add another one and the bulb, it glows brighter in a series circuit for instance. And you do a similar example with the cells now in parallel and there is no change in the brightness of the bulb, then they see it and it starts sticking to their memory better than if you measure voltages and current, they don't usually understand what a voltage and current and what is the difference, but when they see the brightness increase, they understand better.

Interviewer: 5.3. Do you teach additional topics that are not prescribed for Grade 9?

Interviewee: Sometimes yes

Interviewer: Which topics and why?

Interviewee: I am not able to mention specific topics in electricity, but sometimes yes. I say sometimes yes because sometimes when you are teaching maybe you are busy teaching the prescribed topic and a learner asks a question that is beyond what is there, I do explain to them.

Interviewer: 5.4. Do you think that Grade 9 learners need to distinguish between voltage and current when learning about circuits?

Interviewee: Yes they should distinguish between voltage and current

Interviewer: 5.5. Do you think that Grade 9 learners should do calculations in electricity?

Interviewee: yes

Interviewer: Why?

Interviewee: If you just tell them current, voltage and brightness and parallel and series they should see the calculation part of it, to be able to see that if you are talking about cells in series and the voltages increases to make the bulb brighter they should see it in numbers.

Interviewer: 5.6. Do you think that the potential difference concept is important in teaching electricity in Grade 9?

Interviewee: I don't think so, because they don't understand it, it is difficult to explain it to them. I feel

Interviewer: 5.7. The CAPS document for Grade 9 prescribes series and parallel connections of bulbs but not of cells. Do you think it should be taught?

Interviewee: Yes, I think it should be taught

Interviewer: Why?

Interviewee: The cell produces the electrical energy for the bulb so they should see the effect when they are connected in series and in parallel

Interviewer: Do you think if it is not taught it will cause problems?

Interviewee: yes I think so I think it will cause problems in the future, they will be confusing the two but in teaching style it is emphasized in grade 10, 11 and 12. Its is much better than is waiting for a later stage.

Interviewer: 6.1. How do you explain to learners the need for a closed circuit?

Interviewee: If the circuit is not closed then you can't get light out of the circuit for instance. Ja that's how I explain it

Interviewer: 6.2. How do you explain to a learner that the current in a series circuit stays the same throughout?

Interviewee: Okay, what I usually explain to them in the circuit in a series circuit, if I put an ammeter just before the battery in series and then after that they see a light bulb and then the circuit is closed, it's the same as taking that ammeter and putting after the bulb and the circuit is closed because it the circuit is closed. That's how I usually explain it.

Interviewer: 6.3. How do you explain the meaning of conventional current to your learners?

Interviewee: Conventional current. I explain it to them that it's the way it's accepted, the conventional current is the route that the current takes from positive to the negative terminal. So I explain it to them that that is how it is accepted all around the world, that the current moves from the positive to the negative terminal.

Interviewer: 6.4. a) How do you explain that adding light bulbs in series decreases the brightness?

Interviewee: Light bulbs in series, I explain it that the bulb the bulb are resisting. So when you put a resistor is like a barrier, when you put barrier one the resistance the resistance that that barrier is going to put is less than when you put barrier two just in front of it. So the more you put the barrier the more the resistance to the flow of current.

Interviewer: b) How do you explain that adding light bulbs in parallel does not affect the brightness?

Interviewee: Light bulbs in parallel does not affect the brightness because the current gets divided to the bulb unlike when they are in series the current cant pass through all of them in a line

Interviewer: 6.5. How do you explain that connecting cells in series increases the brightness of the bulb, but when you connect cells in parallel the brightness of the bulb is not affected?

Interviewee: When you connect the cells in series their energy sum up so it gives the brightness of the bulb for instance if you put two cells together of 1.5 each you are getting 3 volts if you add another to it the voltage increases to 4 cells in series. But when you put the cells in parallel their voltages don't sum up because when you put the, when you put the voltmeter across all three you will get the same voltage, when you put it across 1 you will get the same voltage.

Interviewer: 6.6. How do you explain to learners what a short circuit is?

Interviewee: A short circuit is when the, when the circuit is bridged and what I do is I normally use a computer simulation to show them. I connect the circuit for them to see then I just pull one side and connected it to another and the bulb blows up and they can see that it's a short circuit

Interviewer: 6.7. How do you explain the difference between current and potential difference?

Interviewee: Current is the rate of flow of charges, charges here we are talking about the electrons in motion, so the rate of flow of the charges, how fast the charges flow constitutes the amount of current that we have in the system. Now potential difference it the energy the cell has in it. That is how I explain it to them.

Interviewer: 6.8. How do you explain what makes a bulb light up in a circuit?

Interviewee: There light bulb has the resistance wire in it and when you connect the light bulb to the cell for instance there light bulb, the resistance in the light bulb the resistance wire in the light bulb resists the flow of current through it and therefore it heats up and then clearly that heat in it, it glows and it produces the light. That is how I explain it.

Interviewer: 6.9. How do you explain that adding a resistor affects the components in front and behind in a circuit?

Interviewee: Ja the resistor in a circuit, whether its in front or behind the components in the circuits its an opposition to the flow of current in the circuit. So no matter where it is it is just stopping that flow of current and it doesn't give it that free flow, so whether its in front or behind the component it offers the same effect

Interviewer: 6.10. How do you explain that a battery produces more current when bulbs are added in parallel?

Interviewee: the battery…

Interviewer: How do you explain that a battery produces more current when bulbs are added in parallel?

Interviewee: When the bulbs are added. I find it easier to explaining it to them from the series point of view, that when they are in series it's a feeling of opposition or barriers in front of them, but when they are in parallel there are branches for the current to flow, unlike if they are in series one chain and several barriers. I combine it with the bulbs in series

Interviewer: Thank you for your time.

Interview Transcript: Nick

Interviewer: Interview with participant D

Interviewee: I consent to this interview and I am aware that the data obtained from this interview will be used for research.

Interviewer: 1.1. Do you feel that your studies prepared you for your classroom practice?

Interviewee: The studies that I have done, not really do the HOD diploma, I was only doing the post degree certificate that does not really prepare you for school

Interviewer: Which topic would you prefer to know better?

Interviewee: Which topic? Is this in the N.S?

Interviewer: In the N.S. syllabus

Interviewee: I don't really have a problem with the topics, I would maybe say if have to go to geography component, yes.

Interviewer: 1.2. Do you find it easy or difficult to explain things that you understand?

Interviewee: Sometimes its difficult, because you understand it, but you have to make it clear to the pupil and you cant see you the pupil why the pupil cant understand something that is clear to you. Its sometimes difficult to explain things that you understand.

Interviewer: 1.3. Do you find teaching electricity more difficult than other subjects?

Interviewee: Electricity in grade 9 yes, because they don't always grasp all concepts that are intertwined in electricity that they have to take in to consideration when they work out problems and stuff like that

Interviewer: 1.4. How do you usually start the topic of electricity?

Interviewee: There are different ways that I usually start, I don't have a certain way it depends on class to class, but I think the way that I usually go is I tell them the importance of electricity and then why they have to study it, why they know how to work with it

Interviewer: 1.5. What do you find most difficult to explain to your learners about electricity?

Interviewee: The most difficult is usually how to do the actual problems, how to use the formulas, because they get meddled up, muddled up with that very easily and if they once have the notion to use a formula like this, its sometimes very, not very easy to get them out of that rut they get in

Interviewer: 1.6. Are there any specific concepts that your learners find difficult to understand in electricity?

Interviewee: I'm new at this school so I don't know where they really battle with electricity, but if I can speak of past schools, the concepts usually are what happens if the resistors are in series or parallel. Those concepts they don't usually understand very well

Interviewer: 2.1. When you explain how a circuit works, which analogies do you use?

Interviewee: The one that I like to use is to compare it with children in a bound together, not bound together but with a rubber band around it or with pins and a rubber band around it and then different things that you put in the different resistors and stuff works

Interviewer: Do you have any specific analogy that you use for a specific concept?

Interviewee: If you the current analogy that I use. An athlete, the current is how fast the athlete runs, how fast, how quickly he covers the distance and that is what I use for current for instance for current

Interviewer: 3.1. Which experiments do you think are most important for electric circuits?

Interviewee: Which experiments? How to use the different meters, they must be able to do that and over all how to connect electric circuits because they don't know how to do it

Interviewer: 3.2. It is difficult to do all the experiments. How do you decide which experiments should be done?

Interviewee: The decision usually goes with the cognitive levels of the class if they know how to use the circuit board and how to connect it then you know if you can go with more difficult experiments and give them something more challenging to work out because they now know how to connect all the things now its just for them to do the readings, that how I usually look at it.

Interviewer: 3.3. Do you think students benefit from practical work?

Interviewee: yes they do

Interviewer: How?

Interviewee: It gives them hands on on these experiments on working with electrical stuff. At home they don't get the chance to do it. Their parents don't let them use their electrical utensils to do experiments on. See how it works. So at school you have a more simpler way of getting them to know electricity

Interviewer: 3.4. Do you sometimes prefer to demonstrate something rather than to have the students do practical work themselves?

Interviewee: That also depends on the class, it depends on how the class handles itself because, you do get classes when you do experimental work they do get out of hand. So it depends on the class but I would prefer them to experimental work than the demonstration.

Interviewer: 4.1. Do you feel that textbooks sometimes cause confusion of concepts?

Interviewee: Textbooks that I've used up to now, I didn't get a confusion of concepts, its more a confusion of the learners

Interviewer: 4.2. Do you feel that the language barrier causes any misunderstandings?

Interviewee: Yes

Interviewer: Can you give examples?

Interviewee: I think they don't always understand the terminology, they don't, some languages don't have terminology in their language so there is no way that you can actually explain to them what it is. They just have to go by the English and Afrikaans that we have.

Interviewer: 4.3. If the textbook and syllabus differ in terms of sequence and content, which do you follow?

Interviewee: Sequence or content? Do you mean the existing textbooks with the sequence that the department gives?

Interviewer: Yes

Interviewee: I will the follow the sequence of the department, with grade 8 and 9 you have actually, you have to do it, especially if your school takes the provisional or district exam

Interviewer: so you will follow the syllabus?

Interviewee: Then you follow the syllabus and not the textbook

Interviewer: 5.1. Is there any of the prescribed electricity content for Grade 9 that you think is too difficult?

Interviewee: Electricity no, I don't think so

Interviewer: 5.2. Do you think it is sufficient to observe brightness of bulbs to understand circuits, or do you think that measurements of current and potential difference are important for Grade 9 learners?

Interviewee: In a way it is sufficient to look at the brightness of bulbs, but to prepare them for further, a further studies in science you must go to the measurements

Interviewer: 5.3. Do you teach additional topics that are not prescribed for Grade 9?

Interviewee: Additional topics, in science?

Interviewer: Yes

Interviewee: No I don't there is no time for it

Interviewer: 5.4. Do you think that Grade 9 learners need to distinguish between voltage and current when learning about circuits?

Interviewee: Between voltage and current? Yes they have to

Interviewer: 5.5. Do you think that Grade 9 learners should do calculations in electricity?

Interviewee: Yes

Interviewer: Why?

Interviewee: Grade 9 is actually the basics of electricity, if you do not teach calculations when they get to grade 10 they don't know how to calculate these things. They didn't have the basic education on how to look at these sums or these questions

Interviewer: 5.6. Do you think that the potential difference concept is important in teaching electricity in Grade 9?

Interviewee: say again

Interviewer: Do you think that the potential difference concept is important in teaching electricity in Grade 9?

Interviewee: potential difference? yes

Interviewer: Why?

Interviewee: Again its its one of the basic concepts they have to be taught. The sooner you teach it the better it is for the learner to grasp the concept. They may have difficulties now in grade 9 but they will get it in grade 10 again and then it is easy to grasp the concept

Interviewer: 5.7. The CAPS document for Grade 9 prescribes series and parallel connections of bulbs but not of cells. Do you think it should be taught?

Interviewee: I think it should be taught

Interviewer: Why?

Interviewee: For one reason if you have it on bulbs its easy to have it on to just connect it to cells. And in life in their lives you do get batteries that are series connected and that are parallel connected and they must know which to choose even if they don't go on with science because grade 9 is not just for grade 10, its to actually prepare them for their, sort of preparation for their life.

Interviewer: So do you think it may cause problems if they don't learn cells in series and in parallel?

Interviewee: It won't really cause problems but it will be better if they know it

Interviewer: 6.1. How do you explain to learners the need for a closed circuit?

Interviewee: The closed is when the current flows. If you don't have a closed circuit nothing works in that circuit. So you must have a way of connecting two points so that the current flows and you can do work on the circuit.

Interviewer: 6.2. How do you explain to a learner that the current in a series circuit stays the same throughout?

Interviewee: That is what I've said previously, that is why I like to use tins or something that is connected rubber band or something and then you mark different spaces on the rubber band and you have a wheel that you turn and then you can see if you turn the wheel and you measure the distances travelled by the different marks that it doesn't matter where in the circuit it is they stay the same

Interviewer: 6.3. How do you explain the meaning of conventional current to your learners?

Interviewee: Conventional current I usually go back to old times when they did not know about electrons and stuff but that they only knew about charges and they used positive charges, and positive will flow from positive to negative and that's how I explain it to them

Interviewer: 6.4. a) How do you explain that adding light bulbs in series decreases the brightness?

Interviewee: Decreases the brightness, there I tell them its like a large pipe full of water if you put in a few smaller pipes in succession you will see that the water that you get out is less so that shows you that the work done as the water pass through is higher as you put in more small pipes and that is why your light bulbs will be less bright

Interviewer: b) How do you explain that adding light bulbs in parallel does not affect the brightness?

Interviewee: That is for bulbs that is identical?

Interviewer: yes

Interviewee: If you it also works with the pipe story, if you have one big pipe and few small pipes identical, the same amount of water will pass through the pipes that's why the light bulbs will have the same brightness

Interviewer: 6.5. How do you explain that connecting cells in series increases the brightness of the bulb, but when you connect cells in parallel the brightness of the bulb is not affected?

Interviewee: Its like how I've explained in the questionnaire its like two lorries that you connect in series the front to the back end of the lorry they will be able to pull a much heavier load because together they are stronger, its not to say that they are going to last long because if one lorry breaks down the other will not be able to do the work because they have to do the work for the other lorry as well broken lorry if you take those same two lorries and put them next to each other you will be able to do the same work of one lorry but you will be able to do it longer, what I usually say is you will use less fuel because you lighten the task of the lorries

Interviewer: 6.6. How do you explain to learners what a short circuit is?

Interviewee: That I always is when you give the current an easier way to travel, its like when you have to travel over a hill, with all the stones in it, or they make a tunnel through the hill, you will take the tunnel through the hill because it is easier the current will do the same thing so you will bypass all those other resistors in your way

Interviewer: 6.7. How do you explain what makes a bulb light up in a circuit?

Interviewee: That sounds kind off tricky, I usually say there is the charges that goes through the light bulb as they go through the light bulb they encounter the atoms of the filament so to go past it they have to use energy, the easier way to get past those atoms the less brighter the bulb will be, so they don't give off a lot of energy to the filament and the amount of energy determines the brightness of the bulb, the amount of energy that they give off determines the brightness of the bulb

Interviewer: 6.8. How do you explain the difference between current and potential difference?

Interviewee: Current is how fast the charges pass through a certain area or point in a circuit. The potential difference is how the potential to do work differs from one point to another in a circuit. That's how I usually explain it to them

Interviewer: 6.9. How do you explain that adding a resistor affects the components in front and behind in a circuit?

Interviewee: How it will affect in front and behind the resistor. If you add a resistor in a circuit it will lower the current strength so in series the effect will be the same in front or behind adding it in the middle will not have a different effect on the components in front or behind

Interviewer: 6.10. How do you explain that a battery produces more current when bulbs are added in parallel?

Interviewee: In parallel the resistance lowers each time that you add a resistor, the resistance lower, the battery can supply a certain amount of current if you add any resistors in series in with the battery, then the current will lower, will be lower so if you take it and then add it in parallel the current will be higher.

Interviewer: Thank you for you time

Interviewee: Thank you

Interview transcript: Olivia

Interviewer: Interview with participant E

Interviewee: I consent to this interview and I am aware that the data obtained from this interview will be used for research.

Interviewer: 1.1. Do you feel that your studies prepared you for your classroom practice?

Interviewee: No

Interviewer: Why not?

Interviewee: Because they didn't take in to account the physical or cultural differences in the class

Interviewer: Which topic would you prefer to know better?

Interviewee: Mechanics

Interviewer: 1.2. Do you find it easy or difficult to explain things that you understand?

Interviewee: Easy

Interviewer: 1.3. Do you find teaching electricity more difficult than other subjects?

Interviewee: more difficult

Interviewer: 1.4. How do you usually start the topic of electricity?

Interviewee: By doing a practical with a circuit board using electricity

Interviewer: 1.5. What do you find most difficult to explain to your learners about electricity?

Interviewee: The difference of potential difference and current in a circuit

Interviewer: 1.6. Are there any specific concepts that your learners find difficult to understand in electricity?

Interviewee: The potential difference definitely, ya

Interviewer: 2.1. When you explain how a circuit works, which analogies do you use? Example: water pipes, people queuing in traffic

Interviewee: Houses, I use houses the lighting up of houses, streets, things like that

Interviewer: 3.1. Which experiments do you think are most important for electric circuits?

Interviewee: The experiments where you look at the increase in potential difference in a circuit as you add more cells to the circuit as well as the potential difference increases the current also increases the graph showing them how to draw a graph of potential difference and current

Interviewer: 3.2. Is difficult to do all the experiments?

Interviewee: No

Interviewer: How do you decide which experiments should be done?

Interviewee: The ones that is a challenge to the learners, the ones the learners will understand the concepts taught, if I see that this is a concept that they struggle with, if I do an experiment with them, so that they can see, “oh this is how it works” and they understand it better.

Interviewer: 3.3. Do you think students benefit from practical work?

Interviewee: Yes they do

Interviewer: How?

Interviewee: When they see it in real life they can actually (what is the word Im looking for) if they see it and how it happens, it becomes a reality and they realise that this is what they are learning

Interviewer: 3.4. Do you sometimes prefer to demonstrate something rather than to have the students do practical work themselves?

Interviewee: yes

Interviewer: In what way do you find it easier to demonstrate?

Interviewee: Time saving

Interviewer: 4.1. Do you feel that textbooks sometimes cause confusion of concepts?

Interviewee: Yes

Interviewer: Can you give examples?

Interviewee: Not out of the top of my head right now

Interviewer: 4.2. Do you feel that the language barrier causes any misunderstandings?

Interviewee: Yes, it does

Interviewer: Can you give examples?

Interviewee: Most of the learners taught in our class, English is not a first or home language to them and other languages which are taught and spoken to at home and when they come to the class and you speak to them in English and that confuses them a lot especially with the younger grades

Interviewer: 4.3. If the textbook and syllabus differ in terms of sequence and content, which do you follow?

Interviewee: I follow the content of the textbook

Interviewer: 5.1. Is there any of the prescribed electricity content for Grade 9 that you think is too difficult?

Interviewee: No

Interviewer: 5.2. Do you think it is sufficient to observe brightness of bulbs to understand circuits, or do you think that measurements of current and potential difference are important for Grade 9 learners?

Interviewee: The measurements between potential difference and current

Interviewer: Why do you think so?

Interviewee: Because if you look at the grade 10 syllabus, we try to prepare them for what sin grade 10, with the grade 10 syllabus they don't go into detail of potential difference and current, if they get the basics in grade 9 then the grade 10 syllabus becomes easy

Interviewer: 5.3. Do you teach additional topics that are not prescribed for Grade 9?

Interviewee: No, don't have time

Interviewer: 5.4. Do you think that Grade 9 learners need to distinguish between voltage and current when learning about circuits?

Interviewee: Yes

Interviewer: 5.5. Do you think that Grade 9 learners should do calculations in electricity?

Interviewee: Yes

Interviewer: Why?

Interviewee: Because again it prepares them for grade 10, 11, and 12 and for the learners that leave grade 9, they need to have the basics

Interviewer: 5.6. Do you think that the potential difference concept is important in teaching electricity in Grade 9?

Interviewee: yes

Interviewer: Why?

Interviewee: Because they need to know the concept, they need to know what is, potential difference in a circuit and how to apply it to their everyday life

Interviewer: 5.7. The CAPS document for Grade 9 prescribes series and parallel connections of bulbs but not of cells. Do you think it should be taught?

Interviewee: no

Interviewer: Why?

Interviewee: I don't think it's necessary, for them to know between the cells and the light bulbs. I teach it to them but I don't think it's necessary.

Interviewer: Do you think it may cause problems?

Interviewee: It can yes

Interviewer: 6.1. How do you explain to learners the need for a closed circuit?

Interviewee: If the circuit is open if then some connections in the circuit wont work, if the circuit is closed, then all your connections work, and that will show them lets say a circuit in the house is in parallel so if one light bulb should short out then why does the rest of the light bulbs still light up

Interviewer: 6.2. How do you explain to a learner that the current in a series circuit stays the same throughout?

Interviewee: Because it does. I cannot explain it

Interviewer: 6.3. How do you explain the meaning of conventional current to your learners?

Interviewee: Can we come back to that one?

Interviewer: Okay. 6.4. a) How do you explain that adding light bulbs in series decreases the brightness?

Interviewee: Because there is more resistance. Each time a connector is connected there is more resistance of the flow of the current. The current has to flow through and extra components so some energy is lost or converted at this why the light bulbs shine dimmer

Interviewer: b) How do you explain that adding light bulbs in parallel does not affect the brightness?

Interviewee: because of the current dividing equally through each light bulb

Interviewer: 6.5. How do you explain that connecting cells in series increases the brightness of the bulb, but when you connect cells in parallel the brightness of the bulb is not affected?

Interviewee: By adding it in series you are actually adding up the voltages to it will be lets say if its 3 cells its 3,5, where if you have it in parallel it stays 1.5, it doesn't get added up like in series circuits

Interviewer: 6.6. How do you explain to learners what a short circuit is?

Interviewee: When there is too much components and not enough energy to supply the components with, it kicks out or it shorters

Interviewer: 6.7. How do you explain what makes a bulb light up in a circuit?

Interviewee: The electrons, the charges in the circuit allows the light bulb, because its energy

Interviewer: 6.8. How do you explain the difference between current and potential difference?

Interviewee: The current is the charges that flow throughout the circuit the potential difference is the amount of energy supplied to the components on a specific circuit not necessarily the whole circuit itself, for example a light bulb and resistor, you able to get the potential difference of each, if there is no components there is no potential difference in the circuit

Interviewer: 6.9. How do you explain that adding a resistor affects the components in front and behind in a circuit?

Interviewee: Quickly read the question again

Interviewer: How do you explain that adding a resistor affects the components in front and behind in a circuit?

Interviewee: Well the components in front will receive charges and some of the energy will be lost and by the time it gets to the last lets say light bulb for example that light bulb will be dimmer because it already went through two components lost well not lost but some of the energy was converted leaving lesser energy for the third one

Interviewer: 6.10. How do you explain that a battery produces more current when bulbs are added in parallel?

Interviewee: Come back to that one

Interviewer: Okay, back to the one we missed. How do you explain the meaning of conventional current to your learners?

Interviewee: In everyday life?

Interviewer: In the circuit

Interviewee: In the circuit, how do I explain it? I just explain that the battery has a positive and negative side and the current needs to flow from a positive to a negative side of the battery

Interviewer: Okay coming back to the last question. How do you explain that a battery produces more current when bulbs are added in parallel?

Interviewee: Because of the current dividing equally between each of the light bulbs. That’s what I would say

Interviewer: Okay

Interview transcript: Kate

Interviewer: Interview with participant 1

Interviewee: I consent to this interview and I am aware that the data obtained from this interview will be used for research.

Interviewer: 1.1. Do you feel that your studies prepared you for your classroom practice?

Interviewee: No

Interviewer: Which topic would you prefer to know better?

Interviewee: Physical sciences

Interviewer: Can you be more specific?

Interviewee: Chemistry

Interviewer: 1.2. Do you find it easy or difficult to explain things that you understand?

Interviewee: If I understand it, its easy

Interviewer: 1.3. Do you find teaching electricity more difficult than other subjects?

Interviewee: Yes

Interviewer: 1.4. How do you usually start the topic of electricity?

Interviewee: Asking by, what do we use, Errrrrm….everyday, in our everyday lives, to make life easier

Interviewer: 1.5. What do you find most difficult to explain to your learners about electricity?

Interviewee: Calculations

Interviewer: 1.6. Are there any specific concepts that your learners find difficult to understand in electricity?

Interviewee: Just the calculations again

Interviewer: 2.1. When you explain how a circuit works, which analogies do you use?

Interviewee: I normally have a cell in my class. I do not have a laboratory, so then I will just try and let them imagine how it works.

Interviewer: Okay, Eeerrmmm..which analogy works best for the concept?

Interviewee: By having like a physical eerrrrmmm… circuit, in front of the class and then show them how all parts or components work

Interviewer: 3.1. Which experiments do you think are most important for electric circuits?

Interviewee: Show the difference between series and parallel connections, eermm.. voltage regarding electrical forces, eerrmmm… ammeters why and how they increase and decrease

Interviewer: 3.2. It is difficult to do all the experiments. How do you decide which experiments should be done?

Interviewee: I decide to do experiments which eerrmm…I feel will let the learners understand better like between series and parallel connections

Interviewer: 3.3. Do you think students benefit from practical work?

Interviewee: Yes

Interviewer: How?

Interviewee: They see it visibly and some learners tend to remember better by seeing and not just by learning theory

Interviewer: 3.4. Do you sometimes prefer to demonstrate something rather than to have the students do practical work themselves?

Interviewee: Ya, for safety purposes

Interviewer: 4.1. Do you feel that textbooks sometimes cause confusion of concepts?

Interviewee: Yes

Interviewer: Can you give examples?

Interviewee: Eeerrrmm… some textbooks for example do not have all the Eerrmm..content that we need to give the learners, so then we have to refer to other textbooks and sometimes that content differ from the prescribed textbook

Interviewer: 4.2. Do you feel that the language barrier causes any misunderstandings?

Interviewee: Yes

Interviewer: Can you give any examples?

Interviewee: Some learners struggle with English itself, so teaching in English for example, and they do not understand English as well, makes it difficult fro them to understand

Interviewer: 4.3. If the textbook and syllabus differ in terms of sequence and content, which do you follow?

Interviewee: eeerrrmmm… Content

Interviewer: Okay, 5.1. Is there any of the prescribed electricity content for Grade 9 that you think is too difficult?

Interviewee: No

Interviewer: 5.2. Do you think it is sufficient to observe brightness of bulbs to understand circuits, or do you think that measurements of current and potential difference are important for Grade 9 learners?

Interviewee: I think both of them because they do need to see why a bulb works and why some bulbs go brighter and why some glow dimmer and they need to understand between amperes and voltage for example

Interviewer: 5.3. Do you teach additional topics that are not prescribed for Grade 9?

Interviewee: With some of the calculations, yes, like conversions from milli-amperes to amperes, from kilo-ohms to just ohms.

Interviewer: 5.4. Do you think that Grade 9 learners need to distinguish between voltage and current when learning about circuits?

Interviewee: Ya

Interviewer: 5.5. Do you think that Grade 9 learners should do calculations in electricity?

Interviewee: Yes

Interviewer: Why?

Interviewee: To prepare them for those that needs to take physical sciences from grade 10 to 12. So that they have the basic background of calculations

Interviewer: 5.6. Do you think that the potential difference concept is important in teaching electricity in Grade 9?

Interviewee: Ya

Interviewer: Why?

Interviewee: Eeerrrmm…. Because it doesn't help if you have the content correct and give that through to them but they don't have the concept for example by visualizing or seeing a current, how a current works. It doesn't help to say you need 3 most important concepts of a circuit but you can't show them how it works.

Interviewer: 5.7. The CAPS document for Grade 9 prescribes series and parallel connections of light bulbs but not of cells. Do you think it should be taught?

Interviewee: yes

Interviewer: Why?

Interviewee: Because so that the learners can understand that eerrrr…electrical sources can also be eerrr…connected in one of the two ways, either series or parallel and what the disadvantages and advantages of it.

Interviewer: Do you think by them not being taught this it will cause problems?

Interviewee: For those of them that need be an electrician or an engineer, an electrical engineer, or something like that. They need to know that.

Interviewer: 6.1. How do you explain to learners the need for a closed circuit?

Interviewee: I will just tell them if a circuit is not closed how are you going to get light in your room or light in your house. There needs to a closed circuit otherwise there is no electricity flow

Interviewer: 6.2. How do you explain to a learner that the current in a series circuit stays the same throughout?

Interviewee: Because there I would say, it is eerrr…because of the cells being connected in series supplies a very strong current and the current is not being splitted up like in the case of parallel

Interviewer: 6.3. How do you explain the meaning of conventional current to your learners?

Interviewee: by using the concept of positive and negative charges that flows and the direction of the current from positive to negative

Interviewer: 6.4. a) How do you explain that adding light bulbs in series decreases the brightness?

Interviewee: Because all the bulbs are errrr…been connected in series means in line so its actually logical sense the more bulbs you add the less electrical energy is going to go through each of them. Its going to glow dimmer.

Interviewer: b) How do you explain that adding light bulbs in parallel does not affect the brightness?

Interviewee: Because there the current is being splitted up so its not going to have an influence on current flow itself

Interviewer: 6.5. How do you explain that connecting cells in series increases the brightness of the bulb, but when you connect cells in parallel the brightness of the bulb is not affected?

Interviewee: Because cells being connected in series supplies a stronger electrical energy than cells being connected in parallel.

Interviewer: 6.6. How do you explain to learners what a short circuit is?

Interviewee: There I would just tell them, the 3 main eerrr… components of a circuit, energy source, conducting wires and a light bulb

Interviewer: 6.7. How do you explain what makes a bulb light up in a circuit?

Interviewee: It's the conversion from electrical energy to heat and light energy in the light bulb itself

Interviewer: 6.8. How do you explain the difference between current and potential difference?

Interviewee: Eeerm… current is electrical energy that moving and potential difference is the voltage of the energy cell

Interviewer: 6.9. How do you explain that adding a resistor affects the components in front and behind in a circuit?

Interviewee: Because the resistor supplies a percentage of resistance to any circuit, doesn't matter how it is connected

Interviewer: 6.10. How do you explain that a battery produces more current when bulbs are added in parallel?

Interviewee: Because a battery consists out of two or more cells which is connected, so thats actually quite obvious. Its like a container

Interviewer: Thank you for your time

Interviewee: Its only my pleasure. No problem