

**The use of an analogy in conjunction with a conventional
practical activity to mediate Grade 11 learners' sense making of
Ohm's law**

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By

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Declaration

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and has not previously in its entirety or in part been submitted at any university for degree purposes.

Signature: .....

Date: 05 September 2016

Abstract

In most South African schools Grade 12 Physical Sciences learners are generally not performing well. As Examiners' Reports reveal, they are particularly weak on the topic of electrical circuits. Because of this, the Examiners recommended that conventional practical activities and revision should be implemented to improve learners' performance whilst they are in Grade 11. These factors contributed to the rationale of this study in using the 'straw electricity' analogy in conjunction with a conventional practical activity to mediate learners' sense making of Ohm's law.

The study falls within the interpretive paradigm, whose focus is on the understanding of human world-views. Within the interpretive paradigm a qualitative case study approach was employed. It is a case study because it aimed to investigate a group of learners in a given context. This qualitative case study used purposive sampling to select participants. Various data gathering techniques were employed, namely, documents, observations and stimulated recall interviews. The gathered data was analysed so as to determine the indicators of how learners made sense of Ohm's law.

The findings of this study are that learners were able to construct new knowledge within a social context where the 'straw electricity' analogy, using easily accessible resources, was incorporated in tandem with a conventional practical classroom task. Moreover, the 'straw electricity' analogy enabled a better understanding of science concepts as it tested and supported different learning skills.

Dedication

This thesis is dedicated to my supportive mother (Maselebeli Ramasike), my two friendly brothers (Teboho Ramasike and Katiso Ramasike), my adorable son (Rorisang Ramasike), and my family. They all care about my well-being and are very considerate to me.

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My family has shown understanding at all times when I had to spend most of my weekends and holidays focusing on my studies and travelling to the University. Family time has been compromised for two years, but it was for good cause.

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LIST OF ABBREVIATIONS AND ACRONYMS

AfL	Assessment for Learning
CAPS	Curriculum and Assessment Policy Statements
DoE	Department of Education
FET	Further Education and Training Band
HSRC	Human Sciences Research Council
L1	Home language
L2	Second language
LoLT	Language of Learning and Teaching
LTSM	Learning and Teaching Support Material
MCQ	Multiple Choice Questions
MKO	More Knowledgeable Others
PEEOE	Predict, Explain, Explore, Observe, Explain
TIMSS	Trends in International Mathematics and Science Study
UK	United Kingdom
USA	United States of America
ZPD	Zone of Proximal Development

CHAPTER 1

CONTEXT OF MY STUDY

1.1 Introduction

The central goal of this study was to explore how Grade 11 Physical Sciences learners made sense of Ohm's law when it was mediated through an analogy in conjunction with a conventional practical activity. The need for this study was triggered by various reports such as the Trends in International Mathematics and Science Study (TIMSS, 2011), Human Sciences Research Council (HSRC, 2015) as well as the Physical Sciences Examiner's Report (Examiner's Report, 2013). These mentioned reports reveal a continuous decline in science performance.

This chapter gives an overview of the context of the study. In this regard, reference is made to the international and national reports, the South African Curriculum and earlier research findings. It also discusses the problem statement, the significance of this study, the research goal and questions, the key concepts used and the framework of the thesis is provided. This chapter ends with some concluding remarks.

1.2 Reports on science performance

The TIMSS (2011) Report reveals that generally most countries are not doing well in Mathematics and Sciences. The Report is based on the international assessment of science subjects such as Life Sciences, Physical Sciences and Earth Sciences. The assessment programme was first administered in 1995 in South Africa in Grade 4 and Grade 8. Thereafter, Grade 9 was assessed from the year 2002 (TIMSS, 2011; HSRC, 2015). Results of such reports show that South Africa is ranked amongst the lowest performing countries. It could be argued that the impact of context as well as language might in part be contributing factors to such poor results (HSRC, 2015). According to Chisholm and Leyendecker (2008), the participation of South Africa in the assessment for international recognition, brought more pressure to this country. The pressure was aggravated by no sign of improvement of learners' performance in science subjects. The country's context such as the widely spread geographical orientation of schools places more pressure on the poor quality of assessment results (Howie, 2004).

For instance, 50% of South Africa is serviced by rural schools with limited resources (Howie, 2004). Such impoverished schools with limited resources are classified as Quintile 1 and Quintile 2. Additionally, most of Quintile 1 and Quintile 2 schools are the senior secondary schools which are classified as ‘no fee’ schools, so they are unable to buy the resources needed. In the South African context, being a ‘no fee’ school implies that parents are not expected to contribute towards their children’s school fees. The result of this is that learning is negatively affected because the South African Curriculum is not encouraging the use of easily accessible materials or analogies in teaching science at senior secondary school level (South Africa. Department of Basic Education [DBE], 2011).

Throughout this project and in line with the South African Curriculum and Assessment Policy Statement (CAPS), this study refers to the Physical Science subject as Physical Sciences (South Africa. DBE, 2011). Physical Sciences is one of the subjects which is nationally examined in South Africa and the sentiments around poor results resonate with the international Reports. At the national level, learners’ performance in each subject is reflected in the Examiner’s Reports. Examiner’s Reports on Physical Sciences Paper 1 examination paper, give annual feedback of poor performance by Grade 12 candidates. For instance, the recent Examiner’s Report highlights that very few learners did well in the electricity question and the majority did not perform well at all (Examiner’s Report, 2013; see Appendix F). Additionally, in comparison with the other topics, electricity is usually the most poorly answered question as reflected in Figure 1 below.

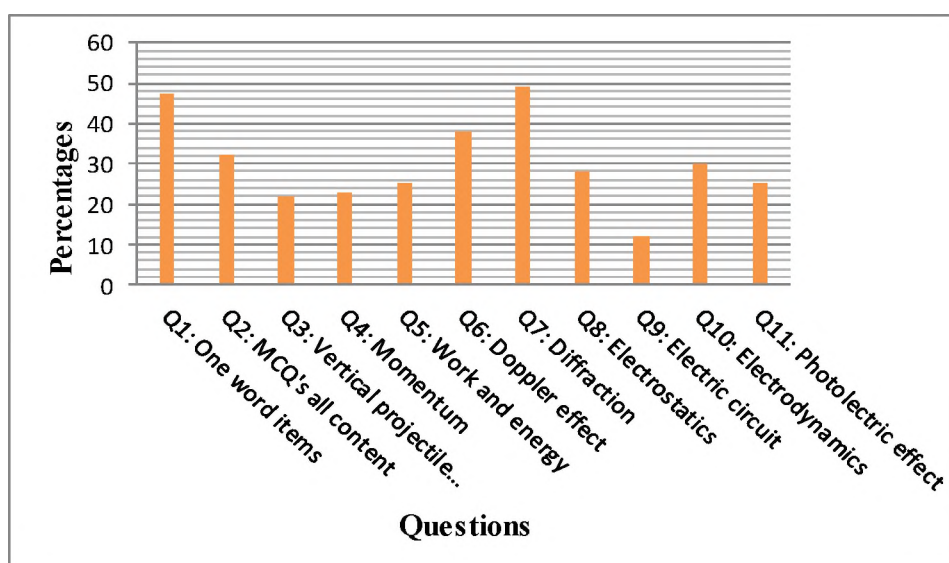


Figure 1: Performance in Physical Sciences Paper 1 topics as reflected in the Examiner's Report 2013

In the same vein, reports indicate that the science literacy level is gradually dropping and the topic on electricity remains a challenge due to the abstract nature of its concepts (Baser, 2006). It is precisely for these reasons that the Examiner's Reports encourage the revision of Grade 11 work to improve understanding of the topic. However, it is possible that revision alone may be insufficient and even where useful, it could be supplemented with the use of additional mediation tools, such as analogies. It is against this backdrop that I became interested in doing research focussing on the use of an analogy in conjunction with a conventional practical activity to mediate learners' meaning making of Ohm's law. Ohm's law is a fundamental pillar of electricity concepts as documented in the South African Curriculum (South Africa. DBE, 2011; South Africa. DBE, 2014).

1.3 South African Curriculum: CAPS and Examination Guideline for Grade 12

In South Africa, teaching and learning is currently guided by the Curriculum and Assessment Policy Statement (CAPS) (South Africa. DBE, 2011). The CAPS document details the scope, depth and sequence of topics in each subject for each grade per term. The distribution of marks as well as the content to be assessed in Grade 12 is highlighted in the Examination Guideline. The weighting in terms of mark allocation and learning expectations needed for effective learning of Ohm's law will be explored as it is documented in the Examination Guideline (South Africa. DBE, 2014). That is followed by a discussion of the impact that the selected textbooks used by schools have on learning.

The mark allocation for the topics on electricity and magnetism is 55 out of 150 which comprises approximately 37% of the entire paper. This is a significantly larger allocation relative to the marks contributed by other physics topics, except for the topic on mechanics as reflected in Figure 2.

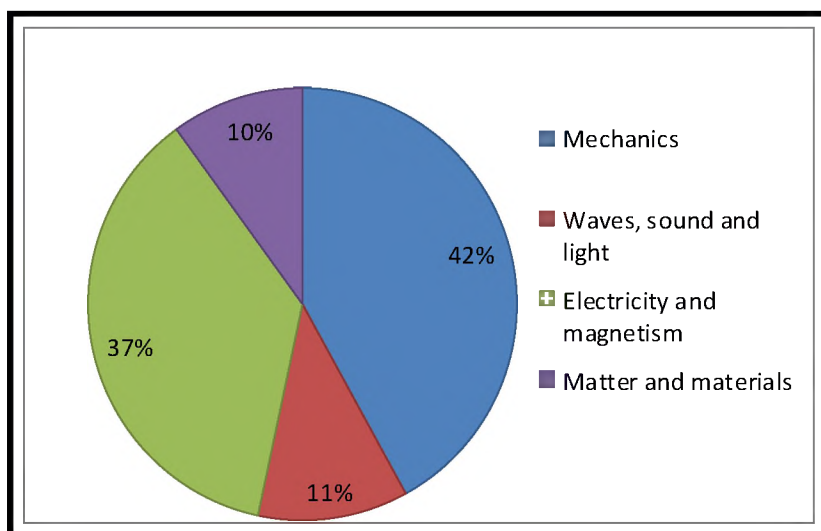


Figure 2: Mark allocation for topics assessed in Physical Sciences examination Paper 1 according to the Examination Guideline (South Africa. DBE, 2014)

According to the Examination Guideline, learners are expected to draw and interpret graphs, look for relationships and draw conclusions from tables and graphs, evaluate the validity of conclusions as well as explain the validity of scientific principles, such as Ohm’s law (South Africa. DBE, 2014). Application of the highlighted scientific principles is a skill necessary to deal with abstract concepts in the science world and the real world. These skills assist learners to use abstract thinking and a high level of reasoning, which helps in sharpening their problem solving abilities as they progressively advance through each grade. Such progression is supported by the CAPS document and Examination Guidelines (South Africa, DBE, 2011, 2014).

According to Kelder (2012, p. 229), Ohm’s law states that “for a conductor at constant temperature, the potential difference across its ends is directly proportional to current”. This law determines the relationship between the physical quantities, specifically electrical current, potential difference and resistance. The challenge, however, is that learners are still performing poorly in topics such as Ohm’s law applications and its related concepts despite the fact that the learning objectives are explicit. According to Treagust (1993), the basic reason is that the curriculum is designed to assess outcomes more than knowledge. Most of the outcomes can be achieved through rote learning, something which does not necessarily enhance learning for understanding (Chisholm & Leyendecker, 2008).

It could also be argued that there might be variations in how some textbooks present content knowledge on Ohm's law. Hence, learners could potentially be advantaged or disadvantaged depending on the textbook that a particular school uses. In addition, a shortage of resources is one of the challenges identified by most schools, and to which they attribute poor science results (Human Sciences Research Council [HSRC], 2011, 2015). Challenging the notion that lack of specialised resources justifies poor science results, most of the science topics can be taught and learned using easily accessible materials (Grant, personal communication, March 25, 2014). For example, an analogy may be used when teaching Ohm's law as I investigated in this study.

Furthermore, Kasanda, Lubben, Gaoseb, Kandjeo-Marenga, Kapenda and Campbell (2005) claim that senior secondary schools do not use as much context related learning as junior secondary schools. This claim illustrates that learners' ability to connect science content to their everyday learning could be hampered. It implies that science is presented as an abstract subject by only focussing on laboratory resources which are scarce at most South African schools. Teachers end up pointing to lack of resources in accounting for poor results in Physical Sciences.

However, throughout the entire CAPS document, analogies are only mentioned once in Grade 11 to explain refraction of light waves in geometrical optics and once in Grade 10 to indicate how small the nucleus is in explaining atomic structure (South Africa. DBE, 2011). Analogies are used as potential learning tools to mediate learning. My belief is that a well-planned analogy can help learners to make sense of abstract science concepts generally and on Ohm's law specifically, as in the context of this study. Thus, teachers should be introduced to the effective use of this tool (analogy). However, no studies directly investigating the use of an analogy in conjunction with a conventional practical activity to mediate sense making of Ohm's law could be found in the literature, indicating a possible knowledge gap. This was the knowledge gap which my study contributed towards filling. As an attempt to further contextualise my study, earlier research findings and recommendations on electricity, specifically about Ohm's law are discussed.

1.4 Earlier research findings on analogies

Vosniadou and Ortony (1983), Treagust, Duit, Joslin and Lindauer (1992), Gentner and Holyoak (1997) as well as Taber (2013) argue that analogies are graphic illustrations which

are used to contextualise abstract ideas. Furthermore, analogies are used to embrace prior knowledge, reinforce theory and explore practical activities. In addition, they are easily accessed and useful if learning is properly mediated.

Lee and Law (2001) recommend that further research on learners' thinking processes should be explored. Furthermore, Tsai (2003) focuses on calculations of resistance and Ohm's law concepts together with graphs of electric circuits, with the emphasis on concept maps rather than learners' sense making. Concept maps are used to identify learners' alternative conceptions and areas of understanding. The successful use of an analogy in the teaching of electricity is later reported by Glynn (2008).

Taking note of such findings, I felt that little research had been done to explore learners' sense making of Ohm's law. It is against this backdrop that I was inspired to explore how Grade 11 Physical Sciences learners made sense of Ohm's law when it was mediated through an analogy in conjunction with a conventional practical activity.

1.5 Making sense of concepts

According to Mezirow (1990), consideration of context, content and thinking processes are units embedded in reflection on the learning process. In line with reflection, the learning environment is taken into consideration in order to support sense making of concepts. Learners make use of their home language to make sense of concepts within a given environment or context.

This study was done within a context where learners' home language is *isiXhosa* and *Sesotho*. The total enrolment for my school at the time of this research was 985 learners of which 420 were *Sesotho* speakers and 525 were *isiXhosa* speakers. That makes English the second language (L2) which is the language of learning and teaching (LoLT). The tendency is that, in order to make sense of concepts, learners communicate in their home language and then complete oral and written presentations in the LoLT.

Failure to make sense of concepts may lead to rote learning. For instance, I observed that during my own science lessons, learners used resistance formulae instead of the relationships between variables in justifying their standpoints. Harrison (2002) and Novak (2010) argue that these are the consequences of little understanding of science concepts and are a failure to reconcile prior knowledge with new knowledge.

1.6 Statement of the problem

The main problem was the poor performance in Physical Sciences and thus there was a need for innovative strategies to improve the mediation of learning and hence conceptual development and understanding. This is exacerbated by the fact that some schools do not conduct practical activities, as science teachers claim that they have no resources. As a result, the learning strategies in such schools depend mostly on memorisation of concepts or rote learning at the expense of making sense of concepts.

For instance, the outcome of rote learning can be seen when a learner recalls the Ohm's law statement instead of using the law to solve problems that demand its application. Learners also show a lack of skills to explain their understanding of electric circuits, for instance, as reflected in the Examiner's Report 2013 (see Appendix F). Mostly, learners are unable to determine the relationship between concepts such as resistance, electrical current and potential difference. Mayer (2002) points out that those learners are not encouraged to develop beyond the level of recalling concepts in order to make sense of them. According to Mayer (2002), such a practice serves as a teaching and learning barrier which can limit learners' level of conceptual understanding. Therefore, learners are limited to the lower levels of reasoning and understanding where they are compelled to depend on rote learning.

Where the mediation plan is to reduce rote learning, then the use of different mediating tools needs to be considered. Essentially, the essence of this study was to explore learning strategies that would assist to minimise rote learning and maximise sense making through the use of an analogy using easily accessible resources together with the use of a conventional practical activity.

1.7 Significance of the study

The incorporation of an analogy into science learning is described in research as including a context baseline for new learning (Vosniadou & Ortony, 1983). Simayi (2014) shares the same sentiment and argues that analogies help to contextualise the content, which is especially beneficial for learners who are studying science in their second language (as is the case for this study, and often the case in South Africa). It is for these reasons that the objective of this study was to investigate how Grade 11 Physical Sciences learners made sense of Ohm's law when it was mediated through an analogy in conjunction with a conventional practical activity.

The topic on electric circuits, specifically Ohm's law, is a pre-requisite for some Grade 12 topics and it deals with abstract and challenging concepts (Driver, Asoke, Leach, Mortimer, & Scott, 1994; Mulhall, McKittrick, & Gunstone, 2001). Learners are expected to use electricity concepts to explain, justify and interpret graphs, something which needs reasoning at a more advanced cognitive level (South Africa. DBE, 2011). It means that learners are expected to make sense of their learning in order to probe critical reasoning.

Mulhall et al. (2001) argue that incorporation of an analogy in a science class stimulates understanding. Hence, learners may be inspired to make sense of the abstract concepts embedded in Ohm's law. The aim of the study's discussions was to answer the following questions.

1.8 Research goal and questions

The goal of this study was to explore how Grade 11 Physical Sciences learners made sense of Ohm's law when it was mediated through an analogy in conjunction with a conventional practical activity.

To realise this goal, I sought to answer the following main question:

How Grade 11 Physical Sciences learners made sense of Ohm's law when it was mediated through an analogy in conjunction with a conventional practical activity?

In order to answer this main question, the following sub-questions were explored:

1. What prior knowledge associated with Ohm's law did Grade 11 Physical Sciences learners have?
2. How did the use of an analogy enable or constrain meaning making of concepts and graphs associated with Ohm's law?
3. How did the use of a conventional practical activity enable or constrain meaning making of concepts and graphs associated with Ohm's law?
4. What challenges did Grade 11 Physical Sciences learners experience when Ohm's law was mediated through an analogy and a conventional practical activity?

Discussion on the unit of work is done below.

1.9 Unit of work

The unit of work serves as a supplement to the textbook on the topic electric circuits based on Ohm's law, since the textbooks do not incorporate the use of an analogy. The depth and scope covering learning of Ohm's law is too narrow in some of the Grade 11 Physical Sciences textbooks.

The content coverage in such textbooks do not meet the expectations stipulated in the assessment guideline (South Africa. DBE, 2014). Textbooks are amongst learning and teaching support materials (LTSMs) which are encouraged to be used at school. In South Africa for instance, each learner is expected to be in possession of a textbook for each subject that he/she is doing, but their learning needs are not met with regards to the topic on electric circuits, specifically the concepts associated with Ohm's law. The learners' performance in the subject under study has not shown signs of improvement despite the individual possession of textbooks. Schools are also encouraged to use units of work as it is important to adapt from textbooks to meet the learners' needs (O'Neill, 1982; Czenierwicz, Murray, & Probyn, 2000; Davis, 2006). Teachers are encouraged to develop a number of lesson plans known as units of work. Such units of work can be used as supplementary LTSMs as reiterated by Czerniewicz et al. (2000). Worksheets can also be developed as part of the unit of work.

1.10 Worksheets: On practical activities

The use of worksheets drawn from the unit of work can assist to develop some science skills. Physical Sciences is a subject which is aimed to test for content knowledge acquisition and development of skills (South Africa. DBE, 2011), therefore, an advanced level of thinking and reasoning as well as creativity skills are needed which makes learning science challenging. Continuous practise of the required skills may lead to understanding science concepts, but continuous practise endorses revision which was highlighted earlier as not yielding better Physical Sciences results for most learners. The content coverage and designed practical activities which are presented to stimulate thinking and development of concepts can be covered using worksheets drawn from the unit of work.

Some key concepts used in this study are now defined below.

1.11 Some key concepts and their definitions in this study

Key concepts which are essential to this study are defined below.

- Make sense: is to make meaning of an experience as well as constructing new knowledge (Mezirow, 1990; Brown, 1997).
- Analogy: a comparison between one thing and another made for the purpose of explanation (Vosniadou & Ortony, 1983).
- Mediation (definition): the intervening process used by the knowledgeable person in assisting learners to make sense of new knowledge (Vygotsky, 1978).
- Mediation (description): a learning process that encourages learners to organise and structure new knowledge (Vygotsky, 1978).
- Mediation tool: the technique incorporated for the purpose of accessing new knowledge or making sense of new concepts (Lemke, 2000).
- Schema (definition): a set of interconnected mental representations of the world, which we both understand and draw from in order to respond to situations (McLeod, 2009).
- Schema (description): the basic building blocks of knowledge (McLeod, 2009).

1.12 Thesis outline for each chapter

Chapter 1 outlines the context of my study based on the topic: A case study of how Grade 11 Physical Sciences learners made sense of Ohm's law when it was mediated through an analogy in conjunction with a conventional practical activity. The context is informed by the international and national reports, South African Curriculum expectations and the need to undertake a study by considering earlier researched literature.

Chapter 2 discusses the literature that supports my study. The literature on mediation tools is discussed. The discussion proceeds to review the theoretical framework that informs my study. Constructivism and in particular social constructivism and its explanatory sub-topics are examined whilst relying on earlier research findings. The focus is on exploring theories that support learning for understanding.

In **Chapter 3**, the research methodology used to shape my study from its design, through data gathering techniques up to data analysis are explained. Literature based on these aspects is highlighted to guide the development of data processing. To be specific, the whole chapter concerns a rationale of how data was gathered and analysed in order to answer the research questions.

The data gathered is presented and analysed in **Chapter 4**. Data gathered using different techniques is reviewed and analysed to identify relevant themes. Such themes emerging from the data are represented in the form of tables, figures and extracts.

Chapter 5 comprises data interpretation and discussion. Research questions, themes and literature are used to construct this chapter. The themes are consolidated to form analytical statements.

Chapter 6 contains the summary of findings, recommendations and conclusions from this study. This chapter encompasses the overall summary results as informed by literature and study findings. Experience acquired through my entire research journey is briefly shared. Since this study has the potential to serve as a baseline for areas of future research, some recommendations and areas for future research are made. Finally, the conclusion of this study is drawn.

1.13 Concluding remarks

In this chapter I discussed the rationale for undertaking a study on how Grade 11 Physical Sciences learners made sense of Ohm's law when it was mediated through an analogy in conjunction with a conventional practical activity. The literature revealed that the topic on electric circuits is a challenging one to most learners. Some of the literature suggested that if mediation tools are carefully chosen, learners can gain an advantage in making sense of new concepts.

In the next chapter, I review the literature relevant to my study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents a discussion of literature that is relevant to my study on how Grade 11 Physical Sciences learners made sense of Ohm's law when it was mediated through an analogy in conjunction with a conventional practical activity. I first discuss literature pertaining to mediational tools, thereafter constructivism and in particular social constructivism as the theoretical framework informing this study. I then conclude with some observations to pull the threads together.

2.2 Mediational tools

In an attempt to explain what mediational tools are, Lemke (2000) suggests that scientific concepts are grasped through the incorporation of different modes of representation. Lemke (2000, p. 248) notes that:

What is special about the use of the multiple modalities in natural sciences, and to only a slightly lesser degree in mathematics itself, is that scientific concepts are articulated across these media of representation. What it means to be able to use a scientific concept, and therefore to understand it in the way that a scientist does, is to be able to freely juggle with its verbal, mathematical, and visual or graphical aspects, applying whichever is the most appropriate in the moment and freely translating back and forth among them.

This implies that meaningful learning concerns how to mediate learning from different learning abilities where individual cognitive stages of development are considered.

Lending support to this view, Gibbons (2003) argues that the mental processing of ideas is mediated by tools between people who do not share the same experiences for the purpose of making sense of learning. It is for this reason that the use of an analogy was the basis of this study. Other mediational tools such as practical activities, language, prior knowledge, graphicacy, assessment and concept maps will also be discussed to strengthen the analogy. I now discuss these below.

2.2.1 The use of an analogy as a main mediational tool

An analogy serves as a mediational tool that bridges old to new knowledge where mediation of learning is supported (Vosniadou & Ortony, 1983; Iding, 1997; Treagust, 1993; Heywood

& Parker, 1997; Treagust, Harrison, & Venville, 1998; Orgill & Bodner, 2004). It should be acknowledged, however, that there are good and bad analogies.

An analogy relates familiar concepts known as ‘an analog’ to planned unfamiliar concepts, which are referred to as the ‘target’ in the science learning process (Thiele & Treagust, 1994; Orgill & Bodner, 2004). This mediational tool which reinforces the connection between known concepts and unfamiliar ones needs to be explained for mutual understanding. It supplements context which might otherwise be missing for learners from different backgrounds. This mediational tool serves the same goal as examples and experiments, which is to eventually make what is unfamiliar familiar, especially when there is a gap between prior knowledge and new concepts (Vosniadou & Ortony, 1983; Treagust, Duit, Joslin, & Lindauer, 1992; Gentner & Holyoak, 1997; Taber, 2013). Taber (2013) argues that making sense of an analogy relies on well-constructed prior knowledge which in turn emphasises the importance of prior knowledge. Alternatively, failure to recognise prior knowledge may hinder learners from making the connection between known concepts and target concepts.

When the connection of ideas is less evident, the incorporation of an analogy makes learners visualise what cannot be seen (Leach & Scott, 2002). For example, the electrical current flowing in a conductor cannot be seen. In such instances, scientists use models like analogies to explain theories for quantities at microscopic level. The rationale is to relate to the real world, motivate learners, embrace prior knowledge and build on it to introduce new ideas. For instance, electric conductors can be likened to water pipes. Gentner and Holyoak (1997) further add that this teaching and learning model activates reasoning, learning and memory as it triggers visualisation. By virtue of being experiment-like, an analogy helps in the visualisation of abstract concepts. This means that learners are given an opportunity to construct new ideas.

Leach and Scott (2003) suggest that analogies are simplified models that can be used in science teaching and learning as they reinforce explanations and connect ideas to future learning. This is a plausible approach to effective learning as it enforces connections when constructing ideas. Actually, an analogy is symbolic in nature which makes the aforementioned characteristics of analogies pre-requisites for scientific reasoning.

At the centre of the whole teaching and learning process lies the incorporation of an analogy to enhance scientific reasoning and meaningful learning. Harrison and Treagust (2000) warn

about the challenges of incorporating an analogy into science learning, therefore a discussion on good and bad analogies is necessary.

The research paper by Iding (1997), which focuses on text-based analogies, reveals that good analogies are easy to explain and understand because the connection is rich. Therefore, learners make sense of the planned learning if they show understanding of the concepts. Furthermore, learners are afforded an opportunity to socially share their understanding. Iding (1997) further reports that low achievers benefit and high achievers can further design other analogies to show their understanding. It could be argued that analogies demonstrate the learners' level of understanding up to an advanced stage of cognitive development where learners can then work without support. This resonates with the social constructivism perspective, which is the theoretical framework of this study (see Section 2.3.2).

Orgill and Bodner (2004) conducted a study in the United States of America (USA) with tertiary students. Their findings were that a good analogy should be simple and easy to remember as it is then less difficult for learners to make sense of learning, which then promotes the connection of concepts in the learners' minds. The use of illustrations or models can encourage visualisation of abstract concepts and increase self-efficacy (Bandura, 1993; Orgill & Bodner, 2004). According to Bandura (1993), self-efficacy can be described as a state where an individual is able to succeed in accomplishing a task without assistance. So, good analogies encourage learners to make sense of new learning.

On the other hand, Mulhall, McKittrick and Gunstone (2001) caution that while analogies are recommended for learners' conceptual understanding, they have the limitation of not probing the complete understanding of abstract concepts. That was discovered in their study based on the teaching of electricity. Learning dissatisfaction was reached when learners did not understand the target concepts and resorted to memorisation. Further, drawing from Treagust (1993), there are certain features that constitute limitations to analogies.

These features are sometimes referred to as disanalogies. Treagust (1993) posits that some learners remember the analogy only and not the new knowledge. That is a feature which hinders the attainment of new knowledge resulting in the desired outcome not being reached. The main cause might be an incorrect aspect transfer (Treagust, 1993). In such a case, a learner cannot see the connection between the analogy and the new knowledge resulting in meaning making of the concepts not being established and new concepts not linking with the

context as expected (Treagust, 1993; Heywood & Parker, 1997). Treagust (1993) continues by highlighting that an analogy may only be suitable for learners at a certain cognitive level which would then be revealed when an analogy does not address learning needs.

A study conducted by Heywood and Parker (1997) in the United Kingdom (UK) on teachers of primary school children, emphasised that a lack of mediation from an analogy to new knowledge is another feature that serves as a barrier to learning. The study was concerned with the usefulness of analogies in the teaching and learning of electricity. This shows that learners may fail to make sense of new knowledge if they cannot see the connection of ideas.

Iding (1997) reiterates that misconceptions and misinterpretations may emanate from an incomplete connection between old and new knowledge. This can cause a rejection of new knowledge and learners may end up basing their reasoning on an analogy instead of the targeted concepts. This in turn hampers the incorporation of analogies into a teacher's mediation repertoire.

Orgill and Bodner (2004) report that using many analogies in explaining one aspect may confuse learners. It yields the same outcome as the incorporation of long and complex analogies. In such a case, learners end up losing interest in their learning. This limitation could then result in no learning in a science class. Such potential problems should be kept in mind and be avoided for the benefit of meaningful learning.

Most of the literature I encountered emphasised that mediation promoted learning when an analogy was incorporated, provided that proper planning was undertaken. For that reason, there is value in mediating learning through an analogy where possible. A conventional practical activity can be used as an extension of an analogy so as to bring more science content into new knowledge. I discuss the role of practical activities below.

2.2.2 The role of practical activities

Mestad and Kolsto (2014) argue that well planned practical activities target identified goals and are administered at relevant times. According to Mestad and Kolsto (2014), such planned practical activities can yield good results meaning that the incorporation of practical activities is a good teaching and learning practice in science. Driver, Asoko, Leach, Mortimer and Scott (1994) as well as Mestad and Kolsto (2014) further reveal that practical activities probe learners' knowledge that then triggers a connection between the world and science ideas. To

be precise, ‘hands-on’ practical activities encourage learners to discover more knowledge and in that way creativity can be developed (Dillon, 2008).

Creativity ensures that learners develop a sense of ownership with their learning as they construct new knowledge. That is made possible through clear guidance by the teacher and such guidance is useful throughout the learning process especially in a case where the expected results do not emerge. Possibly, redoing the experiment to check for experimental errors or to think more about them may lead to the elimination of such errors. The effort required in such a situation may be suitable for learners who are always motivated and enjoy the process of being engaged in practical activities. In addition, Maselwa and Ngcoza (2003) emphasise that learners are encouraged to predict, explain, explore, observe and explain (PEEOE) their actions in science learning if they are used to doing practical activities.

Dillon (2008) also claims that engaging learners in practical activities promotes cognitive development from context to content knowledge. Carefully designed practical activities should also be aligned with practical procedures and enquiry skills, which would inform the cognitive process (*ibid.*). Skills such as tabulating, graphing results, measuring and strategies to plan an experiment as well as justification using principles of Physical Sciences may be developed only through engagement with practical work (South Africa. DBE, 2011). Some of these skills, like accurate measuring and graphicacy cannot be developed through the use of an analogy.

For that reason, in the context of this study an analogy was employed before a conventional practical activity on Ohm’s law was incorporated. This suggests that when learners have finished an analogy activity, they begin to mentally associate and make sense of what they know, whether the information is stored in pictorial or symbolic forms in their minds. Also, it becomes easier to apply the information in a similar situation which demands the application of new knowledge (see Section 1.3). That practice could boost learners’ memory retention capacity, self-efficacy, determination and attitude (Motlhabane & Dichaba, 2013). Language is another mediational tool used to communicate and construct meaning and I discuss it below.

2.2.3 Language and science learning

Lemke (1990) establishes how language is used in secondary schools to communicate and construct meaning in science. According to Mestad and Kolsto (2014), language is used in

the teaching and learning process to communicate abstract concepts. That is, language is a mediational tool which is used for communication and learning as it encompasses reading, writing and speaking. An added complication is that science is also a language in itself.

In addition, Lemke (1990) as well as Leach and Scott (2002) highlight that discussions can also be used to check for understanding in addition to language acquisition. Some learners could have language fluency but may struggle with the specific language of science. To merge the two, that is, informal language and science language, a discussion on self-talk needs to be presented as it has an impact on effective classroom talk (Lemke, 1990).

Lemke (1990) reveals that science is perceived to be difficult due to the fact that it does not easily accommodate common sense which is also referred to as everyday knowledge. That is, learners are not taught how to talk science and science learning is sometimes confined to definitions. Yet, according to Lemke (1990), learners come with prior knowledge into a science classroom which is either science-supported or just common sense. Lemke (1990) accentuates that sense making is observed when a learner is able to describe, compare, hypothesise, argue, generalise and evaluate. Learners' development with respect to understanding signifies their degree of cognitive level together with the degree of mediation and this then point to a change in their state of understanding. Additionally, mediation of learning is encouraged for the purpose of developing learner talk (Vygotsky, 1978; Simon, Erduran & Osborne, 2006). It could be argued that learner talk encourages learners' thinking and contributes positively to sense making (Simon et al., 2006). Critical thinking develops as learners construct explanations and in defending their arguments, learners develop the courage to contribute to classroom discussions.

Lending support to learner talk, Windschitl, Thompson, Braaten and Stroupe (2012) argue that classroom talk promotes the internalisation of concepts and encourages active engagement in planned discussions. The level of engagement in class activities might be influenced by the learners' home language (L1) and language of learning and teaching (LoLT) (Probyn, 2009). Learners in schools where the LoLT is their second language (L2) are faced with a language barrier and that could possibly lead to a higher failure rate (Howie, 2004; Probyn, 2009; O'Malley & Chamot, 1990).

According to O'Malley and Chamot (1990), learners who use L2 as their language of learning have the challenge of participating in both verbal and non-verbal communication and

need to be motivated to actively participate in discussions (Probyn, 2009). Usually, most of the Physical Sciences examination papers are in the LoLT which is English in most South African schools. The examination papers prepared for learners usually set a specific time to complete the paper without considering the language proficiency of the learners. In constructing ideas, learners are obliged to change between L1 and L2 (the LoLT) within a short period of time, especially during assessments such as examinations. Sometimes, that change between languages can be done for the purpose of verifying the answers (Cummins, 2015).

Thinking time should be considered in order to allow learners to make sense of learning as they move to-and-fro between L1 and L2. Ultimately, this change in languages can promote language literacy (Cummins, 2001, 2015). Indirectly, learners may become competent in the LoLT hence the possible improvement in results. O'Malley and Chamot (1990) posit that such learners have an opportunity to improve both language fluency and content acquisition. They are challenged to make sense of new learning whilst learning language for communication purposes as well as science language. The primary goal is that they must make sense of concepts for cognitive development to take place. At an advanced cognitive level of thinking, learners are expected to justify, critique and explain some results.

Cook (1999) argues that cognitive development for L2 learners is restricted by developing on a smaller scale. That could be due to the fact that such learners are usually exposed to lower order questions compensating for language barriers. According to Probyn (2009), that could constitute a tension between content and language. Probyn (2009) researched the issue of L2 as the LoLT in the South African context where there were eleven official languages but where English was used as the LoLT in most schools. The study revealed that code switching was promoted in such contexts.

Code switching is described as a movement between L1 and LoLT in order to assist learners to make sense of concepts to enable them to be conversant with the LoLT. Hurst (2015) supports code switching between L1 and LoLT, rather than just the use of L1 in science classes. Some teachers resort to using only L1 in teaching and that puts learners at a disadvantage, especially when they are examined in L2.

Lemke (1990) reasons that to make more sense of science, the primary meaning of concepts should be incorporated through language then supplemented by prior knowledge, diagrams,

practical activities and other mediational tools. That is, learners' thinking may adapt faster if new knowledge is linked to prior knowledge through a range of techniques (O'Malley & Chamot, 1990; Keys, 1999).

2.2.4 Recognition of prior knowledge

Roschelle (1995) points out that recognition of prior knowledge is essential as it is a baseline for the construction of new ideas. Keys (1999) and Shepard (2000) as well as Stern and Ahlgren (2002) argue in support of Roschelle (1995) that learners draw and later build on information from prior knowledge to acquire new science knowledge. Stern and Ahlgren (2002) further explain that learning takes place when the transformation of ideas from prior knowledge or the known to the unknown, occurs. For example, an analogy may serve the purpose of probing prior knowledge whilst simultaneously bringing context into the class which activates the learning process.

Kasanda et al. (2005) recommend that prior knowledge can be used to complement in-class and out-of-class knowledge in order to make sense of the new science knowledge. The acknowledged prior knowledge may serve as a foundation for science knowledge. According to Kasanda et al. (2005), it became apparent that context plays a major role, yet it is rarely considered in senior secondary schools. They recommend that context needs to be checked for its connection with new learning. This was necessary for the purpose of avoiding overestimation or underestimation of learners' thoughts when developing a unit of work. They highlight that where there is a language problem, code switching is appropriate if the LoLT is not the learners' home language. This would be in order to minimise learning barriers such as language (see Section 2.2.3). Therefore, according to Kasanda et al.'s (2005) notion, accessing prior knowledge grounds the introduction of new knowledge if it is connected to the existing knowledge.

In support of this, Rennie (2011) and Kuhlane (2011) highlight that prior knowledge can be used to expose learners to new knowledge, while Shepard (2000) emphasises the use of local or everyday knowledge to understand real world issues through the knowledge gained in class.

A similar study conducted by Stears, Malcolm and Kowlas (2003) confirmed that learners made sense of concepts by incorporating prior knowledge to connect the science world and real world which led to the integration of science knowledge within real world settings. In

this way creativity and critical thinking are encouraged and this is a requirement in the CAPS policy document (South Africa. DBE, 2011). However, it might also be a possibility that new knowledge does not link with prior knowledge.

The study carried out in Israel by Stern and Ahlgren (2002) on college students, revealed that if new knowledge does not link with prior knowledge, students may find it difficult to accept the new knowledge. This can lead to the rejection of the new knowledge which leads to a learning gap which might result in alternative conceptions or misconceptions. Finally, cognitive development might be challenged. These understandings are applicable to learners in any grade and in any subject. Graphicacy is another mediational tool used in my study to acquire a number of abilities when learning Ohm's law, and I discuss the idea below.

2.2.5 Why graphicacy skills are needed in science learning?

Aldrich and Sheppard (2000) describe the term 'graphicacy' as that concerned with the capacities people require in order to interpret and generate information in the form of symbols such as in diagrams. Graphicacy is a form of communication which can allow information to be more easily interpreted at a glance which can then lead to an understanding of the details because it is usually logically presented, using symbols (Wilmot, 1999).

Wilmot (1999) further highlights that to interpret the information one needs visual understanding, as graphs require practise for both coding and interpreting of the information. The advantage is that one can predict what is to happen next by means of analysing the existing pattern. For example, in order to infer from the given graph one needs to critically observe the variables in order to understand their relationship and to make connections between the graph and the real world. Mastery of graphicacy skills can indicate the level of mental maturity in that making sense of graphs promotes understanding of what is presented whilst keeping track of details (Laverly & Kortemeyer, 2012).

The use of graphs shows signs of mental maturity because learners are able to reason at a symbolic level which means that the power of their reasoning is at an abstract level. In dealing with Ohm's law, for instance, learners are expected to extrapolate data from the outcome of the 'straw electricity' analogy activity in order to draw and later use graphs to represent the relationship between electrical current and potential difference. In other words, graphs are used to affirm theory and make information on the investigated law and its

concepts understandable through the incorporation of practical activities (Postigo & Pozo, 2004). I now discuss the role of assessment in a science class.

2.2.6 Assessment practices

The purpose, critique and weaknesses of assessment will now be discussed. Assessment is defined as a method where verbal or non-verbal data on learners' performance is collected and interpreted (Brown & Hirschfeld, 2008). Harlem and James (1997) note that there are two types of assessment that are used most often, namely, formative assessment or assessment for learning (AfL) and summative assessment.

Harlem and James (1997) argue that AfL is mainly administered to identify learning progress whereas summative assessment is used for progression and to report learners' performance to parents, teachers and to the Department. The available research studies encourage careful analysis of the responses that learners provide which serve as evidence of their level of sense making (Harlem & James, 1997; Black & Wiliam, 1998; Brown & Hirschfeld, 2008). In summation, it means it is informative and the feedback is based on evidence gathered as reflected by the data gathering method used, such as answer scripts from diagnostic and summative tests as well as completed worksheets from practical activities. These data gathering methods will be discussed in the next chapter.

The advantage of including assessment in science learning is that it points out the possible next step in the learning process as well as other possible mediation tools that could be incorporated to iron out misunderstandings, if any, be it a conventional practical activity, an analogy, graphicacy or even language. It is apparent that when the mediation tool under discussion is properly administered, learners will have the opportunity to provide evidence that they have understood the issues through their responses.

Nonetheless, there are numerous critiques against the use of assessment. Assessment is sometimes administered to meet curriculum requirements, without consideration of its value in informing learning (Shepard, 2000). Shepard (2000) argues that a sound learning culture should embrace assessment which will then distinguish what assists new learning. This means that it probes learning with insight, as its target is to access learners' thoughts, as mentioned earlier. It is a mediational tool that connects content and context to planned goals resulting in learning taking place.

Lastly, Stern and Ahlgren (2002) criticise the use of Multiple Choice Questions (MCQ) in assessment, in that such questions result in rote learning. The challenge is that MCQ do not invite reasoning at an advanced cognitive level. This is because learners are not given an opportunity to explain, describe or predict in most cases. This is a limitation to assessment. There are also other weaknesses which demotivate learners in developing a positive attitude towards assessment.

Shepard (2000) cautions against the norm of administering one type of assessment to the whole class as learners are usually at different cognitive levels of learning. Does this suggest that assessment tasks should be in the form of different tasks for different learners? Is that possible? The answers to these two questions might be attended to through the theoretical framework to be discussed in this study. Concept maps as additional mediation and assessment tools are now discussed below.

2.2.7 Concept maps as concept organisers

Dabbagh (2001) describes a concept map as a mediational tool used to determine the meaning of concepts as one seeks deeper understanding and allows interpretation of new knowledge. The differences between the tools that are mostly used, for instance mind maps and those used less often, for instance concept maps, need to be understood for the purpose of eliminating misunderstandings.

The definition of a mind map is that it is a visual and non-linear illustration of ideas and their relations (Davies, 2011). Concept maps, on the other hand, according to Davies (2011), link prior knowledge to new knowledge where there are fewer or even an absence of pictures. Concept maps display relations or connections between concepts which promote cognitive development and meaningful learning. Therefore, learning takes place when learners make sense of the concepts. This structuring of ideas gives learners an opportunity to think and individually construct ideas or organise concepts, hence concept maps are known as concept organisers. Individual creativity, active meta-cognitive participation and thinking are encouraged as learners reflect on past experiences whilst establishing relations between concepts (Nesbit & Adesope, 2006). To add to this notion, Nesbit and Adesope (2006) indicate that low achievers and second language learners benefit from this mediational tool. Concept mapping is not a mediational tool which is language focused but promotes

construction of concepts from past experience. This affirms the value of the constructivist approach to learning.

The process of formulating a concept map implies that reflection is promoted. It is revealed in the same study by Dabbagh (2001) that the process of formulating concept maps benefited learners in identifying unrelated concepts. Concept maps can easily eliminate unrelated concepts while conceptual change is promoted (Liu, 2004). Conceptual change will be discussed later in this section.

Liu (2004) carried out a study on concept maps, in a Grade 12 chemistry class. Drawing from the research results, Liu (2004) confirmed that concept maps assisted in reflection on the learning process. Grammatical mistakes are not emphasised in concept map construction so learners who use a second language as the LoLT are not disadvantaged in using this learning tool. The only focus is on the capturing of correct science concepts not language fluency. In that way, efficacy in knowledge transfer is demonstrated by all learners. The study by Sellmann, Lieflander and Bogner (2015) is in favour of a new perspective on the value of concept maps in the learning process.

Sellmann et al. (2015) carried out a research study in Germany on climate change. Their claim about the use of concept maps is in agreement with Dabbagh's (2001) findings but only partially aligns with those of Nesbit and Adesope (2006). Nesbit and Adesope (2006) recommend that concept maps be used at the end of a unit, but Dabbagh (2001) and Sellmann et al. (2015) endorse that concept maps can be formulated at the beginning and the end of the unit presentation. In the context of this study, they were used at the end of the lesson presentations.

There are however some limitations identified in connection with this mediational tool. For instance, Davies (2011) highlights that concept maps are not easy to design, especially when links appear to be limited. That could possibly result in a mind map. Furthermore, there might only be a few links extracted from the daily presented lessons. Sellmann et al. (2015) add that this mediational tool is not easy to design particularly on a daily basis as it is time consuming to construct. So, the time required to draw a concept map needs to be considered.

In sum, concept maps are good mediational tools which trigger learners' thinking and if they are used strategically, learners at different cognitive levels can benefit either individually or as a group depending on how they develop them. Lastly, mind maps can also meet different

needs throughout the learning process. The most salient factor is that they are regarded as monitoring tools for conceptual change (Sellmann et al., 2015).

2.2.8 Conceptual change

The notion of conceptual change was initially pioneered by Kuhn (1970) and it embraces prior knowledge as well as the restructuring of concepts, for example, through the use of analogies and graphicacy (Lee & Law, 2001; Duit & Treagust, 2003). Duit and Treagust (2003) argue that conceptual change is learner-centred and learners' minds are referred to as the change agent. This idea is commonly regarded as a theory but in the context of this study, is regarded as reinforcement to the idea of concept maps.

This thinking is in line with the constructivist perspective whereby learners are responsible for the construction of ideas to accommodate new concepts. Similarly, Baser (2006) defines conceptual change as the ability of teachers to change the learners' prior knowledge which might be inconsistent with new knowledge or new scientific knowledge taught at school. There must be a change in conceptualisation, not that concepts be replaced if out of context or content.

Chi, Slotta and de Leeuw (1994) propose that conceptual change determines whether the level of learning concepts is easy or difficult depending on learned experiences. To that notion, Chi et al. (1994) argue that it is not easy to learn scientific concepts since some of them are represented by mathematical symbols or equations. To be specific, most learners rely on using the formula, $R = \frac{V}{I}$ when required to justify for instance, what happens to electrical current when one of the resistors in parallel is removed. This becomes a source of a learning barrier which results in the inability to solve problems appropriately (Appendix F). Conceptual change takes place after learners are exposed to conceptual dissatisfaction in the learning of scientific concepts (Tsai, 2003; Duit & Treagust, 2003). This requires appropriate mediational tools to bridge the gap from context to abstract reasoning, for instance, by considering graphicacy when incorporating an analogy and assessment, as in the context of this study.

Referring to assessment, data gathered through a diagnostic test provides a way to close the content gap as learners are at different cognitive levels. Noticeably, the use of an analogy may assist learners to blend context with content and additionally, concept maps may be used

to connect concepts, hence known as concept organisers. Therefore, all these mediational tools assist a learner in constructing ideas to inform new knowledge. That process of construction informs the theoretical framework that underpins my study, which will be discussed below.

2.3 Theoretical framework

A theoretical framework encompasses a theory that predicts, explains and shapes a study. The theories under discussion are based on making sense of ideas where a learner draws from ideas in the existing schema in order to construct new knowledge in a social context (Vygotsky, 1978). In the next section I discuss constructivism in general and then narrow the focus to social constructivism.

2.3.1 Constructivism

Constructivism is a fundamental theory that encourages learners to build ideas based on prior knowledge drawn from experience and social reality as they make sense of new knowledge (Vygotsky, 1978). All mediational tools discussed in this chapter contribute positively to learning using the constructivist approach to learning.

Guba and Lincoln (1994) as well as Terhart (2003) position constructivism as a research paradigm or perspective. Guba and Lincoln (1994) define a paradigm as “a basic belief system or world view that guides the investigator, not only in choices of method but in ontologically and epistemologically fundamental ways” (p. 105). It focuses on reality as well as what can be revealed by the researcher and participants. It also embraces how to collect data for the purpose of answering the research questions. In this study, I describe constructivism as a perspective followed by its connection to language and then its connection to an analogy. Appleton and King (1997) prompt that this perspective assists in accessing first-hand information through relying on context (Terhart, 2003). This classifies this research as a case study.

According to Terhart (2003), learners use assumptions drawn from their social realities in acquiring experiences. That inference informs construction of new knowledge, hence the constructivism perspective. Guba and Lincoln (1994) highlight that data collection methods like documents, interviews and observation are cornerstones of the constructivism perspective where learners are encouraged to tap into their existing schema to construct new

concepts. Science communication is fostered as construction of concepts occurs as a result of reliance on the existing schema.

Learners construct new knowledge when prior knowledge that was acquired from informal set-ups is recognised when learning science (Driver et al., 1994; Leach & Scott, 2003). So, learners use prior knowledge as a stepping stone to construct abstract ideas. The process of constructing ideas develop the tendency to internalise concepts or own ideas. Language is one of the previously identified mediational tools that play a role in synthesising concepts.

Learning science language supports constructivist learning. Keys (1999) argues that through language, prior knowledge can be accessed, writing can be used to communicate familiar and unfamiliar concepts and meaning is extracted from observation. Learners are encouraged to use their own words but align themselves with science language. The use of the learners' own words implies that constructivism is generated and that learners who use LoLT as L2 construct knowledge as they juggle between L1 and L2 in order to make sense of science concepts. Probyn (2009) recommends that code switching from L2 to L1 enhances social balance in learning as mental constructions occur during the thinking process. This implies that learners make sense of learning concepts although it takes time to switch between different languages (Shepard, 2000).

Exposure to mental construction activities reflects a constructivist perspective, which is a cornerstone to effective learning. Can the incorporation of an analogy trigger learners' minds to construct ideas? According to Harrison and Treagust (2000), analogies are the learning tools which probe conceptual understanding as they connect prior knowledge with future learning. Hence, the use of an analogy promotes a constructivist perspective since an analogy is used to explain abstract ideas by connecting with the known ideas (Chou & Shu, 2015). Presentation of new knowledge is made accessible through the analogy system as the possibility exists that learners can easily identify the known ideas and then assimilate them to accommodate the new ideas. Beard (2006) defines assimilation and accommodation as follows, using Piaget's terms: assimilation means incorporation of new objects and experiences into existing schema and accommodation is the modification of schemas as a result of new experiences. Throughout the above mentioned processes, learners construct new ideas.

However, some studies signal a warning about the barriers that constructivism can impose. For instance, Leach and Scott (2003) criticise constructivism as focusing on common sense and they argue that there is no evidence that learners make sense when a constructivist approach is employed.

It is clear that learners construct new ideas from existing schema as influenced and supported by the social context and that access to new learning depends on language, context and content. The focus theory of this study, the social constructivist perspective, is discussed below.

2.3.2 Vygotsky's social constructivist perspective

According to Vygotsky (1978), learners construct new concepts within a social context using language, therefore language can be used to mediate learning (see Section 2.2.3). It is noted that mediation of learning is a central concept found within Vygotsky's (1978) social constructivist perspective (Donato & McCormick, 1994). The social constructivist perspective is explored further by viewing how learners make sense of ideas via the zone of proximal development (ZPD) (Stott, 2016) whilst scaffolding takes place.

In a learning situation, all learners from different cultural contexts have to learn common/new science concepts even if they are at different cognitive levels. New knowledge is acquired and is geared towards academic independence of an individual learner. Mediation of learning is goal directed and monitored by a teacher or more knowledgeable peer (Harrison, 2014). Mediation of learning helps learners to construct ideas through the ZPD and scaffolding within a social constructivist perspective. The focus is on construction of ideas from individual to group or social learning and the other way round.

Construction of ideas from prior knowledge initially takes place individually and then is shared in class during planned activities, such as, project presentations and meaningful discussions among others. That encourages learners to adapt to a new science culture (Driver et al., 1994). Then, a change in social structures occurs to supplement science demands. The vehicle employed is language exchange between individuals, which is embedded in learners' prior experiences (Lemke, 1990; Atwater, 1996; Keys, 1999). The challenge, however, is that science itself is a language that demands understanding. Language plays a key role when learners exchange ideas as they learn from each other in a social set-up. Learners use language in the process of internalising thoughts (Harrison & Muthivhi, 2013). Individual

learners construct knowledge from ideas shared within a social learning space. The construction of new knowledge encourages critical thinking. Vygotsky (1978) refers to deep internal mechanisms that accentuate mindful, purposeful and thoughtful behaviour in the learning process as self-regulation. Language can also be used for relational understanding when collaboration occurs in small cooperative learning groups. That is where sharing of ideas is encouraged and mediation of learning occurs when learners communicate in verbal or non-verbal modes (Lantolf, 1994; Anton, 1999).

Anton (1999) posits that the sharing of ideas in a social environment promotes the development of thoughts and learners' ability to communicate their thoughts scientifically through symbols which signal a cognitive development. Classroom talk encourages active participation through discussions and promotes social interaction (Windschitl et al., 2012). Lantolf (1994) makes reference to abstract science symbols like algebraic symbols and graphicacy (see Section 2.2.5). It is apparent that graphicacy and language are the bases required to make sense of Ohm's law.

Another connection exists between speaking, thinking and writing revealed in the practice of journal writing. Learners are engaged in language usage to construct ideas from text, prior knowledge and experience (Lantolf, 1994). So, learners' writing as they learn is a language skill that is necessary in processing their presentations.

Leach and Scott (2002) argue that knowledge is socially acquired and constructed. Hence, they refer to prior knowledge as pre-social knowledge and suggest that prior knowledge should be checked for alternative conceptions so that there is a connection to the scientific knowledge. Learners find themselves in a scientific world so they are obliged to make sense of abstract concepts. Electricity concepts like charges, electrical current, resistance and energy are labelled as abstract.

For learners to make sense of such concepts, the use of an analogy can promote and initiate visualisation, as discussed earlier in this section (Gentner & Holyoak, 1997; Leach & Scott, 2002; Mestad & Kolsto, 2014). If an analogy is incorporated that uses easily accessible materials, learners quickly identify with such familiar materials which helps them to actively participate in a social exchange of ideas as they are at ease with the resources being used in the learning process. Chou and Shu (2015) recommend that an analogy should be carefully

chosen for the purpose of being relevant to the planned goal. The purpose is to ensure that learners' needs with respect to context are attended to.

The social constructivist perspective enhances construction and reconstruction of concepts as learners use mediational tools to make sense of new science concepts (Shepard, 2000; Leach & Scott, 2003). I will now discuss mediation of learning as the main pillar of social constructivism.

2.3.2.1 Mediation of learning in a social context

Mediation of learning is a technique or skill incorporated to answer how knowledge is acquired in the learning process; it is a learner centred skill which supports the social constructivist perspective. It is sometimes referred to as a theory which assists learners to make sense of abstract scientific concepts when cognitive development is acquired (Windschitl et al., 2012). This study views mediation of learning as a skill drawn from the theory of social constructivism.

Learners' cognitive development is the primary focus when new scientific concepts are constructed. In that way, mediation of learning is believed to promote such a development (Vosniadou & Ortony, 1983; Iding, 1997; Treagust, 1993; Heywood & Parker, 1997; Treagust et al., 1998; Orgill & Bodner, 2004). Learners' development is supported to the full potential through this skill. According to Karpov and Haywood (1998), language, signs and symbols help learners to internalise ideas as they develop their inner potential. As mentioned earlier in Section 2.3.2, the development of inner potential promotes improvement of individual self-regulation. Such an improvement informs construction of mental structures.

Gibbons (2003) argues that mediation of learning is the bridge from the existing state of mental development through ZPD to the destined scaffolded state. It is possible that some learners' cognitive reasoning and level is higher than their peers. In these cases such learners should be given an opportunity to share ideas with peers in order to promote joint construction of ideas which is a basic element of social construction (Gibbons, 2003; Stott, 2016). Learning therefore takes place at a social level. Donato and McCormick (1994) assert that mediation of learning involves construction and reconstruction as learners try to make sense of new concepts with the assistance of the more knowledgeable person.

According to Shepard (2000), social mediation of learning develops from an individual person to a group of learners. The exchange of ideas through language acquisition between individuals in a social setting, signals active involvement and leads to social interaction. In that social exchange of knowledge, continuous support by the knowledgeable person assists learners to gradually progress from a lower level of understanding to the expected level. The hypothetical area of development is known as the zone of proximal development (Vygotsky, 1978).

2.3.2.2 Learning in the Zone of Proximal Development (ZPD)

Vygotsky (1978, p. 7) defines the ZPD as the distance between the actual development level as determined by independent problem solving and the level of potential development, as determined through problem solving under adult guidance or in collaboration with more capable peers so learning becomes a joint venture. ZPD recognition encompasses collaborative learning, which is a social learning approach (Kuusisaari, 2014). ZPD is referred to as the ‘construction zone’ and a space where an individual learner reasons by constructing knowledge from the existing schema through social interactions (Gibbons, 2003).

Coaching learners is a pre-requisite to reach learning goals. Harrison (2014) accentuates that the ZPD establishes the relationship between learning and instruction. The fundamental goal is offering support to learning. Support to learning involves giving hints and leading questions at a point where there is a need to progress to the next cognitive level. Learners are assisted to reach a self-regulation stage where they attain a state of internalising ideas on their own as suggested by Karpov and Haywood (1998). Shepard (2000) argues that supporting learning through the ZPD should not focus on challenges to learning only, instead, it has to cater for the development of all learners. Mediation tools such as an analogy, in conjunction with a conventional practical activity, strike a ‘balance’ between learning and self-independence.

Shepard (2000) recommends that it must be established what a learner can do independently or with little help from others, before any assistance can be incorporated. This is due to the fact that appropriate help is required to meet an individual’s learning needs. Such an intervention is helpful when administered at a particular ZPD, but out of the ZPD context, any assistance becomes dysfunctional and irrelevant. So, recognition of learners’ ZPD is a

way of reinforcing understanding (Shepard, 2000). It is Vygotsky's (1978) idea that actual learning takes place within the ZPD.

2.3.3 Scaffolding

Drawing on Bruner's (1986) work, van de Pol and Elbers (2013) highlight that scaffolding is a process that indicates a teacher's perspective on learners' understanding. Holton and Clarke (2006) define scaffolding as, "an act of teaching that supports the immediate construction of knowledge by the learner and provides the basis for the future independent learning of the individual" (p. 131). The assistance can be offered by more knowledgeable others (MKO), for instance, peers and not necessarily only by teachers.

MKOs are to assist when learning barriers surface but where less assistance is needed as traces of progress are evident they should give the assisted learner an opportunity to work on his/her own. Howe (2013) argues that in the social world, the MKO assists the low achievers to attain the expected goals and make sense of new knowledge. In Bruner's (1986) terms, a meaningful learning process is termed a scaffolding process and comprises the following steps:

1. Use of mediational tools like an analogy, practical activity, prior knowledge and language to link learners to new and abstract knowledge;
2. Assist learners to make sense of the new knowledge by internalising new concepts with understanding whilst they are at their individual ZPD'; and
3. When a learner shows an increase in competence, he/she is given an opportunity to work on related tasks with no assistance. At this stage, the learner is independent and given full responsibility as well as control over the task process. The learner refers to the guiding questions and steps which were used by the MKO (Howe, 2013).

Cognitive reasoning gradually increases until the assisted learner masters the required skills. That means an independent state is reached. Howe (2013) and Anton (1999) refer to such a social interaction as a collaborative interaction. Afterwards, a learner is in a position to solve problems without assistance. At that stage, self-mediation occurs (Anton, 1999). Self-mediation arises when a learner questions himself/herself in trying to make sense of the available information in order to solve problems on their own in a similar situation. The independent processing of results is known as self-scaffolding (Holton & Clarke, 2006).

It becomes clear that the ZPD and scaffolding focuses on individual learners, in contrast to assessment which is generally administered to a group/class of learners, irrespective of their different cognitive levels. Thomas (2003) claims that language skills like dialogue between individuals, enhances scaffolding. Scaffolding involves mediational tools such as an analogy, language, graphicacy and prior knowledge, with the focus on learners making sense of abstract concepts (Elbers, Rojas-Drummond, & van de Pol, 2013). Howe (2013) argues that the use of an analogy keeps learners motivated until the task is complete as at that point learners are believed to have made sense of the concepts. So, the use of an analogy enhances learning but has limitations if not well employed. Incorporation of an analogy is a social responsibility as it involves more than one person, so it would stem from a social constructivist perspective (Howe, 2013). It is advised that scaffolding is a support that decreases over time especially when the learner is out of his/her ZPD or when the learner has reached the destined goal and takes responsibility for their own learning (van de Pol & Elbers, 2013).

Scaffolding is regarded as an effective learning technique if the final destination or outcome is reached. The final destination is observable when a learner is in a position to perform complex tasks without any support.

2.4 Concluding remarks

The discussion of literature on mediational tools such as analogies, practical activities, prior knowledge, language, assessment, mind maps and conceptual change was outlined in the first part of this chapter to determine how learning can be enhanced. The mentioned mediational tools assist learners to socially construct new knowledge whilst individual cognitive development is promoted.

In the next chapter I discuss the research design that shaped this study.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This project was a South African case study which focused on one rural senior secondary school. The research design shaping this study is discussed in this chapter. This chapter also discusses the research paradigm and the mixed method approach that underpinned this study. The methods I selected as data gathering techniques are described, namely, documents, interviews and lesson observations. The stated data gathering techniques give insight into how the data were gathered and triangulated. An analysis of the gathered data follows and lastly the concerns of validity, ethical issues and possible limitations are considered in this chapter.

3.2 Research design

The research design mapped out the nature of the study as informed by the identified theoretical framework. Furthermore, the research design incorporated the theoretical framework on which the study was built, specifically social constructivism. According to Devers and Frankel (2000) as well as Cohen, Manion and Morrison (2011), research design suggests the overview of purpose, methodology, types of data required, data gathering methods and data analysis techniques of the research study. The research design helped to acquire insight into the research study through the interpretive paradigm.

3.2.1 Interpretive paradigm

This study embraced the interpretive paradigm. According to Cohen, Manion and Morrison (2011), the interpretive paradigm seeks to understand the subjective world of individual experience. Furthermore, Cohen et al. (2011) argue that the interpretive paradigm informs understanding of human thoughts as the focus is on an individual. Lending support, Bertram and Christiansen (2015) describe the interpretive paradigm as concerned with in-depth understanding of how people make sense of the context they live in.

In the setting of this study, this paradigm encompassed learners' sense making of their experiences and context in order to understand the science world. The use of an analogy in conjunction with a conventional practical activity assisted me in understanding learners'

thoughts by relating the context and the science world or content. The study helped in recognising that learners were able to make sense of science concepts when incorporation of mediational tools was considered.

As highlighted in the previous section, mediation of learning and scaffolding learners in their ZPDs are developmental processes that equip learners to make sense of ideas from simple concepts to abstract concepts (see Sections 2.2.2 and 2.2.3). It is in the same vein of these developmental processes founded through the interpretive paradigm that this study was to take the nature of a case study.

3.2.2 Case study on learners' sense making of Ohm's law

Bertram and Christiansen (2015) define a case study as an “in-depth investigation of a specific group of people in the given context” (p. 42). My project was a case study of one school in a South African rural area (see Section 3.4). The case study of 12 Grade 11 Physical Sciences learners was undertaken, the project being how they made sense of Ohm's law when it was mediated through an analogy in conjunction with a conventional practical activity. Essentially, the study investigated the cognitive development of learners' content from context. According to Sofaer (1999) and Rolfe (2006), qualitative research is characterised as interpretive; contextualised and holistic.

In the process of gathering data, participants were enriched to develop holistically. To be precise, cognitive, motivational and affective domains were developed. The research process targeted learning in a school environment using easily accessible resources. That brought the study into the learners' context whilst construction of ideas developed from context to science content. Development of science content, as informed by real life context, influenced the development of learners' self-efficacy. In the context of this study, the participants accessed new knowledge whilst the researcher accessed data. That indicated a mutual benefit between the participants and the researcher. Cohen et al. (2011) advocate that a case study provides rich data as well as providing an opportunity to gain in-depth understanding within a context. Bassey (1999) and Yin (1994, 2006) add that a study which uses context to gain in-depth understanding of human thoughts, takes the form of a case study.

The learners' thoughts or ideas were constructed on existing schema and experience which connected this case study to a social constructivism approach. In as much as the project was a case study, when mediation of learning took place, social interaction took place as well. That

subscribed to social constructivism through scaffolding. Mediation of learning was made possible through the assistance of the teacher or a peer (More Knowledgeable Other - MKO) (see Section 2.3.2.1).

Mediation of learning is more focused on classroom interactions between learners during analogy activity and conventional practical activity as well as collaboration during discussions. The notion of incorporating an analogy to build science concepts from real life context to abstract ideas links with the constructivist perspective, in particular, social constructivism (see Section 2.3.2). Making sense of learning concepts around Ohm's law was at the heart of this case study. Learners' thoughts as they made sense of Ohm's law concepts were accessed through data sources.

Additionally, however, some data sources such as documents, observations and interviews were used to make some of the findings clearer, without losing the fact that this was a qualitative case study. According to Yin (1994), sources of data are documents, interviews, observations, archival records and physical artifacts. This study relied on the first three mentioned data sources. The gathered data is presented in the form of tables, figures, including graphs and extracts from learners' interactions during classroom discussions (see Section 4). The data presented were analysed and interpreted within the classroom context in which they were produced. The different methods of data presentation signified that qualitative and quantitative approaches were used to interpret gathered data.

Foss and Ellefsen (2002) argue that both qualitative and quantitative approaches can be used to access precise representation of reality in order to address different aspects of knowledge. The aspects of knowledge focus on addressing general to deeper insight, micro levels as well as seeking knowledge about meanings (Foss & Ellefsen, 2002). Johnson and Onwuegbuzie (2004) support the assertion that qualitative and quantitative approaches can be used to supplement each other, as in a 'mixed method' design.

3.2.3 Mixed method design

Mixed methods are situated halfway between qualitative and quantitative approaches. The qualitative approach assists in drawing deeper meanings from quantitative data. In the context of this study data were initially gathered through a diagnostic test. Analysis of the gathered data informed the development of intervention processes and additional data were gathered from a summative test before it was interpreted.

Initially, quantitative data emerged from the diagnostic test which was used to narrow the focus on aspects that retained the qualitative nature of this study. For instance, in this study, graphs and tables were used to draw data from documents. The drawn data were analysed and more easily interpreted. The study was aligned with Morse and Niehaus's (2009) notion of using fixed mixed methods at the start of the research process. Fixed mixed methods were predetermined to access learners' thoughts at macro and micro levels. Data sources such as observation were used to gather data during the research process in order to check on the effect that the intervention plan had on the learning process. In that regard, emergent mixed methods were considered where the need arose (Morse & Niehaus, 2009).

In addition, meaning making of electricity concepts was made clearer when learners were able to explain by the use of graphs how to calculate resistance and establish the relationship between variables, such as potential difference and electrical current. Data from documents, observation and interviews were useful to check on the extent to which the study's purpose, theoretical framework and questions were attained or answered. According to Maxwell and Loomis (2003), a mixed method design could combine a typology-based approach and a dynamic approach in ensuring that the research goal is achieved from the project planning stage. Different data sources in the mixed method design enhance the validity of the study, the complementarity of data, development, initiations, explanation, sampling, contextualisation, illustration and processing results.

Throughout the entire research process both qualitative and quantitative approaches were used interchangeably in order to critique data. I was mindful of the theoretical framework throughout the research process, for instance, through data analysis, interpretation and discussion. I was guided by ideas from Greene, Caracelli and Graham (1989) and Bryman (2006) together with Morse and Niehaus (2009) in considering blending the qualitative and quantitative approach to this study.

Given that this was a case study with a specific focus, the aim of the project was to study only a sample from the entire Grade 11 Physical Sciences learners (see Section 3.4). The purpose was to access deeper insight into the learners' thoughts. Notwithstanding, this study focused on the qualitative approach more than the quantitative approach with respect to data analysis and interpretation. Purposive sampling was used in this qualitative case study and the participants were specifically selected in order to form a focus group.

3.2.4 Purposive sampling

Purposive sampling is categorised under qualitative research and exists in harmony with the interpretive paradigm (Cohen et al., 2011; Bertram & Christiansen, 2015). The selection of research participants was based on sampling 12 learners out of the entire Grade 11 Physical Sciences class, as informed by diagnostic test results.

The diagnostic test was designed to assess learners' thinking across all cognitive levels from less difficult to more difficult questions. The questions covered were Multiple Choice Questions (MCQ), simple recall questions and some questions which led to calculations, graph sketching, explanations as well as comparisons for deducing results. In most questions, learners were required to provide explanations to their answers. The explanations provided were used as indicators of learners' prior knowledge and existing level of meaning making on electricity concepts. Some of the learners left blank spaces in their answer books. Learners with few blank spaces were selected to be the research participants irrespective of their correct or incorrect responses to some questions. Therefore, those with the least or no blank spaces were the first criteria in choosing the sample of 12 learners.

The second selection criteria was ensuring that the sampled participants were heterogeneously spread across all achievement levels, that is, high achievers, moderate achievers and low achievers were selected. The achievers were categorised according to the scores from the diagnostic test results. Learners who scored above 50% of the total test mark were labelled as high achievers, those who scored between 30% and 49% were labelled as moderate achievers and the low achievers scored less than 29%. Four learners were selected from each category of achievers. The reason for selecting high achievers was to identify successful learning strategies whilst the moderate and low achievers were selected to clearly determine the effectiveness of this study in the learning of Ohm's law. In addition, some of the high achievers served as more knowledgeable learners to support their peers. Therefore, the 12 sampled learners constituted the focus group members. The data gathered for this study were sourced from the focus group. In this study, the focus group members were first time Grade 11 Physical Sciences learners. Learners repeating the grade were not included as their presence would possibly have influenced data by introducing an additional variable.

Tongco (2007) suggests that purposive sampling is informed by what is to be discovered. This study was thus intended to discover how Grade 11 Physical Sciences learners made

sense of Ohm's law when it was mediated through an analogy in conjunction with a conventional practical activity. Purposive sampling assisted in accessing the overview of the impact of the study without administering it to the entire Grade 11 Physical Sciences learners (population). The criteria used to select the participants represented the broader spectrum of learners' abilities. Therefore, research findings from the focus group served as an indicator and insight into data that could have been drawn from the entire class.

Purposive sampling was used to get a glimpse of the research findings of the entire population. Sampling learners from different achievement levels contributed in making a fair selection. All learners constituting the focus group benefited from the study whilst their thoughts were noted, analysed and interpreted to answer the study's questions.

3.3 Research goal and questions

The goal of this study was to explore how Grade 11 Physical Sciences learners made sense of Ohm's law when it was mediated through an analogy in conjunction with a conventional practical activity.

To realise this goal, I attempted to answer the research questions as indicated earlier in Section 1.8. The main question was: How did Grade 11 Physical Sciences learners made sense of Ohm's law when it was mediated through an analogy in conjunction with a conventional practical activity?

In order to answer this main question, the following sub-questions were explored together with their associated data gathering techniques:

1. What prior knowledge associated with Ohm's law did Grade 11 Physical Sciences learners have?
 - ❖ To answer this question, I set the learners a diagnostic test with the purpose of considering the focus group's thoughts by analysing their responses and identifying their prior knowledge, misconceptions and learning gaps in order to inform the lesson planning for my intervention phase. Semi-structured interviews with the focus group were also conducted. The purpose was to access information which was not reflected in the learners' answers to the diagnostic test.
2. How did the use of an analogy enable or constrain meaning making of concepts and graphs associated with Ohm's law?

- ❖ To answer this question, learners did a ‘straw electricity’ analogy activity. I analysed learners’ answers on the worksheets and the transcripts of video-recorded observation lessons.
3. How did the use of a conventional practical activity enable or constrain meaning making of concepts and graphs associated with Ohm’s law?
- ❖ To answer this question, learners did a conventional practical activity. I analysed learners’ answers on the worksheets and the transcripts of video-recorded observation lessons.
4. What challenges did Grade 11 Physical Sciences learners experience when Ohm’s law was mediated through an analogy and a conventional practical activity?
- ❖ To answer this question, I made use of summative test results. Video-recorded semi-structured interviews were conducted. The main aim of these interviews was to gain some insight into learners’ thoughts about the effects of an analogy in conjunction with a conventional practical activity in learning Ohm’s law.

3.4 Research site and participants

This study took place at a rural school which is situated about five kilometres from the *Maluti* District Office of Education (pseudonym) in the Eastern Cape Province. The district office is comprised of 23 senior secondary schools that offer tuition up to Grade 12. The goal of my study was to explore how learners made sense of Ohm’s law (see Section 3.3). The research participants were my Grade 11 Physical Sciences learners which meant that teaching and learning was to take place at my school. My research site was therefore the school where I teach, which offers tuition from Grade 10 to 12.

In my school, *Lerato* Senior Secondary School (pseudonym), most learners were doing Physical Sciences as one of their science subjects. The school’s enrolment and streams are such that there are two Physical Sciences classes in each grade. The challenge was that each class had a high number of learners but few educators. To be specific, I was responsible for one Grade 10 class with 115 learners as well as a total of 199 Grade 11 Physical Sciences learners from two classes. The other Grade 10 class was comprised of 120 Physical Sciences learners. My study was focused on the Grade 11 class. The nature of my project was a case study which focused on 12 purposely sampled learners (see Section 3.2.3). The composition of the focus group learners was more or less a representation of the entire Grade 11 class. The

entire class was represented in relation to language, learning abilities and geographical orientation.

All educators/teachers and learners were *isiXhosa* or *Sesotho* home language speakers. However, the language of learning and teaching (LoLT) was English (L2) which is a second language for everybody in my school. Most of the learners in the *Maluti* district grow up knowing both *isiXhosa* and *Sesotho* whilst being conscious of their individual home languages. The same applies to most educators in that area. The influence of home languages was evident during group discussions where, for example, learners communicated in *isiXhosa* most of the time and a *Sesotho* home language speaker would use *Sesotho* to convey the sense of his/her ideas to other group members (see Section 4.2.2). Surprisingly, all oral and written presentations were in English. A wide range of learners' abilities were accommodated in the sampled learners.

The study sample considered criteria discussed in Section 3.2.3 to ensure that all learners' abilities were represented in the focus group. The range of learners' abilities assisted to gauge the extent to which the research questions were answered (see Section 5). As the research process proceeded, the way in which learners thoughts were content aligned signified the effect of the study's goal for all the achievers' categories. Most learners showed a positive learning progress as drawn from their summative assessment scores and/or their self-efficacy. The learners in *Lerato* Senior Secondary School were from different geographical locations.

The focus group for my study was represented by learners who were either local residents or who travelled for more than five kilometres to school on a daily basis. In the South African context especially in the Eastern Cape, which is one out of nine provinces, some of the learners who travel a distance of more than five kilometres are subsidised with government transport. Buses are made available to transport learners on a daily basis. Unfortunately, learners in my school were not benefiting from the transport subsidy. In that case, parents had to organise common transports from various places and pay for their children's transport fare. Sampling learners for a research process from such widespread geographical locations compelled me to have prior discussions with their parents as there were expenses involved. Such discussions were motivated by the fact that I gathered data during the schools' mid-year holidays when the rest of the Grade10 - 11 learners were at home, though the Grade 12 learners were at school for extra lessons. The parents' agreement with regards to

transportation of their children to school throughout the research process session was done and fulfilled.

The research site for my project was a rural school in South Africa and my research participants were 12 purposely sampled Grade 11 Physical Sciences learners as stipulated by the goal and nature of my study. Language and geographical orientation of the focus group revealed interesting data around home language versus language of learning and teaching as well as insight into ethics, respectively. The focus groups' thoughts served as the main data source for this study. I now discuss the data sources or data gathering techniques that were used in this study.

3.5 Data gathering techniques

Thurmond (2001) recommends employing a variety of data gathering techniques in the same study for the purpose of supplementing each other and enriching the data (Denzin & Lincoln, 2005). The process where two or more data gathering techniques are used is referred to as triangulation (Thurmond, 2001; Denzin & Lincoln, 2005).

The idea of triangulation was initially pioneered by Campbell and Fiske (1959) in embracing multiple methods used to gather data (Foss & Ellefsen, 2002). Foss and Ellefsen (2002) claim that triangulation is a strategy used to strengthen data accuracy and access a precise representation of reality (Foss & Ellefsen, 2002; Cohen et al., 2011). Hence, the project was a qualitative case study and insight into the participants' thoughts, voice and context were at the heart of this study (see Section 3.2.2). On that note, both qualitative and quantitative approaches were used, as highlighted in Section 3.2.2, to explore the case study underlying this project. The two approaches were noted to indicate that methodologic triangulation was used as suggested by Denzin (1970).

Denzin (1970) identifies the following types of triangulation: data source (informed by time, space and person), investigator or observer, methodological and theoretical or theory. I mostly used data from the research participants in this study. On those grounds, my study did show traces of methodologic triangulation. According to Denzin (1970), methodologic triangulation consists of qualitative and quantitative data gathered from research participants and non-participants for the same study. Data from the non-participants was only used in checking whether the research participants and non-participants were sharing the same sentiments with regards to prior knowledge on electricity as presented through diagnostic test

documents (see Section 4.2.1.1). On the other hand, theoretical triangulation can be used to test various theories using the same data set (Denzin, 1970). My study did not use theoretical triangulation (only social constructivism was used), data source as well as investigator triangulations (not used).

Triangulation served to ensure the validity and reliability of this study (see Section 3.7). In this study the following data gathering techniques were used: documents (diagnostic test answer scripts; summative test answer scripts as well as journal entries); observations (video-recorded lessons) and semi-structured interviews (see Section 3.2.2). The techniques employed are briefly summarised in Table 1 below.

Table 1: Purpose of data gathering techniques

Data sources	Data gathered	Purpose
Documents	Documents such as: learners' answer scripts on diagnostic test, completed worksheets from an analogy activity as well as conventional practical activity, transcripts of video-recorded lessons and interviews, learner journals and learners' notes as well as scripts from summative test responses.	<p>Diagnostic test responses from scripts: To verify the level of content knowledge learners are expected to have. To probe the level of understanding and gap in prior knowledge so as to provide appropriate intervention. To identify learners' ZPDs.</p> <p>Completed worksheets: To find out if an analogy served as prior knowledge for learning of Ohm's law concepts as well as graph interpretation. The concepts developed through incorporation of an analogy to be connected to conventional practical activity outcomes.</p> <p>Transcripts: To access data gathered through verbal and non-verbal responses.</p> <p>Learner journals: To see how learners made sense of their learning by looking at their reflections and concept maps as well as their notes. That served as an indicator that determined the progress of the lesson presentations.</p> <p>Summative test responses from scripts: To identify strengths and challenges that learners had at the end of the presentation of the designed unit of work.</p>

Observation	<p>Learners' participation and engagement during lesson presentations.</p> <p>The role played by an analogy in conjunction with a conventional practical activity in enhancing Ohm's law concepts and its graphs.</p>	<p>To understand how learners interacted with one another as well as with their teacher during lesson presentations. To see how mediation of learning took place, when watching a video-recorded lesson with a critical friend. Assistance and feedback by a critical friend informed me on the areas of development throughout the research process.</p>
Semi-structured interviews: with individuals and focus group.	<p>In-depth thoughts on diagnostic test responses, video-recorded lessons and summative test responses.</p>	<p>To probe the learners' prior knowledge. To gain insight into how learners synthesised and constructed meaning of concepts and graphs associated with Ohm's law. To find out challenges that learners experienced when Ohm's law was mediated through the use of an analogy and a conventional practical activity.</p>

3.5.1 Documents

Documents as data source, such as learners' scripts on the diagnostic test, summative test answer scripts, completed worksheets from an analogy activity as well as a conventional practical activity (see Section 1.10), learners' notes and journal entries, provided insight into how learners made sense of Ohm's law. Additionally, I also analysed curriculum documents to strengthen my context. I now discuss each of these below.

3.5.1.1 Diagnostic test responses

A diagnostic test is defined as in-depth check to discover particular strengths, weaknesses and difficulties that a learner experiences, and is designed to expose causes and specific areas of weaknesses or strength (Cohen et al., 2011). Drawing from the definition, it is apparent that this kind of assessment can be administered at any stage of the topic discussion. In the context of this study, the diagnostic test was used at the beginning of the research process, to elicit learners' prior knowledge in order to inform my intervention lessons (see Table 1 and Appendix G).

Grade 11 Physical Sciences learners at my research site were informed about the purpose of the diagnostic test before it was administered. Learners were also made aware of the content area to be covered in preparation for the diagnostic test. This area comprised of electric circuits and included work covered in previous grades as well as graphs and relations from the Grade 11 work already done. I developed the diagnostic test as informed by the Curriculum and Assessment Policy Statements (CAPS) document considering Grade 10 Physical Sciences content on electric circuits (South Africa. DBE, 2011). The test was moderated by my critical friend thereafter administered. The test was administered to 85 Grade 11 learners at the beginning of the research process. I expected a total of 199 Grade 11 Physical Sciences learners to write the diagnostic test but only 43% of them actually wrote it. This was understandable, however, as it was a voluntary exercise.

The learners' scores from the diagnostic test helped in categorising learners into achievement levels (see Section 3.2.3). The 12 research participants were selected from all the achievement levels. The data gathered from the diagnostic test was presented and analysed. Strengths and weaknesses from the learners' prior knowledge were identified. Such weaknesses might have emanated from misconceptions or alternative conceptions or an inability to make sense of electricity concepts and/or an inability to link the required information with prior knowledge. Weaknesses identified from the diagnostic test were targeted to be addressed in the planned lessons or intervention lessons (see Appendix I). The areas where learners showed understanding were also covered in the planned lessons so as to show content progression from Grade 10 to Grade 11. After that, the intervention lessons were drawn from the unit of work. The unit of work consisted of a collection of intervention lessons which I taught throughout the research study process.

I presented and analysed the diagnostic test responses in order to answer the research question: What prior knowledge associated with Ohm's law did Grade 11 Physical Sciences learners have? Data drawn from the diagnostic test answer scripts served as a foundation for presentation of Grade 11 content on electric circuits. At the end of the research process specifically the lesson presentations, the focus group members were allowed to write a summative test.

3.5.1.2 Summative test responses

According to Harlem and James (1997), a summative test/assessment can give insight on the understanding of the content presented. This assessment incorporates checking the impact of the teaching and learning process as well as rating learners' performance (Sofaer, 1999). In Sofaer's terms (1999), the rating of learners' performance informs the scores which appear on school report cards. Formulating report cards was not the focus of this study. The purpose of using a summative test was to determine the extent of achievement of the study's goal as well as the challenges that learners experienced when Ohm's law was mediated through an analogy and a conventional practical activity.

The summative test was set and administered to the focus group learners at the end of all the lesson presentations. The test was aimed at checking on the effect of the study on learners' cognitive development, answering the research question 4 (Section 3.3) and providing the data to be used in selecting interviewees.

The types of questions set in the summative test were mostly designed to probe deeper insight into content. The summative assessment consisted of the Multiple Choice Questions (MCQ) and long questions. The MCQ that required explanations encouraged more thinking and long questions also challenged critical thinking. The responses that learners supplied were presented, analysed and interpreted to indicate the role played by an analogy together with a conventional practical activity in learner's sense making of Ohm's law. The data was also used to indicate the effect of learning in an environment where learners were allowed to share their thoughts. The indicated effects to learning pointed to strengths, weaknesses and possible opportunities for incorporating the two core mediational tools under study. The data gathered from the summative test were used in selecting interviewees.

The selection of interviewees was based on the difference in scores between the diagnostic test and summative test. The difference between the two tests was used to gauge the measure of development the study had on learners' thoughts. The nature of answers pointed to how learners were constructing their ideas at the end of the study, which measured the effect of scaffolding (an element of the theoretical framework).

Data on summative assessment were analysed and discussed to determine the effectiveness of the study goal. Reasoning at an advanced cognitive level was also checked by analysing learners' responses through consideration of strengths and weaknesses.

I now highlight the impact of journal entries in this study.

3.5.1.3 Journal entries

Walker (2006) reveals in a research study on athletics, that journal information was most efficient when shared between the researcher and a participant. This study by Walker (2006) is set in a different context to my study but I have drawn from it because the same learning progress sentiments are shared with education practices, for instance, reflections from experiences that inform new learning. Hence, I refer to research participants as learners.

According to Walker (2006), the practise of journal writing provides an informative overview on the progress of the learning process. Reflections and recommendations assist in gradual improvement of learning, promoting critical thinking and learning from experience. Schön (1995) relates journal writing to a purposeful practise by referring to it as ‘reflection-in-action or reflection-for-action’. Walker (2006) modifies Schön’s (1995) idea on the importance of reflections for learning. Walker (2006) highlights that journal reflections should not rely on language usage or language mistakes, instead the focus should be on construction of ideas. Construction of ideas was always considered at all times during the discussions amongst group members or in class.

With reference to my study, a template was designed to be used for reflections in the journal (see Appendix P). Learners were given time to individually note some daily reflections in their journal entries and sharing of such reflections were done the following day. I noted that journal writing had allowed learners to practice writing skills. All learners had an opportunity to put down their individual thoughts without worrying about language issues and scoring marks. When learners read their journals, they tried to correct some language mistakes they had made. Questions and points of concern that needed clarity as well as some comments were also shared amongst learners. Thereafter, the report on the discussions was given to the entire focus group. The discussions made me aware of the need to track learning progress and identify the level of support needed by the learners.

There might be limitations facing journal writing technique. Chan (2009) points out that confidentiality, as one of the limitations, is difficult to maintain. As such, the ethics code might have been violated to a certain degree. In the context of my study, learners’ level of willingness to write and share journal entries improved as the research process progressed.

Journal entries helped me to access the learners' overall viewpoint on the teaching and learning process. The level of understanding and learning progress was also brought to the surface through the practice of sharing journal entries. The practice of interacting with journal entries gave learners an opportunity to reflect on learning so as to access learners' thoughts.

Another data source, observation, is discussed below.

3.5.2 Observations

Observations were made possible by using a video-recorder to capture data that were later transcribed then analysed and interpreted. Devers and Frankel (2000) advise that the researcher takes the video-recorder to the class a few days before video-recording in order to familiarise learners with it and explain the purpose of its use. The critical friend was a Physical Sciences teacher invited to assist in the research process (see Section 3.7). The critical friend was also made aware of the study's purpose and was responsible for video-recording. Most of the video-recordings gave attention to interactions (catchy moments) between learners as the study was learner focused.

In the context of this study, catchy moments were moments of interaction when mediation of learning took place. It was observed that the discussions that took place when learners processed verbal and non-verbal answers invited more social interactions and a lot of data were therefore collected. Observations assisted in gathering data when learners were still discussing and processing their written responses, especially during practical activities incorporated in this study. The 'straw electricity' analogy activity was introduced to establish Ohm's law and a conventional practical activity was also incorporated. The analogy comprised the use of easily accessible materials: a drinking straw, a clothes peg and a glass half filled with water. The clothes peg was placed halfway down the straw for the purpose of squashing it flat to limit air movement/current. The pinned drinking straw was placed in the glass of water. Learners had to blow through the drinking straw in order to make observations, which led to discussion and the sketching of graphs (see Figure 12). Throughout both the activities, learners were involved in discussions where they had to complete worksheets that guided them to make connections, predict and explain, sketch graphs, find relationships and reach conclusions. These discussions pointed to how construction of ideas was taking place, which was the gist of this study. Observation considered a lot of aspects that contributed interesting data.

Observation of the environment, gestures, mediation of learning through social interaction amongst participants, as well as their participation proved to be important aspects in sourcing interesting data for this study. The collection of data through observation supported data sources and noted group interactions during the learning process. The use of video-recorded lessons is advantageous in that it is easy to record and play over time whenever critical analysis is needed (McKernan, 1991).

McKernan (1991) further suggests that video-recordings can be replayed so that tentative affirmation can be fully explored by all researchers or a critical friend in order to check the degree of trustworthiness, especially if there is something unclear from the observation transcript. A video-recorder was used to capture data for all lesson presentations. After some time, the video-recordings were played so that transcripts were formulated. I replayed the video-recordings for the purpose of verifying that most of the captured data was transcribed. Playing the video-clips at least three times in small intervals allowed me to grasp most of the information. Sometimes I could not pick up what the learners were saying due to the background noise, as the lesson site was under construction during the data gathering time. Stimulated recall interviews were then used to assist in accessing that data. The transcripts were later given to the critical friend for verification of correct transfer of information from audio-visual version to a text version before data was analysed and interpreted.

Original data were accessed through the data source of observation. Original data were recorded by capturing learners' voices. The analysed transcripts represented learners' voices which reflected their thoughts at the moment they were video-recorded.

I now discuss interviews as the last type of data source that was used in this study.

3.5.3 Interviews

Groenewald (2004) quotes Kvale (1996) describing an interview as gaining insight into someone's view based on the issue at hand. In Green, Willis, Hughes, Small, Welch, Gibbs and Daly (2007), interviews where participants are free to construct meaning are referred to as qualitative interviews. The interviewees were selected from the prior sampled focus group members. In this study, group interviews and individual interviews were conducted targeting the members of the focus group after a diagnostic test and a summative test were administered and were informed by learners' responses from such tests. The questions for

both types of interviewees were structured in such a way that they fostered reflection on experiences.

Kitzinger (1995) argues that merging individual interviews results in a group interview. On the other hand, Lambert and Loiselle (2008) carried out a health-based study in Canada and revealed that combining group and individual interviews could benefit a study. The emerging data was referred to by Lambert and Loiselle (2008) as interaction data as it arose from diverse perspectives. Organised data from diverse perspectives makes the data richer as compared to individual interviews. To this end, Lambert and Loiselle (2008) claim that group interviews as well as individual interviews provide rich data, therefore both types of interviews were used in this study. With regards to this data source, I started with group interviews and individual interviews followed thereafter.

The group interviewees comprising of four members were selected based on the difference in scores from the diagnostic test to the summative test scores (see Table 4 in Section 4.2.1.2). The selected learners had shown a positive improvement at a different scale. Different scale levels assisted to form a heterogeneous group. The decision to consider a heterogeneous group interview was informed by Rabiee (2004). Rabiee (2004) prefers heterogeneous groups based on the fact that members display honesty as interviewee members tend to be more relaxed. In this study, the heterogeneous group interview was composed of learners with low improvement to learners with high improvement.

The use of scores pinpointed the insight into the degree of the study's impact on the learners' thoughts. The overview on the purpose and aspects to be covered in the interview process were discussed before the interview process started so that learners' thoughts were constructed in a relaxed environment. The discussion covered the expectations from the learners as well as permission to video-record the interview discussions. The additional criteria used to select group interviewees apart from scores, was based on the learners who had interacted more in the observed lessons. Such interactions were not focussed on the providing of correct or incorrect ideas.

Kitzinger (1995) advises researchers about choosing group interviews as they imply that confidentiality is compromised. On that note group members may end up discussing only shared information (Kaplowitz & Hoehn, 2001). Taking note of this mentioned advice, I tried to engage all interviewees in the discussion. Where there were moments where there was less

engagement, I decided to ask if some of the participants had anything to share with the rest of the group. That approach often worked and valuable data emerged. I felt that it would be unfair to both group members interviewed as well as individual learners to allow shy or less talkative learners to be part of the group interviews. Therefore, prior discussions on expectations and permission to video-record interviews were done before interviews took place.

The criteria used to select group interviewees which were based on the score difference between the diagnostic test and summative test responses was also used in selecting three individual interviewees. The broad score difference from low to high scores were selected where the key element was targeting shy learners. The learner named *Boithabiso* (pseudonym) was also selected because she was passive throughout almost all group activities. I found that there was no literature on learners who were shy and passive in class yet showed a recognisable indication that learning did take place.

Bertram and Christiansen (2015) warn researchers about the possible influence that power relations might cause especially where a researcher is a teacher and participants are learners. The interviewee may try to impress the interviewer by giving the assumed responses. The influence of power relations might have had an impact on the data gathered using interviews. In such cases, imbalances between presentation and gestures were continuously checked. I had to be mindful of Lambert and Loiselle's (2008) caution that researchers are advised to video-tape and transcribe the interviews so as to analyse such incidents and note where an interviewee is sending out mixed messages.

Video-recording was done during the interviewing sessions to gather most of the data which might have been lost when the interviewee was speaking fast or the interviewer was not able to note down important information. Semi-structured interviews were used to give the interviewees an opportunity to provide in-depth responses to the research questions (Appendices U, V, W & X). Semi-structured interviews which consisted of open-ended questions were used to access learners' thoughts. Where interviewees struggled to understand a question or did not provide a thorough response, a simplified follow-up question was asked. That gave learners the independence to discuss their understandings as well as to give their thoughts regarding their understanding of Ohm's law. Recognition of learners' thoughts assisted in retaining the qualitative case study nature of the project.

In this study, both group interviews and individual interviews were used to access data and not to compare the two types of interviews. This data gathering technique was used to access data which were not revealed through other data sources such as documents and observations. In addition, video-recordings were done to assess the effect of gestures and environment on the quality of data gathered through interviews. The emerged data were later presented and analysed.

3.6 Data analysis

Attride-Strirling (2001) as well as Fereday and Muir-Cochrane (2006) argue that data analysis can be deductive or inductive. Deductive analysis is theory driven. This study used inductive analysis as gathered data were used to identify themes. Fereday and Muir-Cochrane (2006) define thematic analysis as a search for common themes that emerge from data which is in line with the research goal.

The raw data gathered by means of video-recording interviews were changed from an audio-visual version to a text version (see Section 3.5.3). The data from the text version were presented as transcripts. In the context of this study, the triangulated data gathered through interviews, documents and observations were sorted according to patterns in the information or similar aspects that informed related themes. The related themes from each data source were subsequently categorised according to their similarities and then refined as advised by Bertram and Christiansen (2015). The collection of themes were considered and analysed to form four analytical statements (thematic analysis). These four analytical statements were developed with the help of supporting literature on the theoretical framework and mediational tools (see Table 5 and Section 5.3). Analysis that depends on themes emerging from data to inform generalisation, is known as inductive analysis (Johnson & Onwuegbuzie, 2004). An inductive analysis favoured this case study's chosen paradigm, that is, the interpretive paradigm (Cohen et al., 2011).

Hycner (1999) warns researchers to be wary about themes that overlap as they may signal areas of particular significance to the researcher. On the other hand, it is interesting to critique emerging themes from data to establish generalisations. Therefore, both inductive and deductive methods of analysis can also be used in qualitative research.

In the context of my study, symbolic representations such as tables, graphs, figures and in-depth discussions that reinforce sketches were used to represent research data (see Chapters 4 and 5). Such representations pointed to the qualitative nature of the study where some quantitative aspects were used to draw ideas that led to comprehensive conclusions. Qualitative analysis was used to basically examine data so as to support or refute the findings. Hycner (1999) and Thorne (2000) further suggest that at the end a comprehensive conclusion should be drawn based on the critical analysis of the emerging data and the extent to which the theoretical framework of the topic studied as well as the research questions were in line with the study. Gay (2006) advises that the core of data analysis is to focus on answering research questions. Data analysis and discussion helped me to make sense of the data in order to detect what was missing as well as which questions were not answered (see Section 5). The extent to which the research questions were answered was also revealed through the data analysis process.

I now discuss the validity of the study.

3.7 Validity and trustworthiness

Validity and trustworthiness are supported by inductive analysis in qualitative research (Shenton, 2004; Rolfe, 2006; Cohen et al., 2011). This implies that data interpretation is done based on emerging data. The cornerstone for validity in this research was the triangulation of data. Cohen et al. (2011) claim that triangulation can be used to check on the accuracy, reliability and validity of a data source in order to avoid the researcher's bias (Shenton, 2004; Johnson & Onwuegbuzie, 2004) (see Section 3.5). Maintaining accuracy, reliability, validity and originality of data were the basic characteristics of this qualitative study as proposed by the interpretive paradigm.

The interpretive paradigm envisages that the gathered data is rich and thick (Geertz, 1973; Sofaer, 1999; Cohen et al., 2011). The data used in this study were drawn from data gathering techniques such as documents, observations of lesson presentations (of the unit of work) and interviews as a follow-up on documented data, for instance diagnostic test answers, summative test answers, journals and completed worksheets.

According to Shenton (2004), qualitative research is founded on the context that supports the problematic statement which grounds the need for undertaking such a study. The study context points to the research design and the sample size as well as the type of research

participants. In Shenton's (2004) terms, validity has an element of trustworthiness in it, which bears the condition that if the study is done again on similar participants, it might yield the same findings. In the light of the discussed characteristics, Cohen et al. (2011) caution researchers about limitations that might tamper with accurate data.

There is the likelihood that external factors might influence the behaviour of participants and encourage a flaw in the gathered data (Cohen et al., 2011). Factors such as an unfavourable learning atmosphere, an example being the noise from the construction of classes on the research site during data gathering which negatively affected the video-recording process where some participants' voices were less audible. The learners' perceptions towards the researcher (teacher) can also influence their thinking in a positive or negative way (Cohen et al., 2011).

Additionally, the role played by a critical friend served to contribute to the validity of my data analysis and interpretation. A letter inviting a critical friend from a neighbouring school to assist in my research study was formulated and forwarded to the consent person (see Appendix E). The critical friend was selected for convenience and for the fact that he is a Physical Sciences teacher at FET phase. Additionally, at the time of this study he had a Master's degree in Science Education. Kember, Ha, Lam, Lee, Sandra, Yan and Yam (1997) describe a critical friend as someone who supports and offers reflections to ensure that a research study is a success. The support from the critical friend was to be offered by the moderating of my diagnostic and summative tests, helping in developing the unit of work, and checking the validity of my transcripts when watching the video recordings with me as well as by observing my teaching. The main purpose of inviting a critical friend was to validate data as it was impossible to observe my own teaching practice since I was both the teacher and researcher. That also helped to minimise researcher bias. Being biased implied that the possibility existed that I was likely to influence the research data and decisions even though I was mindful of my role in this study. Therefore, the critical friend promoted neutrality throughout the research process.

Triangulating data gathering techniques and the role played by the critical friend promoted validity and trustworthiness in this study. The emphasis on validity and trustworthiness suggests that the study aims at establishing that the information gathered can be considered true, reliable and without any trace of bias (Merriam, 2002; Denzin & Lincoln, 2008; Cohen, et al., 2011). I now discuss ethical considerations below.

3.8 Ethical considerations

According to Cohen et al. (2011), researchers must be conscious of ethics by considering the nature of the study, research questions, participants, context, as well as the entire research process. For this study, ethics entailed informed consent, anonymity and confidentiality. Firstly, consent means the agreement between the researcher and the research participants which is reached after discussion (Bertram & Christiansen, 2015). Informed consent forms were signed by learners before the data gathering process took place.

Informed consent to conduct research at my school was sought from the subject advisor in the district office as well as the principal of the school for access and permission to the research site (Appendices A, AA & B). According to Cohen et al. (2011), informed consent involves the signing of a participation contract. The contracts or consent letters were signed after the research highlights and expectations were discussed (see Appendices C). The sampled learners for the study were given an opportunity to participate or refuse to participate. The freedom to withdraw at any stage was also highlighted. When meeting research participants, verbal consent is necessary for renegotiations in order to start the journey with a common understanding and clear expectations as well as for the forming of a meaningful relationship (Powell, Fitzgerald, Taylor, & Graham, 2012). However, renegotiations give the freedom to withdraw participation at any time, as previously mentioned (Groenewald, 2004; Powell et al., 2012). A learner who was selected to be part of the focus group disappeared after two sessions and it was not easy to trace him.

The withdrawal of that learner resulted in Figure 3 (Section 4) not reflecting any results above 60%. I then substituted him with another Grade 11 learner. The justification of my substitution was based on the fact that the substitute was involved from the beginning of the research process. My decision was supported by Cohen et al.'s (2011) idea of the snow ball sampling technique. Such sampling method helps in keeping the research size intact but does not indicate that the research is quantitative in nature. The participants' choices were to be respected and this was indicated on the informed consent letter. Also the research participants were notified that the research outcomes would be available at a later stage.

Parents whose children were involved in my research process were invited to a presentation (see Section 3.4 and also Appendix D). The invitation to the parents was based on the reason that parents had to know about the details of the programme to be attended by their children,

be aware of the transport arrangements as some of the learners were transported to school, as well as avoiding the situation where permission letters given to learners would be signed by parents who did not understand the contents of the letter. Such a process was intended for transparency in the rural context. At the end of the study the same parents were invited to watch the video-recordings for the purpose of seeing how their children learned science. The aim of that exercise was to address ethical issues and power imbalances. The parents did attend and were happy to discuss their children's planned learning process. A level of trust developed between the parents and me (researcher), to such an extent that when a learner was to be absent, the parent would report this to me the day before. The parents also indicated their interest in the research process not ending until their children passed Grade 12.

Devers and Frankel (2000) stress that the researcher needs to develop and maintain a good relationship with the participants. Good relations imply that the researcher and participants come to a common understanding of the expectations of both parties throughout the research process. The key lies in sticking to a code of ethics which is negotiated in advance and involves a sense of transparency.

Lastly, a pseudonym for the school was used to address ethical issues of anonymity and confidentiality. In addition, participants were allowed to give themselves pseudonyms in order to observe confidentiality. They came up with some interesting pseudonyms. For instance, one learner named himself after the 2013 top learner from my school. That top learner served as his role model as he managed to achieve all subjects at the highest level, above 80 %, including science subjects. That means his attitude towards science changed in a positive way. Another learner named himself '*Cozmo*'. I discovered that the name was connected with the study of stars and the galaxy as he intended pursuing his career in 'cosmology'. Another chosen pseudonym was '*Zodiac*'. She named herself after the general star guide.

Anonymity was compromised by the possible identification of the school when viewing the video-recordings and seeing the research participants' uniform. This was a limitation to this study and it will be discussed later in this section. Such a case could not be avoided especially as the participants were learners and the research goal was curriculum orientated. To play the tape or share the photos, I had to seek permission from the parents, learners and the school. I was granted permission to use the photos and share video-recordings for study purposes only. For that reason the photos were used in validating data in this study, for instance, to show the

set-up for the straw electricity analogy as well as in showing a learner gesturing whilst thinking about an explanation of some lesson observations. Observing ethical issues implied that I had to expose the entire Grade 11 Physical Sciences learners to the same research content which was accessed by the focus group.

Ethical considerations in a research study include promotion of a safe working environment. Mutual understanding of the expectations of the study put participants at ease. An on-going relationship between the researcher and participants may continue for some time even if the research process is complete. That is advantageous in the building of trust.

The study has some limitations that are discussed below.

3.9 Limitations of my study

The limitations of this study might be influenced by it being a qualitative case study which involved a researcher who is a teacher and participants who were learners. The sample size of 12 learners might be too limited for generalisation.

In general, a case study is not open to generalisation (Tongco, 2007; Cohen et al., 2011). Since the study was on my own teaching practice no generalisation based on findings might be attempted. The reason being that the findings could be prone to the researcher's bias, even though that was considered throughout the entire research process by including a critical friend and triangulating data. A small amount of incorrect data could have been gathered as participants might have been eager to please the researcher due to power relations (Tongco, 2007).

Notwithstanding, my research findings provide some insights on the use of an analogy when mediating learning of concepts and graphs associated with Ohm's law. It will thus add valuable information to the understanding of teaching Ohm's law within the South African context.

3.10 Concluding remarks

This chapter discussed the purpose of undertaking a qualitative case study on how Grade 11 Physical Sciences learners made sense of Ohm's law when it was mediated through an analogy in conjunction with a conventional practical activity. The data gathered in this study is presented and analysed in the next chapter.

CHAPTER 4

DATA PRESENTATION AND ANALYSIS

4.1 Introduction

In this chapter I present and analyse the data gathered using techniques such as documents, observations and interviews. Data gathered from each technique is presented and analysed in accordance with emerging themes. I discuss the most salient instances of learners' sense making as revealed in their verbal and non-verbal responses. The identification of such indications or moments was guided by the theoretical framework of social constructivism. In this chapter, I start by highlighting data distribution and thereafter present and analyse data.

4.2 Data distribution

Data distribution refers to the kinds of data obtained in the attempt to answer the study's research questions. The sample distribution was outlined so as to systematically present the data. It is accompanied by qualitative presentation in the form of tables, figures and extracts from appendices. Extracts from interactions between learners are presented as evidence of the raw data gathered. The presented data is also analysed.

4.2.1 Documents

The data presented in this category was informed by diagnostic test responses; responses recorded on both the analogy activity and conventional practical activity worksheets; journal entries, mind maps and summative test responses. Data emanating from each category were analysed.

4.2.1.1 Diagnostic test results

Figure 3, below, shows the results of the diagnostic test that was written by 85 learners at my research site.

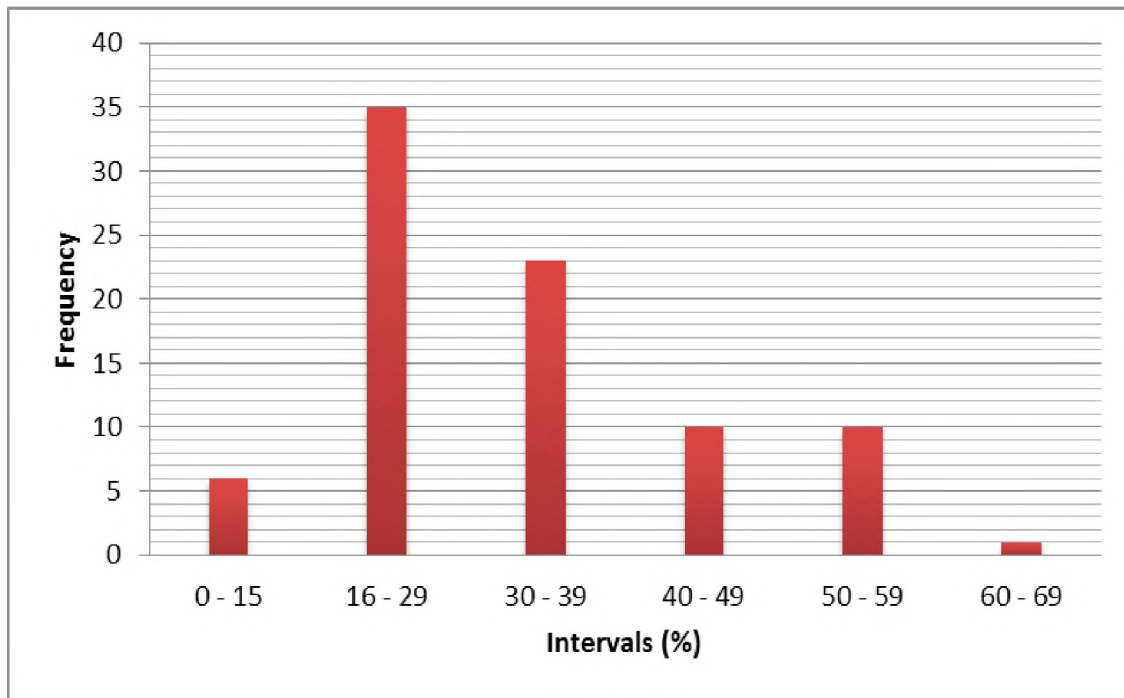


Figure 3: Diagnostic test results

The distribution of marks reflected in Figure 3 revealed that few learners managed to score more than 40%. The pass percentage in Physical Sciences is 30% in South Africa (South Africa. DBE, 2014). In order to best gauge strengths and weaknesses, I focused my analysis on the responses supplied by learners across all intervals. The intervals were used to demonstrate a layout of the different learners' abilities. Different intervals were later combined to form achievement categories where sampling of research participants took place (see Section 3.2.3). The purpose was to gain insight into areas where learners indicated well-built prior knowledge on the topic, electric circuits and the sketching of graphs from learners who represented the Grade 11 Physical Sciences population. Then, twelve (focus group) learners were sampled.

The responses from the sampled learners constituted data which was presented and analysed later. Data from the research non-participants were only used to check the linking of ideas to guard against misrepresentation by the focus group. Thereafter, all the data presented in this study were gathered from the research participants (see Section 3.5, triangulation). The gathered data (from the focus group) were analysed to access strengths as well as misconceptions or alternative conceptions. Such data assisted in developing the unit of work. The diagnostic test results for the focus group learners are reflected in Figure 4, below.

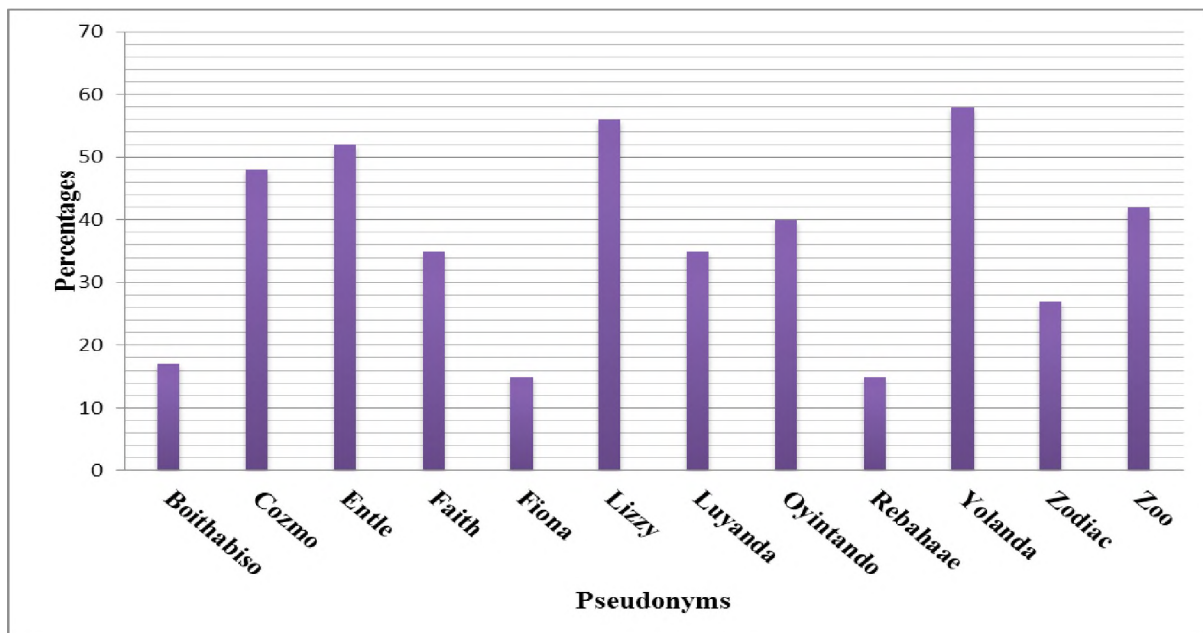


Figure 4: Diagnostic test results for the focus group members

The aim of presenting the responses for the focus group, as shown in Figure 4, was to gain an insight, particularly, of the continuum of the learners' prior knowledge. The focus group consisted of different achievement categories. Figure 4 showed that: *Yolanda, Lizzy, Entle* and *Cozmo* were identified as higher achievers; *Zoo, Oyintando, Luyanda* and *Faith* were identified as moderate achievers and *Zodiac, Boithabiso, Fiona* and *Rebahaae* were identified as low achievers. These twelve learners formed a heterogeneous focus group of the study's participants. Throughout the research process, learners had to work in small groups. Group work gave learners the opportunity to learn from one another, promoting the exchange of ideas from different backgrounds and cognitive levels. The learning atmosphere encouraged learners to assist one another. The overall performance of focus group learners presented in Figure 4 was narrowed down to look at their actual scores for sub-questions.

The scores for all sub-questions in the diagnostic test are reflected in Table 2, below.

Table 2: Detailed scores for diagnostic test

	QUESTION 1		QUESTION 2				QUESTION 3												TOTAL	
	1.1	1.2	2.1	2.2	2.3	2.4	3.1	3.2.1	3.2.2	3.2.3	3.2.4	3.2.5	3.2.6	3.2.7	3.2.8	3.2.9	3.2.10	3.2.11		3.2.12
Pseudonyms	2	2	6	3	3	3	3	2	2	4	2	1	2	2	2	2	2	2	3	48
1 Boithabiso	0	0	4	0	0	0	0	0	0	2	1	1	0	0	0	0	0	0	0	8
2 Cozmo	0	0	6	0	1	0	3	2	2	3	2	1	2	1	2	2	0	0	1	28
3 Entle	2	0	2	0	1	0	2	2	2	3	1	1	2	2	1	1	2	2	1	25
4 Faith	0	0	2	0	1	0	1		0	2	1	1	1	2	2	2			2	17
5 Fiona	2	0	2	0	0	0	2		0	0	0	0	0	0	1	0	0	0	0	7
6 Lizzy	0	0	3	0	1	1	3	2	2	4	1	0	2	2	2	1	2	0	1	27
7 Luyanda	2	0	2	0			3	0	0	3	1	1	1	2	2	0	0	0		17
8 Oyintando	2	2	2	0	0	0	2	0	2	3	1	1	0	2	2		0	0	0	19
9 Rebahaae	0	2	2	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	7
10 Yolanda	2	0	3	0	1	1	3	0	2	1	0	1	2	0	2	2	0	0	0	20
11 Zodiac	0	0	2	0	0	0	0	0	0	3	2	1	1	2	2	0	0	0	0	13
12 Zoo	2	2	5	0	1	1	3	2	2	3	2	1	1	2	2	0	0		1	30
AVERAGE	1	0.5	3	0	1	0	2	1	1	2.3	1	0.8	1	1.3	1.5	0.7	0.4	0.2	0.6	18.2

Table 2, above, indicates that some questions were well answered, some were poorly answered, while others were not attempted by the learners.

In the context of this study, well answered questions were indicated by the average mark which was equal to or greater than half the total mark. Table 2 indicated that the following sub-questions were well answered: 1.1; 2.1; 3.1; 3.2.1; 3.2.3; 3.2.4; 3.2.5; 3.2.6 and 3.2.8. In these mentioned questions, learners managed to score 50% or greater than 50%. In questions such as 2.1; 3.1; 3.2.3; 3.2.5 and 3.2.8 learners were expected to define, and draw an electric circuit, sketch a graph, describe the nature of the graph, as well as use words to interpret the table of results (Appendix H). The following responses were provided by learners in defining electrical current, potential difference and resistance (Appendix H where R1 to R4 represents response by learner 1 to response by learner 4):

Electrical current:

R1: Is the amount of charge that flow past a point per second (8 responses).

R2: Is the amount of electricity across an electric circuit (2 responses).

R3: Is the energy that flows through a conductor in one direction to operate a system.

Potential difference:

R1: Is the difference between current flow and charges e.g. voltmeter.

R2: Is the volume consisting across an electric circuit. You use a voltmeter to measure potential difference.

R3: Is the difference between two points in a circuit (2 responses).

R4: Is the work done per unit charge.

Resistance:

R1: Is the opposite of electric current.

R2: Is the ability of a conductor to not let current or allow electricity to pass through it. You use a resistor to measure resistance (8 responses).

R3: Is opposition used to show relationship around the circuit.

R4: Is the wire that carries the flow of charge.

To begin with, most learners were able to define electrical current at an acceptable science level. Few learners provided an acceptable definition of potential difference. The learners provided a correct measuring instrument instead of the expected definition. Lastly, learners provided a description of resistance instead of defining the term. The evidence on defining concepts indicated that learners' understanding of such terms needed attention although a 50% average mark was shown in Table 2.

Focusing on scores for questions 3.2.1 and 3.2.2, the learners' average mark was shown to be 50% as indicated earlier (Table 2). Further, considering the frequency of the two sub-questions of which the learners were to score either 0% or 100% it was revealed that four learners scored 100%. It led to the achievement of 33%. On the other hand, the scores for sub-section 3.2.2 led to an average of 50% of which six out of 12 learners scored 100%. That led to an average mark which is the same as the actual achievement. The use of frequency of scores assisted in understanding data gathered more than relying on average marks.

From Table 2 it is clear that most of the low achievers managed to score some marks in these questions. Most learners were able to draw circuit diagrams, as revealed and shown in Appendix H (or Figure 6). The graph sketching sub-question was well answered as well, but there were some areas where learners did lack certain graphicacy skills, such as labelling,

scale, plotting and showing the line of best fit. It was shown that they came up with alternative conceptions.

The alternative conception which emerged from a few learners is reflected in the graph below. The graph shows that the symbols used for labels were inaccurately recorded (see Figure 5). For instance, 'P' was used to denote potential difference, 'V' for potential difference and 'C' for current. The gas concepts were confused with the electric concepts. For instance, 'P' was later confused with pressure and 'V' with volume. The confusion was shown when a relationship between the two physical quantities was stated in words. That confusion led to the loss of units for the two physical quantities. Some learners did not make sense of the relationship between the heading and labels (see the second graph of Appendix H). The plotting of points led to a straight line when the line of best fit was considered.

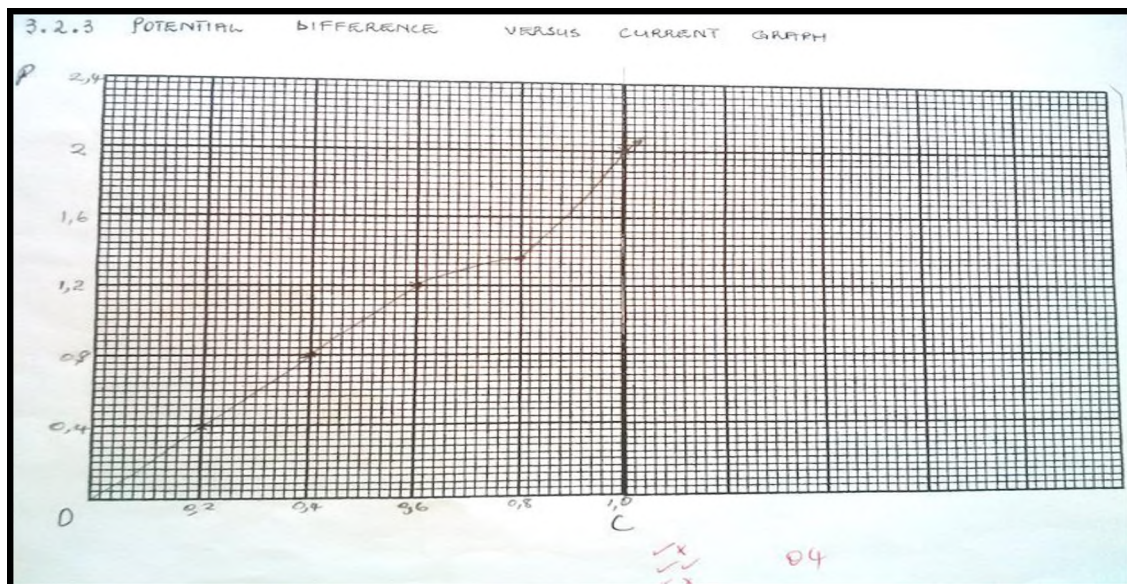


Figure 5: Graph of potential difference versus electrical current (diagnostic test)

Most learners did not graphically represent the line of 'best fit' as a straight line, although they indicated that the graph would be a straight line. The same applies to the graph shown in Figure 5. That was an indication that making sense of graphicacy characteristics was a challenge to the learners. Lastly, correct graphicacy meant that scale had to be considered in sketching the graph. Most of the learners did not make use of a correct scale, unlike the one shown in Figure 5. The learners just put down points that they were given without verifying the consistency or equal magnitude of the spaces between the points. Some learners assumed that 'uniform scale' meant equal spaces regardless of magnitude represented. A response to the other question which was well answered is shown below, in Figure 6.

Current (A)	Potential (V)	$\frac{V}{I}$
0.2	0.4	2
0.4	0.8	2
0.6	1.2	2
0.8	1.6	1.95
1.0	2.0	2
1.2	2.4	2

Current (A)	Potential (V)	$\frac{I}{V}$
0.2	0.4	0.5
0.4	0.8	0.5
0.6	1.2	0.5
0.8	1.4	0.6 = 0.57
1.0	2.0	0.5
1.2	2.4	0.5

Figure 6: Learners' calculations of the resistance ratio

Learners had to fill in the last column. Most of them were able to provide correct responses, as in the case of the example above (Appendix H). Some learners responded differently by exchanging the numerator and denominator values. Their responses led to the inverse of the expected results, as can be seen in Figure 6 (the example on the right). I was interested to find out why the learner decided to exchange values. I thought that the possible reason for providing such a response was due to mechanically answering the questions, without much focus on the processing of answers. So, I decided to access her thoughts through interviewing the learner. She indicated that the exchange of values was a mistake as she was panicking (Appendix W). Here are the responses to the learners' interpretation of results shown in Figure 6 (where R1 to R7 represents response by learner 1 to response by learner 7):

R1: The current is directly proportional to the potential difference (3 responses).

R2: It means that they are at constant pressure or velocity.

R3: Current is half the value of potential difference.

R4: Want to observe the value of $\frac{V}{I}$.

R5: Means that it does not affect the readings of both voltmeter and current to a certain degree.

R6: The potential difference doubles the current and $\frac{V}{I}$ remains constant, where current is directly proportional to the potential difference.

R7: This means when current and potential difference increases the ratio of the two remains constant.

(Extracted from Appendix H: data on diagnostic test)

Most of the learners were able to see the relationship between potential difference and electric current. The relationship was described as both quantities increasing and directly proportional to one another. One learner referred to a constant variable or ratio, although he/she was not exactly sure about its science term. That learner decided to use the term pressure or velocity. This is an indication that prior knowledge needs to be checked before new lessons take place. Another learner regarded the ratio as a collective reading for both ammeter and voltmeter. That reading was not affected, from the learner's perspective, meaning that it remained constant. It was evident that learners were in a position to juggle between mathematical symbols and words. Table 2 shows that some learners did not answer some questions.

As noted, Table 2 reflects some blank spaces. I initially thought that learners were simply unable to derive the answer required from their prior knowledge or were not given enough time to answer all the questions. This seemed to be confirmed by subsequent interviews, with most of the learners concerned with not doing well in other questions.

Learners were expected to identify physical quantities, relationships and to find patterns; calculate gradient and compare and summarise in questions such as 2.2; 2.4; 3.2.1; 3.2.10; 3.2.11 and 3.2.12. The mentioned questions were poorly answered, as revealed by low marks and an average of less than half the total mark for the sub-question (see Table 2). Question 1.2 was also poorly answered although it was a Multiple Choice Question. Blank spaces were mostly found in the questions identified as poorly answered (see Table 2). Reasoning at an advanced level of thinking was triggered by such questions as they had to apply the knowledge they had gained. Learners had to draw from the information given to respond to some of these questions. A detailed analysis table of diagnostic test results for the focus group is shown below.

Table 3: Detailed analysis of diagnostic test results

Pseudonyms		Correct and Partially Correct Explanations	Wrong Explanations	Correct Graphicity	Partially correct graphicacy	Wrong Graphicity	Correct Calculations	Partially Correct Calculations	Wrong Calculations	Blank Answers
	Frequency →	6			2		1			
1	Boithabiso		6		2				1	
2	Cozmo	4	2		2				1	
3	Entle	6			2		1			
4	Faith	4	1		2				1	3
5	Fiona	1	5			2			1	1
6	Lizzy	5	1	1	1		1			
7	Luyanda	2	3		2				1	3
8	Oyitando	1	4		2				1	1
9	Rebahaee		6			2			1	
10	Yolanda	4	2		1	1			1	
11	Zodiac	2	4		2				1	
12	Zoo	5			2				1	1

Table 3 indicates the frequency of explanations, accurate graphicacy and calculations. There seemed to be a high frequency of learners with correct and partially correct explanations. Two groups consisting of three learners each obtained 100% and 50%, respectively, in accuracy of explanations. As reflected in Table 3 above, learners with correct explanations had partially correct graph interpretations and few wrong calculations.

Erroneous calculations were mostly obtained by learners with incorrect explanations and graphs. To be specific, out of ten learners with incorrect calculations, five of them had erroneous explanations and two had erroneous graphs. Lastly, blank answers were noted on the part of three learners with incorrect explanations and two with correct explanations. It became evident that the ability to explain had an impact on other skills such as calculations and graphicacy. For instance, *Boithabiso*, *Fiona*, *Oyintando*, *Rebahaee* and *Zodiac* had shown a high frequency of incorrect explanations hence the incorrect calculations and graphicacy for these few learners (see Table 3). Diagnostic test responses assisted in identifying alternative misconceptions and planning for intervention.

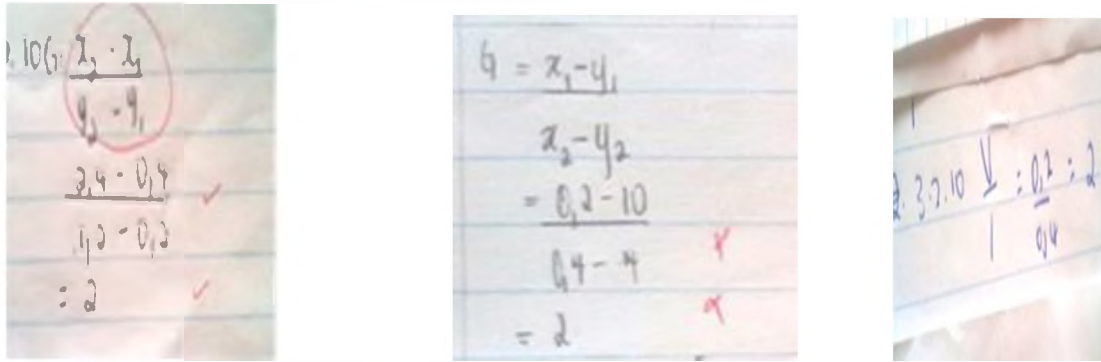


Figure 7: A sample of how three learners calculated the gradient (of a line)

The learners were expected to calculate the gradient of the graph. The examples of attempts from three learners are shown in Figure 7. All of them correctly identified the gradient with the ratio of the two physical quantities as is portrayed from the sampled responses of the three learners. They had an idea that gradient is the ratio of change in physical quantities but the exact quantities were swopped around. This indicated the alternative conceptions that learners had with regards to interpretation of graphs. The alternative conceptions shown in Figure 7 were in relation to the calculation of a gradient that: gradient is a ratio for change in 'x' by change in 'y' (first response), gradient is the ratio of difference between two points (second response) and gradient is potential difference divided by electrical current (last response). It could thus be argued that the link between different scientific data representation was a challenge. To be explicit, it was not easy for learners to see the connection from the data in the table to a graph and calculations. The results from Figure 5, Figure 6 and Figure 7 were such an example of establishing data connections. Although most of them managed to get the ratio from the table of values, they struggled with calculations. That led to their difficulty in describing the relation in words, as shown in Figure 8 below.

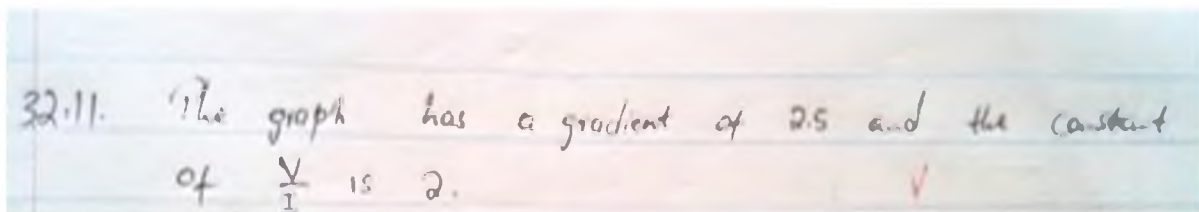


Figure 8: Learners' responses drawn from two previously answered questions

Despite the fact that the connection of representations was not clear, most learners were able to state the relationship between electrical current and potential difference (3.2.12 in Appendix H). The learners' responses (R) are shown below:

R1: The aim was to find out whether truly current is directly proportional to potential difference and the results proved that they are directly proportional (2 responses).

R2: The conclusion, the current increases as the potential difference increases, the relationship between them is 0,2.

R3: When current is used it increases as it goes up and that also causes the potential difference to increase more and in the two ratio they are both constant, which is their quantities.

R4: Ohm's law states that for a conductor at constant temperature, the current of the conductor will be directly proportional to the potential difference (voltage) across it, therefore resistance will also increase. The resistance of the circuit is equal to the volume divided by the current. The gradient of a circuit (the results drawn on a graph) is equal to its resistance. If temperature is not constant, the current will not be directly proportional to the potential difference meaning in this experiment, the temperature was kept constant because current is directly proportional to the voltage.

The correct conclusions were reached by almost all learners although they failed to include the third physical quantity (resistance) in their arguments. Their justification stopped with a 'constant ratio'. Only response 4 (R 4) included the third physical quantity (variable) when detailing his/her conclusion. The learners' reasoning started from gradient, through resistance to temperature and the results confirmed that the learners were not at the same cognitive level.

The diagnostic test was an indicator of existing knowledge, content gaps and alternative conceptions. Once I had the results of the test, a unit of work was designed and implemented (see Section 3.5.1.1).

I will now present the comparison between responses from the diagnostic test and summative test.

4.2.1.2 Diagnostic test and summative test scores

Figure 9 below, reflects an average change in performance as informed by the diagnostic test scores and summative test scores for the 12 focus group members.

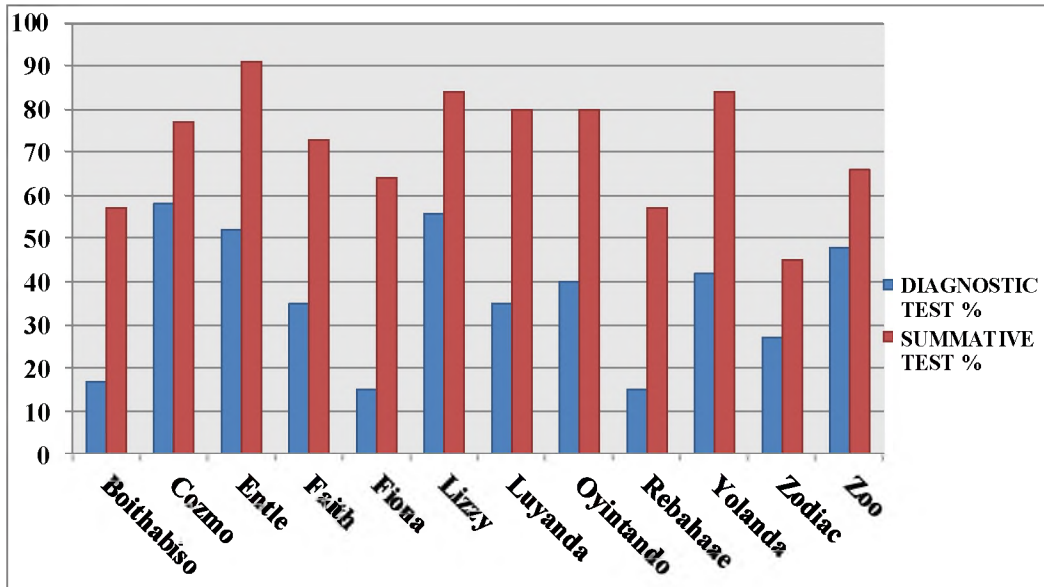


Figure 9: Diagnostic test and summative test scores

It can be seen at a glance that there was a marked overall improvement in performance by the learners. All learners achieved above 40% and three learners achieved below 60% in the summative test. That is a much better outcome compared with the diagnostic test where the range was between 15% and 58%. All learners showed a pronounced improvement in their summative test scores as can be seen in Table 4. The improvement was also shown by the following learners: *Bothhabiso*, *Fiona*, *Rebahae* and *Zodiac*. The mentioned learners were previously categorised as low achievers when I first sampled the study participants. The improvement may be due to the consideration of different mediational tools such as the ‘straw electricity’ analogy and a conventional practical activity that were incorporated during lesson presentations. Table 4 displays specific individual change in scores for the two assessments.

Table 4: Difference in scores between diagnostic test and summative test

PSEUDONYMS		DIAGNOSTIC TEST%	DIFFERENCE	SUMMATIVE TEST %
1	Boithabiso	17	+ 40	57
2	Cozmo	58	+ 19	77
3	Entle	52	+ 39	91
4	Faith	35	+ 38	73
5	Fiona	15	+ 49	64
6	Lizzy	56	+ 28	84
7	Luyanda	35	+ 45	80
8	Oyintando	40	+ 40	80
9	Rebahaae	15	+ 42	57
10	Yolanda	42	+ 42	84
11	Zodiac	27	+ 18	45
12	Zoo	48	+ 18	66

Table 4 shows the scores with a positive difference. The magnitude of the difference was used to determine the effectiveness of the intervention as well as to sample learners for interviews.

The quantitative measure such as the scores from both tests were used to signal the extent to which learners made sense of Ohm's law. Since this study was a qualitative case study, those differences in levels were used to select learners for both group and individual interviews. Heterogeneous grouping based on the differences shown in Table 4 were considered in selecting interviewees. Group interviewees were *Yolanda*, *Oyintando*, *Faith* and *Cozmo*. The following learners were selected for individual interviews - *Boithabiso*, *Lizzy* and *Zodiac*. I planned to include either *Fiona* or *Luyanda* in my interviews but unfortunately they were absent from school on interview set dates which were scheduled to take place in July (at the beginning of Term 3 or third quarter of the year). I will now present the summative test results.

4.2.1.3 Summative test results

At the end of the lessons, a summative test was administered to check the level of content development and sense making of Ohm's law. The data gathered showed that learners

responded well to multiple-choice questions when they were required to provide explanations for the choices made from the suggested options. Choosing from the suggested explanations led to an achievement of 100%. The explanations provided by learners in question 1.2 showed that learners made sense of resistance but only to a certain extent (Appendix OOO). Further enquiry on explanations generated interesting responses from learners (see the extract below from Appendix OOO).

Learners discussed the effect on the experiment's results once the switch was closed for a long time when taking readings on the ammeter and voltmeter (R represents responses by different learners):

R1: The longer the constant, the greater is its resistance - the thickness of the constant, the smaller is its resistance and the temperature will become hotter.

R2: The reading could end up wrong if the switch is closed for a long time, the resistor gets hot and gives wrong results (4 responses).

R3: If the switch is closed for a long time, the resistor will become hot and ammeter as well as voltmeter won't be able to give out relevant reading as the ticker will go up and down - that is why the switch should be closed and let it go (3 responses).

R4: The temperature will not be constant and the reading of ammeter and voltmeter will increase.

R5: The results and the readings taken won't be accurate, because by the time the switch is left closed, current will keep on flowing non-stop.

R6: The experiment results will not have a common difference because the temperature on the resistor will rise. The results will be incorrect because the temperature will not be constant.

The responses pointed to sense making as learners interpreted the effect of ammeter and voltmeter readings on temperature. The mediational tool to access learners' thoughts was language. Language appeared to play a role as the medium of instruction as well as an indication of identifying the learners' cognitive level.

Learning science in second language seemed to have an impact on R1's explanation. For instance, 'the longer the constant' and 'the thickness the constant' were the phrases used to

emphasise the increase in resistance from the learner's perspective. In comparison to R4, R1 seemed to arrive at the same explanation. But both of them were not as elaborative as R2, R3 and R5. The latter showed competence in science language. It was interesting to see how R6 articulated the explanation.

R6 showed a recognisable cognitive development. The ability to integrate between subjects was a sign of maturity in mental structure. I never thought of associating constant temperature with common difference. Common difference is commonly used in Mathematics. This meant that R6 made sense of the science concepts rationally by using mathematical skills, such as graphicacy, to make sense of new concepts.

Learners were given Cartesian grids to sketch the graphs as shown in Figure 10. Most (nine) of them showed an awareness of graphicacy requirements. They were able to show labels with units on both axes, sketch the graph which started at the origin, draw a line of best fit and use the scale properly (Appendix OOO). Few learners were challenged in sketching graphs. Most of the graphicacy aspects were met but scale seemed to be a challenge for some learners, as represented in Figure 10.

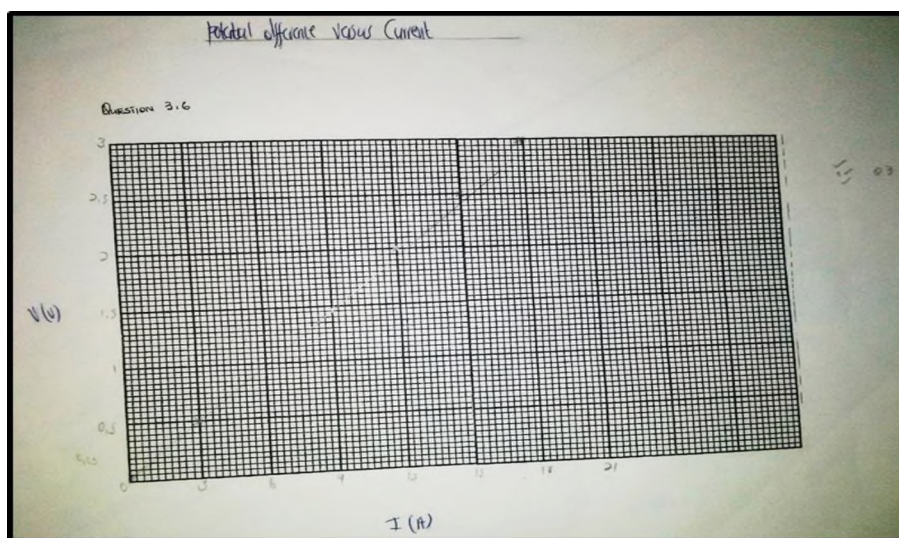


Figure 10: Graph of potential difference versus electrical current (summative test)

There was a misrepresentation of scale in the horizontal axis. The learner picked up that the scale is a multiple of three but failed to stick to the chosen scale when plotting points. The points were given as decimal numbers such as 0,3; 0,9; 1,2; 1,5 and 1,8 for ammeter readings. This learner was then challenged by plotting the given points. Then the graph was sketched on the assumed whole number scale. Lastly, calculations were done based on the drawn graph

and the graph they had to draw themselves. Figure 11 shows responses from two different learners in two different calculated questions. Workings on question 2.6 and 3.8.3 respectively are presented in Figure 11.

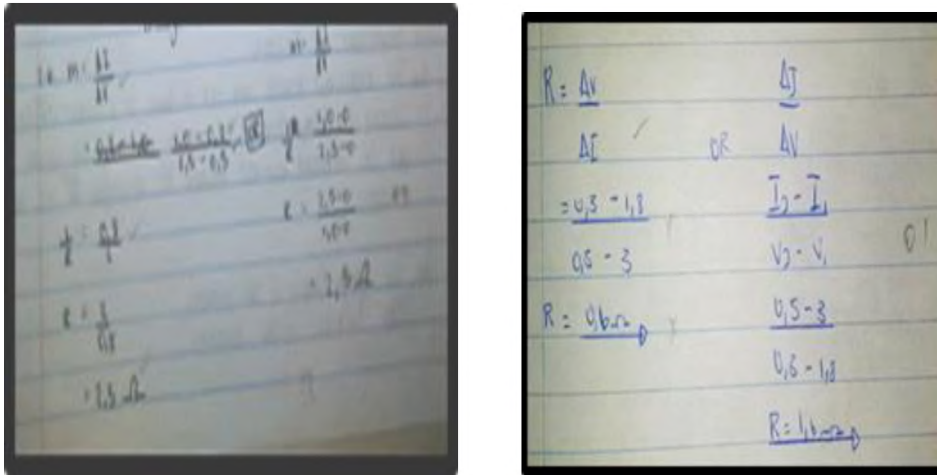


Figure 11: Resistance calculations from two learners

It was interesting to see that most of the questions requiring calculations were seen through to the completion level. The shown calculations displayed commonalities and differences. Both learners had the courage to work through the calculation twice in order to check their solutions. That builds one's self-efficacy, especially if the final solution is the same. Such a learner would be motivated to assist others. It was evident that that learner had made sense of Ohm's law and was able to use mathematical symbols to show understanding. Alternatively, calculating one problem twice does not necessarily signify mutual understanding of concepts (refer to the sketch on the right).

The response from the learner on the right in Figure 11 seemed to show that he/she knew that resistance is a ratio of potential difference and current. The confusion arose when the learner did not stick to one quantity in the numerator or denominator. That confusion might be an indication that dealing with resistance using calculations is above the learner's cognitive level. This was shown when the learner left both answers, without cancelling one or the other, even though the solutions were different. This learner did not use different points, instead he/she swapped the numerator with the denominator.

I will now present data extracted from worksheet responses.

4.2.1.4 Worksheet responses

Learners had to complete worksheets as they worked in groups when doing practical activities such as the 'straw electricity' analogy and conventional practical activity. The analogy was used to establish electricity concepts used for learning Ohm's law. Figure 12 shows how the learners used easily accessible resources to do an analogy activity. Learners were working in small groups of three members.



Figure 12: 'Straw electricity' analogy in action

Learners were working in groups of threes. The following extract was taken from Appendix K where the bulleted points indicated responses from different groups:

Predict what will happen when you blow through the straw with a peg on it?

- *There will be less air coming out of the other end.*
- *Current will be reduced so current will move more slowly.*
- *The peg will resist flow of current.*
- *There will be no bubbles produced.*

Explain:

- *The straw acts as a conductor and the peg as a resistor therefore the peg limits the amount of air coming out (from two groups).*
- *The resistor reduces the speed that the current flows.*

- *There is no air going through water to form bubble.*

Now place a clothes peg on the straw so that the straw is squashed almost flat. Try blowing air through the straw. Does any air go through or not?

Yes, it goes through. (Response from all the groups).

Place the other end of the straw in the glass of water to verify your answer.

Does air still go through the straw? Explain your choice of answer.

- *Yes but the amount of air passing through is not equal to the amount of air passing through when there is no resistor because it limits the amount of air passing.*
- *Yes. The air still goes through the straw, because the water still enters inside the straw.*
- *Yes because as the peg acts as a resistor that doesn't mean the air won't go through - it will but is limited.*
- *Yes, because it acts as a voltage, which allows less air to be transferred into the water.*

When air is flowing through the squeezed straw, what can you say about the air in the straw between your mouth and the peg, and the air in the straw on the other side of the peg?

- *The amount of the air between the mouth and the peg is greater than the amount of air on the other side because the peg reduces the amount of air passing.*
- *The peg will reduce the amount of the air that passes to the other side.*
- *The air between the straw and the other side of the peg is greater after passing a resistor.*
- *I forced more air until it reached the peg, but after the peg the air was reduced, therefore it formed less bubbles.*

All the groups managed to make a connection from the analogy to the targeted concepts, for instance, by relating the air blown to current. With reference to the straw, however, 75% of the 12 focus group learners related it to the conductor whereas the remaining 25% linked it to the cell (Appendix K). This was a signal that an alternative conception might occur. The predict-explain-explore-observe-explain (PEEOE) approach was tested in the analogy activity. The results proved that learners were able to make sense of the analogy. They further related the attachment of a clothes peg to the effect of a resistor. This was because of its

function, which was to limit the current flowing. If learners were not given the opportunity to observe and then explain the findings, one of the groups would have been left with an incorrect notion about the role played by the peg. The graphs were drawn according to the frequency of bubbles formed after blowing through the straw as shown in Figure 13.

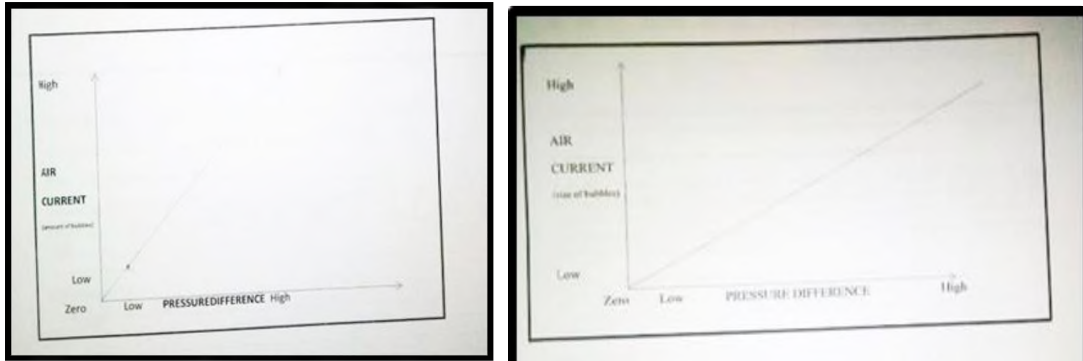


Figure 13: Graphs drawn from 'straw electricity' analogy results

All groups indicated that the graphs drawn resulted in a straight line, irrespective of whether they focused on the number of bubbles or size of bubbles and pressure difference. One of the groups inserted points so as to sketch the graph (Appendix K), which suggested that the analogy had implications for future learning: that is, that accurately drawn graphs could be accurately interpreted. It was of course possible that the points were put in because it was normal to plot some points before sketching a graph. The nature of the graph could possibly indicate the relationship between the physical quantities used.

Most learners indicated that the pressure difference and air current were directly proportional to each other. The following extract was taken from Appendix K where the bulleted points indicated responses from different groups:

Addition of one cell at a time after readings are taken, leads to:

- *Potential difference.*
- *Current.*
- *Pressure difference.*

Being the independent variable and

- *Current.*
- *Potential difference.*

The dependent variable (choose between current and potential difference).

Now, rewrite the relationship using ‘current’ and ‘potential difference’ variables in comparison with the results from the ‘straw electricity’ analogy.

- *The relationship between potential difference and current is directly proportional.*
- *The current is directly proportional to potential difference.*
- *The relationship is directly proportional.*

The ability to use relevant science terms with a correct justification for their use showed that the learners were making sense of their learning. Varying the quantities concerned led to the identification of variables. Only one group was unable to correctly identify a dependent variable and an independent variable (Appendix K). The connection between the analogy results and science concept conclusion reached by all the groups revealed a correct statement of Ohm’s law. The conclusion was developed from systematic interpretation of the ‘straw electricity’ analogy. The learners were thereafter allowed to do a conventional practical activity and set-up the apparatus as shown in Figure 14, below.

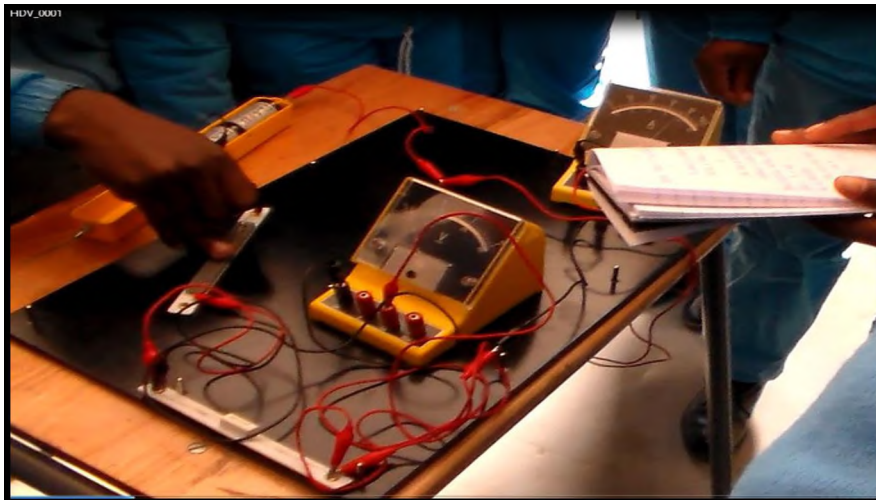


Figure 14: Conventional practical activity set-up

Most of the knowledge from the ‘straw electricity’ analogy was used in the conventional practical activity. To be specific, the PEEOE approach, the identification of variables, interacting with the table of results, the shape of the graph (same) and then the conclusion were commonly shared from the analogy to the conventional practical activity. The difference was that measurements were taken and points used to plot and sketch the graph as learners were working in pairs to process answers although the readings from an ammeter and

voltmeter were taken once by the focus group of 12 members. Learners had difficulty with identifying a control variable, unit of the ratio $\frac{V}{I}$ and the graph.

Most of the learners were able to differentiate between dependent and independent variables. There was a significant problem with stating that cells or current constituted a control variable as shown in the following response:

Control variable is:

- *Current because temperature is constant.*
- *Cells because they can be controlled and be kept constant.*

Current was chosen as a dependent variable though the explanation was that such a variable must be constant. It was clear that their knowledge on such a variable was limited. One of the groups decided to use the results and draw two sets of graphs in one set of axes (Appendix N).

The joining of points to form a straight line gave a number of choices as line of best fit. That was caused by the fact that there were few points. This group of learners calculated for the gradient and arrived at an answer different from the values in the $\frac{V}{I}$ column. Then they used the other pair of points (Appendix N). That led to the value they were looking for, as indicated below.

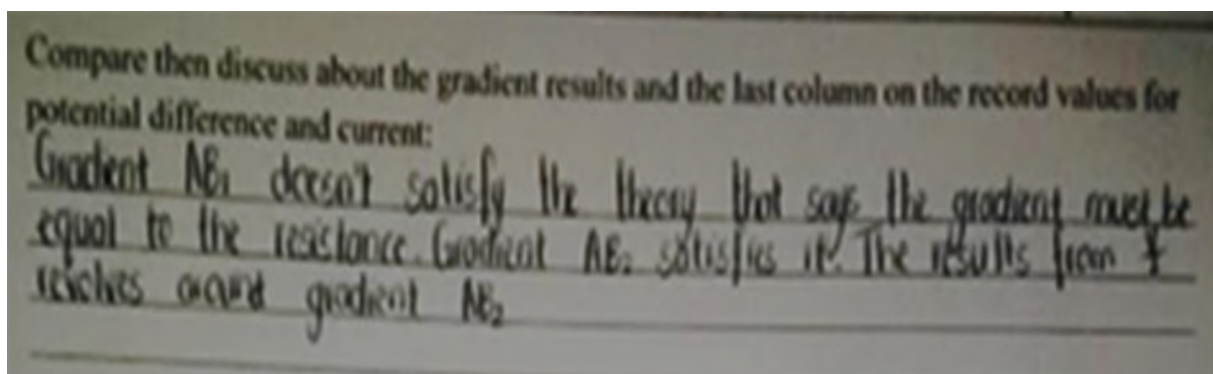


Figure 15: Learners' critique of the results

Therefore, they ended up with two graphs in one set of axes. This was a clear indication that they had an idea of what they were doing. There was a challenge on the derived unit from the ratio $\frac{V}{I}$. All learners supplied the unit as Ohm (Ω). The main challenge was the lack of

ability to differentiate between the SI unit and a derived unit. The conclusions were drawn from the processing of results for this activity.

One of the groups commented as follows on the findings from the 'straw electricity' analogy and conventional practical activity, with reference to Ohm's law:

The analogy showed non electrical connection and it was not real but it helped us to make sense of what is going on in Ohm's law. The experiment was connected electricity and we were able to see that the connection was good or bad, but the analogy helped us to know what was going to happen across the electrical circuit and how to set up the apparatus in the circuit. The analogy based on the graphs didn't have the gradient while we have it in this graph.

It was apparent that learners considered an analogy as an indicator for future learning. The limitations of an analogy are that the state of correct or incorrect connections cannot be highlighted from it. In addition, details like points limit the opportunity to practise calculations, which they (learners) had difficulties with. Practical activities allowed learners to be hands-on. The benefits and limitations to learning were documented in learners' journals and by using mind-maps. I will briefly share their impact on learning.

4.2.1.5 Synthesis of concepts revealed in journal entries and mind maps

Learners were requested to write in journals, draw mind maps and write notes as they synthesised new concepts. Those exercises elicited access to the learners' thoughts as they reflected on their learning process. Journal entries in particular, supplied first-hand information from the learners where the contents assisted in informing progress across a broad-spectrum as extracted from the following entries from learners:

Luyanda wrote: I have learned the analogy whereby in an analogy we were doing the current flow but there was no electric set up there was some apparatus like straw, water and clothes peg. Some exciting moment was that I was excited to see that I can understand the current in different ways by using whatever I have as long as it make me understand.

The area that needs more clarity: *Area that needs clarity is the graphs and the way of answering questions.*

Entle wrote: Questions I have about today's lesson: *When water is boiling inside a kettle, it automatically switches off, what causes it to switch off? And when the kettle is opened, the water boils but the kettle never switches off, why?*

Comments: *Explaining to other learners is exciting knowing that you are helping someone else out is nice. If we could help each other out just like we did today, learning could be a lot easier because you'd freely talk to someone your age.*

Such reflections revealed learning progress, areas of emphasis, probed clarity through posed questions and exposed general feelings about the learning process. Determining the learning progress was advantageous to the teaching and learning process.

It would be a challenge to proceed with lessons if the learners did not make sense of previous learning so the reflections determined the pace of covering the lessons from the unit of work. The opportunity to be upfront about the level of one's understanding served as a guide to areas that needed more emphasis. Here learners were recognised as being at the centre of teaching and learning and the journals extended the opportunity to ask questions about areas that needed clarity.

Questions were attended to by learners in their groups. In most cases, they indicated the level of interest, like the one below.

Entle: Questions I have about today's lesson: *Although most conductive materials obey Ohm's law, some do not and are said to be non-Ohmic, for example a diode. Why don't they obey Ohm's law?*

Entle was interested to know about non-Ohmic conductors as the previous lesson ended after discussing Ohmic conductors. That journal entry signalled that some learners were actively participating and were interested to learn more about content by referring to the known concepts. This showed a passion for future learning. The question about boiling water using an electric kettle, indicated that the learner was trying to make sense of new learning by applying science to an out of class situation.

It was apparent that critical thinking was challenged in pondering the fact that boiling water is associated with temperature increase. Here knowledge on thermostats was needed to respond to the question and justification using scientific reasoning was triggered. Thermostats are electronic devices that respond to changes in temperature. The application of science

knowledge in real life situations was an indication of positive cognitive development by the learner. Journal entries also provided for the sharing of general feelings about the learning process style used as shown in Figure 16.

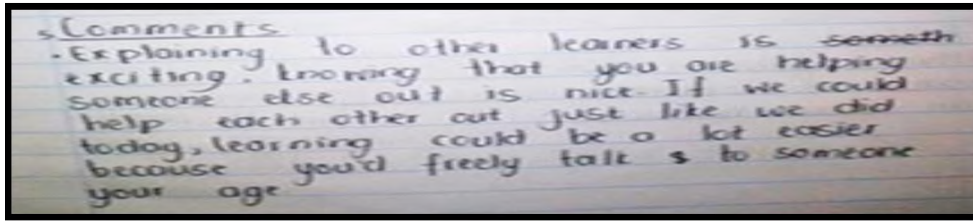


Figure 16: Learner's experience on assisting others

Sometimes learners specified that they felt excited or bad. They felt excited when making sense of learning when learning objectives were achieved. More Knowledgeable Others (MKO) felt excited to be granted an opportunity to help others and they discovered the benefits of social learning (Figure 16). For instance, they highlighted that they were free to talk because they are of the same age and status.

That feeling motivated the MKOs as a result of an increase in their self-efficacy. Learners also felt bad and confused at times. That was caused by their inability to take correct voltmeter and ammeter readings. Such reflection led to me redoing the process of measuring for the purpose of mastering the measuring skill and completing the worksheet. I could not have accessed the feelings about learning pace, achievements and pitfalls on the lessons presented if journal entries had not been compiled. In trying to make more sense of learning, I requested learners to make mind maps as shown in Figure 17.

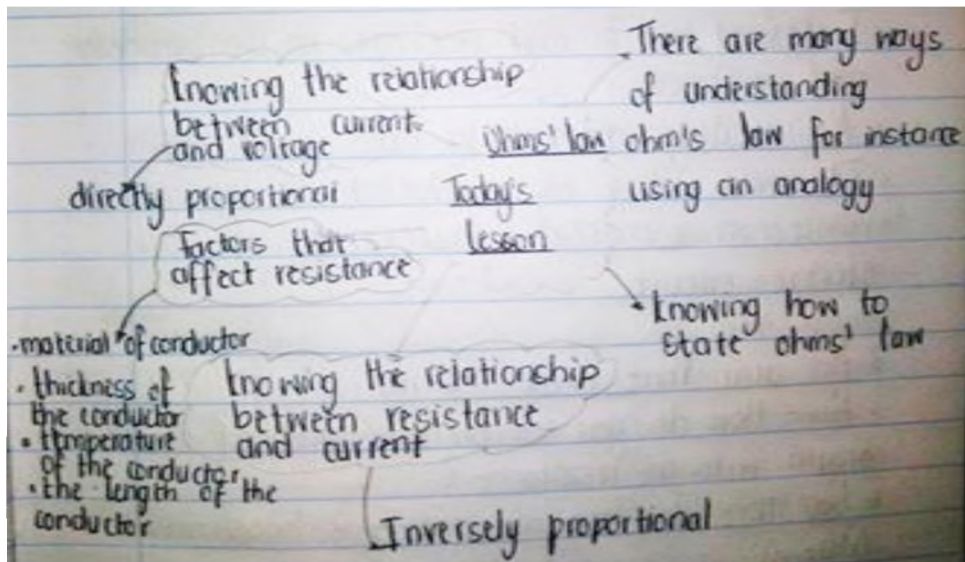


Figure 17: Mind map on one of the observed lessons

The mind maps challenged learners' ability to present how they organised their thinking with regard to consolidating new learning. The primary aim was to allow them to see the lesson contents at a glance. Mind maps were meant to organise concepts so that they would be easily remembered at a later stage. By referring to the mind maps shown above, learners noted the most salient aspects around the topic which was an indicator of how they made sense of the topic contents. I observed that through designing a mind map, learners were writing a brief summary on new learning.

Learners were also allowed to write down the lesson notes that were compiled through the development of a unit of work. The benefit here was to give them an opportunity to familiarise themselves with writing as a language skill. Spelling mistakes were checked and were found to be non-existent. That allowed them time to make sense of learning as they were writing in their books. Throughout the lesson presentations, video-recordings were done as permitted by the parents and learners. These were later transcribed.

4.2.2 Transcripts

In presenting the data that emerged from the video-recordings, I will only focus on specific points to be discussed in the next chapter. Extracts from lesson observations during practical activities and the interviews are presented and analysed.

4.2.2.1 Extracts from lesson observations

It was observed in almost all the video-recorded lessons that learners used language to construct meaning, benefited from the PEEOE approach and showed active engagement in subscribing to science knowledge. Learners used language to make sense of learning.

Learners either used English as the language of learning and teaching (LoLT) or *isiXhosa* and/or *Sesotho* as home language(s) in constructing meaning. The extract below served as substantiation of the fact that sometimes learners used home language to make sense of meaning. (Extracted from Appendix K, where L1 up to L9 represented learner 1 up to learner 9 responses):

L1: “*Sawuthini?*” (Translation: What to say?) “Ok. When you blow, ok! When we were blowing! The air we were blowing ... ok ... the air that I was blowing was ... *kanene xa into inintsi sithini?*” (Translation: How do we put it, if something is more?)

L2: “More ... was more”.

Due to the fact that home language is well established, they started by using it then considered more relevant terms in English. Referring to the last part of the extract, the learner was thinking of the English word for ‘*inintsi*’, meaning that the learner resorted to L1 when struggling with the LoLT. The main objective was to convey a message to the others. As mentioned in the context of this study, some of the learners were *Sesotho* speakers but they ended up speaking *isiXhosa* in their small cooperative groups. In such cases, a learner ended up using L1, which is *Sesotho* as indicated below:

L9: “*Kungoba umoya awuphumi wonke; qha iya ... ke hoba ...*” (Translation: It is because not all air comes out, but ... because...) [Started in *IsiXhosa* then changed to *Sesotho*].

This scenario showed that learners made more sense when expressing themselves in their L1. That made it easier to switch to English at a later stage. To make sense of experiences, sometimes incorporation of ‘hands-on’ activities yields interesting results.

‘Hands-on’ practical activities such as observation of an analogy brought interesting data to this study. The extract revealed how learners made sense of the analogy activity.

L1 and L2: “*Hayi angeke! Aa*”. (Translation: How come? [Amazed by the outcome](No).

L9: “It is true”.

Another group:

L3: “*Xa ugqiba ukuphusha*, the air comes into water in glass, bubbles *ziyenyuka ziyephezulu*. What causes them to move up ...?” (Translation: After blowing, the air comes into water in glass. The bubbles rise).

L4: “It is because they are less dense”.

L3: “*E-ewe*”. (Translation: Yes).

L4: “It’s because ...”

L5: “... force of gravity”.

L4: “Force of ... *Hayibo!* If *uthi* force of gravity, *ngabe ibubbles ziyezantsi* [laughing]. *Sawuthi...*”. (Translation: If you say ‘force of gravity’, bubbles should be moving downwards. We will say ...).

L3: “*Ndizabe ndiright xa ndithetha nge-density or something*”. (Translation: Will I be correct to talk of density or something?). [Hand signalling the upward motion]. Gesturing and verbal communication from the data contributed by L3 was captured and is shown in Figure 18.



Figure 18: Interactions within small cooperative learning groups

L4: “*Uzothi* (Translation: You will say), because they are less dense than water!”

(Extracted from Appendix K)

Drawing from the contribution by L1 and L9 from the extract above, the formulated prediction led to an incorrect outcome. Testing the prediction also steered them to implausible results but probing for an explanation stimulated learners to search for the scientific reasoning.

More profound thinking led to digging deeper into science knowledge. L5 suggested the reason was ‘force of gravity’ which caused the bubbles to move up. I did not want to interject in the discussion as they were making sense of the observations. Fortunately, one of them reasoned that ‘force of gravity’ acts downwards. L3 was gesturing the upward motion of bubbles in the process of thinking of the reason for the motion, then she thought of density and checked if the group members agreed. Meaning that, the term ‘density’ instead of elaborating the difference in densities for different substances or the effect of unbalanced vertical forces was the only idea that crossed her mind as an opposing force to gravitational force. The thought tapped into scientific language vocabulary where a learner used words when making sense of ideas. The ‘thinking aloud’ process was observed to be helpful in constructing science knowledge, as indicated in the extract (Appendix K) below.

Learners showed active engagement in discussions when explaining the observations on the motion of bubbles. The discussions were detailing the development of science reasoning. The sense of ownership by all group members signalled collaborative learning as shown when a learner verifies if he/she has represented the correctly observed phenomenon. It was interesting to observe how learners assisted one another in shaping thoughts through communicating ideas using their home language then changing to present them in English. It seemed as if they had an opportunity to learn both language usage and science language when developing concepts.

L3: “*Andi-understandi*” [Shaking her head]. (Translation: I do not understand)

L4: “*Awu-anderstandi? If i-peg i-squeeza i-straw, the volume of the straw will be reduced ... the volume ... i-volume ine-space andithi? So, i-air ... Yhooo!*” (Translation: You do not understand? If the peg squeezes the straw, the volume will be reduced. Volume has a space, is that so? So, the air ...yhoooo!).

The last part of the previous extract showed that reflection occurred as the learner did a presentation to the group members. He was aware that the presentation should make sense to

him as well. The sharing of ideas was extended to the support offered to one another as highlighted in the dialogue between L3 and L4 (Appendix K).

Learners were assisting each other in order to socially construct meaning of science concepts. The symbolic representation from physical relationships through knowledge of the type of the graph to be sketched up to actually doing it demanded an advanced level of thinking (Appendix K & Appendix N). The ability to switch between different modalities showed cognitive development and the assistance offered to the less able identified an element of scaffolding. The MKO's self-efficacy, such as *Entle*, was developed as well in the process of assisting the others. The other learners also worked cooperatively in their small groups, where MKOs appeared to assist their peers:

L2: "Plus 0,05 (7). Plus 0,05 (8) ... 1,9. *Uphi u 0,3? Mnike i-calculator azojonga i-space then a-plote ii-points*". (Translation: Where is 0,3? Give her a calculator so as to look for spaces then plot the points).

L6: "*Ke e ntshitse*". (I got it).

L5: "0,6 ... *Haa.. TEN kaloku*. Ten plus six. *So, it is 16 ukufika apha*". (Waiting for L7 to work on a calculator). "*Uyabona, ziyi 20 ezi-space ukuzofika apha*. Half of 20 is 10. *So, ziyi-10 ezi-space ukusuka apha*". (Translation: 0,6 ..No... TEN. Ten plus six. So, it is 16 to reach here. Do you see? There are 20 spaces up to here. Half of 20 is 10. So, there are 10 spaces from here).

[Helping another one to plot the points]:

L2: "*Masiqale apha*". (Translation: Let us start here).

L8: "*Ihambe straight*". (Translation: It must go straight).

L9: "*Ke hoba o ne a se na point*". (Translation: It is because she had no point).

L1: "*Faka u-ZERO apho ziqala khona*". (Translation: Put ZERO where they start).

[L1 and L9 focused on L3, leaving L8 to work on her own]:

L9: "*Uswipe isubstitution*". (Translation: She has swiped the substitution).

L2: "*Oh! Ja*". (Translation: Oh! Yes).

L9: “*Makayilungise, acalculate lena kuqala*”. (Translation: She has to correct it by calculating this one first).

[L3 works on her own, then L8 gets attended to. L8 is to sketch another graph on the same set of axes]:

L1: “*Hm. Ilula le*”. (Translation: Yes. This is simple).

L2: “*Uyayitshintsha. Ngoba ngu ONE OVER R. Potential difference ngu-V. Xa kuqalwe ngayo. Le kuqalwe ngayo, uzaqala ngayo uthi V over I. Le ekuqalwe ngayo apha*”. (Translation: You change. Because it is ONE OVER R. Potential difference is V. If they started with it. The one they started with, you start with it say, V over I. The one they started with here).

L9: “*If kuthwe current?*” (Translation: If it is current?)

L2: “*If kuthwe current versus potential difference, uza qala ngecurrent apha*”. (Translation: If it is current versus potential difference, you start with current here).

[Focus on L3]:

L1: “*Ifuna ungayikhethi ipoint ehamba yodwa ecaleni. Wena le point i-wrong, uyikhethile nantsi*”. (Translation: You must not choose a point that is not on the line. You have chosen a wrong point here).

L3: “*Ndiyikhethe kuba kule graph yam...*”. (Translation: I chose it because in my graph ...)

L1: “*Na le*”. (Translation: This one too).

L3: “*Hayi, andiyikhetanga le*”. (Translation: No, I did not choose this one).

L1: “*Yima, masize apha. Uyabona u 0,9 uphi? Nanku... Uphi u-0,9 wakho? U 1,9 wakho uphi?*” (Translation: Wait, let us come here. You see where 0,9 is. Where is yours? Where is your 1,9?)

L3: “*Hmm ...*” (Thinking)

L1: “*Akekho, ngu 1,5 lo. Ee, nanku u 1,9 wakho. Ukhetha yena, akafanelanga umkhethe, xa ubala kulaa table leya. Andithi uyibonile ukuthi leya ethi 1,9 ayihambi ngokwe-scale*”

sakhona?” (Translation: It is not there. This is 1,5. Here is 1,9 that you chose. You were not supposed to choose it. Looking at that table, you saw that 1,9 is not in the scale).

L3: “*Eh*”. (Translation: Yes).

L1: “*Le ethi 0,9 ... 1,9, le ezikhethile esecaleni uyayibona? Awufanelanga uyikhethe, ukhethe ezi ezikwi BEST FIT*”. (Translation: This 0,9 ... 1,9, do you see that it is aside. You were not supposed to choose it. You only choose the ones in the BEST FIT).

The role played by the MKOs (mentors) was primarily to assist their peers (mentees). They started by identifying where the mentees went wrong through comparing the processing of answers. Thereafter, assistance was offered mostly using questions and answers to keep the mentee actively involved. When the mentee seemed to show signs of understanding she/he was given an opportunity to work on her/his own. The mentor would check the progress after some time. Characteristics of graph sketching were thoroughly explained, for instance, the nature of the graph as well as where the graph starts. The MKO would check if the key features of graphicacy were met. The learners with challenges such as choosing an appropriate scale and drawing the line of best fit were also assisted to a point that they could work on their own. Lastly, advice on how one should provide calculations of resistance from the drawn graph were highlighted and discussed. It was interesting to discover that learners made more sense of concepts when they discussed amongst themselves as indicated earlier on by *Entle*. The identified MKOs from the above extract are L1, L2, L5 and L9 whereas the mentees were L3, L6 and L8.

What data were gathered through interviews? Extracts from transcripts were used to triangulate data. The following sub-section seeks to present such data.

4.2.2.2 Extracts from interviews

The data gathered from interviewing the focus group pointed to learners’ understanding, science knowledge and difficulties with regards to the diagnostic test as well as the impact of teaching and learning strategies. Most of the interviewees showed that they had made sense of learning. However, all interviewees identified a number of challenges as reflected from diagnostic test responses, summative test responses and participation in the conventional practical activity.

Boithabiso's response on diagnostic test:

Boithabiso: “*Eish ... e ne e le thatanyana empa tulong tse ding e le bobebe*”. (Translation: It was difficult but easy at some parts). “I did not know what to write. Yes, I did not have a clue. Yes, that is why there are some blank spaces here and there in my answer sheet.”

When interviewed, *Boithabiso* (*guided in answering questions*) indicated that she was unable to answer all questions in her diagnostic test paper (Appendix V). The basic reason was that she was not taught most of the aspects examined. I think the challenge was that there was poor foundation of prior knowledge as the other interviewees indicated that most of the questions were based on Grade 10 work. That means that learners can be taught well but if they cannot make sense of the new knowledge, there is likelihood that they cannot relate the new knowledge with poorly established or understood prior knowledge. This also emerged when learners struggled with gradient calculations, especially plotting of graphs and interpreting them. *Lizzy's* opinion was that the use of scale was the problematic focal point in gradient calculations (see Appendix X). I assumed that almost all learners would master those calculations as gradient is linked to mathematics.

The learners' responses on the effect that an analogy had in learning of Ohm's law follows:

Cozmo: “When we used the analogy, we understood better since we could see what is going on ... than when there is nothing”.

Yolanda: “The examples of analogy you gave us made it simple”

Cozmo: “It is not easy to forget because we have seen it”.

Oyintando: “We were unable to take out readings from analogy”.

(Appendix U – group interview).

Lizzy: “Analogy mem ... It's easy for us to understand because we are using real things that we use on a daily basis. It was nice mem, because we started with analogy ... I saw a little bit of how Ohms' law works then when we worked on the experiment, it was better”. (Appendix X - individual interview).

Zodiac: “I can *say impractical* ... by doing practical ... *siyenza siyibona futhi ku easy uba siyi anderstende than siyibone ephepheni. Sizazibuza ukuba yenziwa ... iyintoni kwa yona mem.*”

So, if siyibona facial izayenza la nto sibe excited, sikholwe ukuthi izinto zihambe lula, mem". (Translation: I can say the practical ... by doing practical ... we see what we do so it is easy to understand than seeing it on a paper. We can ask ourselves how it is done ... what is it, mem. If we see it ourselves, that makes us excited, then we believe - so things become easy, mem). (Appendix W- individual interview).

Zodiac, during an interview indicated that it was easy to understand what was seen. That referred to the observation of hands-on practical activities. Some of the learners indicated that they became excited and believed in the science world when practical activities were incorporated instead of seeing the test experiments in the textbooks (Appendix W). The emphasis was on the analogy activity and conventional practical activity. The greater impact was mostly from the incorporation of the analogy which helped in the conceptualisation of ideas. *Lizzy* highlighted the benefit of incorporating an analogy as giving them a glimpse into how Ohm's law operates. It was clear that the group interview data was similar to individual interview data, with respect to learners' opinions about incorporation of an analogy in learning Ohm' law.

Now, data benefits and challenges of using a conventional activity follow:

Faith: "We learn how to deal with circuits. For instance, if you go for engineering you apply the information from it".

Yolanda: "And also at home, when using electricity there are some things you need to look at like switching off the... [Touching the wall with her finger] ... socket on the wall when electricity is not used. Learning about electric circuits".

Faith: "Sometimes you get harmed ... *ubungozi xa u-connecta ama wires, ne-ammeter, ne-voltmeter or unganaki ukuthi i-ammeter ibale kanjani ne-voltmeter. I-wrong connections zenza ubungozi*". (Translation: Sometimes you get harmed...when you connect wires, ammeter or voltmeter without taking care of how ammeter and voltmeter reads. Wrong connections cause danger).

T: "What else?"

Faith: "Sometimes *kumele ujonge i-resistor yakho ingatshisi kakhulu cause yenza ubungozi kwi-equipment ozisebenzisayo ... The house may burn okanye loo ketile ingaphinde isebenze*". (Translation: Sometimes you have to check your resistor so that it does not

overheat because that can harm the equipment in use... The house may burn or the electric kettle stops functioning). (Appendix U - group interview).

Lizzy: “Disadvantage is that you MUST have someone who knows how to use all the apparatus so you cannot take the wrong readings”. (Appendix X - individual interview).

Boithabiso: “Connecting these things was not easy for me. *Nna tjhe* “. (Translation: Not me). [Shaking her head]. (Appendix V – individual interview).

T: “The challenge was connecting the apparatus. What else was a challenge?”

Boithabiso: “What I found eh ...”

T: “*O ka e tjho ka Sesotho*”. (Translation: You can express yourself in *Sesotho*).

Boithabiso: “*Ke hore, ke ne ke sa kgone miss ho ... ho recorda di-scores tsane*”. (Translation: It is because I was unable to ... to record those scores).

That suggested that some of the learners were more comfortable when an analogy was incorporated before the conventional practical activity which led to the development of science knowledge.

Acquisition of science knowledge was observed when learners showed the ability to apply new learning in the real world. For instance, they related the discussed topic to associated careers like engineering (Appendix U). *Zodiac* was able to cite the precautions of handling electrical appliances at home, using science reasoning (Appendix W). *Faith* mentioned electricity safety measures such as switching off at the socket when electricity is not in use (Appendix U). When demonstrating this, she touched the wall as she was explaining, although the electric socket was not within her reach. The implication here is that she was conveying a message whilst ensuring that everybody understood her. The data pointed to the recognition of learning within a social space.

Boithabiso indicated that her challenge was the inability to take readings from an ammeter and voltmeter (Appendix V). That was a challenge to most of the focus group members hence the discussions on how readings are taken from a voltmeter and ammeter were done and the activity was also re-done. The aim of re-doing the conventional practical activity was to

ensure that basic skills like measurement and recording were mastered because most of the information was used to achieve the goal of this study.

Learners were aware that they could learn effectively with the guidance of a more knowledgeable person (Appendix W). In that way, they gained the confidence to be hands-on in doing practical activities, hence, the increase of efficacy. The mentor/researcher assisted in recognising the areas where learners made mistakes as demonstrated by incorrect experimental results. The guidance they received encouraged them to try again until they attained the expected results.

4.3 Concluding remarks

In this chapter I presented data gathered through multiple techniques such as documents, observations and interviews. The presented data were extracted from both diagnostic and summative test responses, worksheets, transcripts from observations and interviews as well as journal entries for the purposes of triangulation and to produce a unit of work. The learners benefited as the learning approaches forced them to supply explanations for every answer they chose.

The social set-up encouraged the use of both home language and LoLT in constructing science language. That was evident when they used words, symbols, calculations and scaffolding to learn science. A few learners still showed some graphicacy challenges towards the end of the research process. I will now focus on data interpretation and discussion in the next section.

CHAPTER 5

DATA INTERPRETATION AND DISCUSSION OF FINDINGS

5.1 Introduction

This chapter focuses on the interpretation of the data presented and analysed in the previous chapter as well as a discussion of the findings. Research questions which guided this study are presented then analytical statements that consolidate themes that emerged from the gathered data are discussed in line with literature and the theoretical framework.

5.2 Research questions

The main question was: How did Grade 11 Physical Sciences learners made sense of Ohm's law when it was mediated through an analogy in conjunction with a conventional practical activity?

The formulated sub-questions:

1. What prior knowledge associated with Ohm's law did Grade 11 Physical Sciences learners have?
2. How did the use of an analogy enable or constrain meaning making of concepts and graphs associated with Ohm's law?
3. How did the use of a conventional practical activity enable or constrain meaning making of concepts and graphs associated with Ohm's law?
4. What challenges did Grade 11 Physical Sciences learners experience when Ohm's law was mediated through an analogy and a conventional practical activity?

5.3 Analytical statements

Research questions and data gathering techniques were used to create themes. Table 5 shows the analytical statements which were shaped by these themes. The research questions led to the formulation of analytical statements which served as indicators that learners did make sense of Ohm's law in this research study.

Table 5: Analytical Statements emanating from data sources and themes

Data Sources	Theme	Analytical Statements	Theory	Related Research sub-questions
Documents: Answer scripts from a diagnostic test.	Learners' responses.	Prior knowledge of electric circuits.	Assessment, prior knowledge, and constructivism.	1
	Concepts based on prior knowledge.			
	Sketch graphs.			
	Symbolic representations.			
Responses from a 'straw electricity' analogy worksheet, transcripts from lesson observations and interviews.	Practical activity.	Analogy and sense making of concepts and graphs based on Ohm's law.	Use of analogy, practical activities, and social constructivism.	2
	Verbalisation.			
	Written explanations.			
	Concepts and graphs on Ohm's law.			
	Gestures and sense making.			
Responses from the conventional practical activity worksheet, transcripts from lesson observations and interviews.	Practical activity.	Conventional practical activity and meaning making of concepts based on Ohm's law.	Practical activities and social constructivism.	3
	Learners' responses.			
	Graphs and interpretations.			
Documents: Answer scripts from summative test, transcripts from stimulated recall interviews and journal entries.	Strengths of learning Ohm's law.	Challenges experienced by learners when learning Ohm's law.	Assessment, journal entries, conceptual change, constructivism and social constructivism.	4
	Challenges experienced when learning Ohm's law.			

Table 5 above was used to unpack the analytical statements in interpreting data and discussing findings.

5.3.1 Analytical Statement 1: Prior knowledge on electric circuits

Assessment was used to access prior knowledge in order to discover how learners constructed their ideas when processing answers to the diagnostic test questions. Harlem and James (1997) propose that assessment is the key to identifying prior knowledge and so one cannot discuss the impact of diagnostic assessment whilst overlooking prior knowledge. Rennie

(2011) argues that learners use prior knowledge to make sense of experience. That makes the learning process meaningful instead of underestimating or overestimating the knowledge learners bring to the science class. I now discuss the learners' responses regarding concepts, graphs and symbolic representations.

Black and Wiliam (1998) argue that the purpose of assessment is to access learners' thoughts. They claim that, assessment is incorporated to assist in learning not valuing scores (Black & Wiliam, 1998). In so doing, learners' level of understanding can be identified and thereafter they can be placed in their cognitive levels for appropriate intervention when scaffolding takes place (Harlem & James, 1997; Black & Wiliam, 1998; Brown & Hirschfeld, 2008). For instance, the data gathered informed the depth of content required in designing a unit of work.

Prior knowledge is recognised as part of Grade 11 content knowledge on Ohm's law and so establishing learners' prior knowledge was vital (Horner & Williams, 2012; Kelder, 2012; De Vos, Gebretnsae, Grayson, Harris, Roodt & Schrender, 2012) (see Appendix I). Therefore, the purpose of the diagnostic test in this study was to identify the learners' level of understanding so that if there were learning gaps or alternative conceptions, these could be addressed when co-designing the unit of work with a critical friend. The diagnostic test provided an informative view of the level of learning needs, hence it was known as informative assessment.

The data from the diagnostic test responses indicated that not all learners were at the same cognitive level (Figure 2). That broad spectrum of scores gave me clues for the selection of my focus group, as informed by Tongco (2007). It did not signify that my study was quantitative in nature. It had traces of a mixed method approach. The data drawn from the focus group members' responses was narrowed down to base information on sense making. Such responses presented thoughts for non-participants as well since 85 learners wrote the diagnostic test and only 12 represented that population through purposive sampling. The responses from the diagnostic test revealed that it was easy for learners to answer simple recall questions (Table 2). It might be possible that those questions were based on prior knowledge which did not trigger critical thinking as such.

Drawing from prior knowledge, most of the learners were able to draw circuit diagrams, define some concepts such as electrical current and the nature of the graph. Table 3 reflects

the overall responses to all questions. For instance, there were learners with incorrect explanations or definition of concepts, some could not answer questions and there were only a few correct calculations. I thought that the blank spaces were a result of limited assessment time, language problems or those learners could not link the questions to their required prior knowledge. I therefore decided to interview two of the participants from the focus group. The learners indicated that they did not know the answers which put them at a disadvantage especially as there were follow-up questions which might probe reasoning from the unanswered questions.

Prior knowledge indicated the weaknesses and strengths of the learners. The aspects related to calculating gradient, identifying the nature of the graph, drawing the line of best fit, drawing conclusions from a table of values and calculations were not well answered. A recent study by Anagnostopoulou, Hatzinikita and Christidou (2015) revealed that few learners are able to correctly identify the coordinates and complete accurate gradient calculations. Such data were revealed in my study as well whereby some learners did not come up with correct gradient formula (Appendix H). Those challenges pointed to areas where more emphasis in developing the unit of work was required, without overlooking the learners' strengths. So, learners revealed a lack of skill in presenting ideas in symbolic representations.

Problems with graphicacy skills were identified. The inability to correctly label graphs leads to loss of scientific meaning (Simayi, 2014). Some learners correctly symbolised the ammeter as a small circle with a capital letter 'A' and the voltmeter with the circled capital letter 'V' whilst the components were connected in series. Incomplete understanding of some scientific ideas was shown through such responses.

The responses to the diagnostic test showed strengths and weaknesses in concepts, graphs and symbolic representations. Such responses needed to be considered when building new knowledge on Ohm's law. The findings of the study revealed the prior knowledge that the learners had on electric circuits as a foundation to the learning of Ohm's law.

5.3.2 Analytical Statement 2: 'Straw electricity' analogy and sense making of concepts and graphs based on Ohm's law

This section discusses the incorporation of an analogy activity in making sense of learning. The predict, explain, explore, observe, explain (PEEOE) approach was observed to channel scientific reasoning by probing different modes of responses (Maselwa & Ngcoza, 2003;

South Africa. DoE, 2011). Such modes of responses were probed by the engagement of learners in a practical activity, verbalisation of prior written explanations as well as gestures.

The ‘straw electricity’ analogy worksheet template was designed to be used to establish Ohm’s law. Studies by Leach and Scott (2002) as well as Orgill and Bodner (2004) reveal that analogies help to visualise what cannot be seen.

This connection and visualisation is the groundwork for understanding science concepts. Leach and Scott (2003) argue that analogies connect prior learning and current learning to future learning. That is made possible if the mediated tool is designed as a good analogy (Iding, 1997). A good analogy is easy to understand and is relevant to learners at different cognitive levels. Some science skills were tested, such as the predicting, justifying and drawing of graphs. The nature of responses assisted to identify the level of cognitive development learners were at and to process thinking as elicited by findings from practical activities.

The nature of learners’ responses whether written, oral and/or demonstrated, highlighted the level of cognitive development where the learners were situated. According to Vygotsky (1978), learners get assistance as identified by the needs in their specific ZPDs (Stott, 2016). In that way, scaffolding leads to the independent state (Howe, 2013). Therefore, the MKOs were observed assisting other learners where the need to do so arose as indicated in Section 5.3.3.2. The incorporation of an analogy envisaged reflective responses (Weick, Sutcliffe, & Obstfeld, 2005).

The ability to visualise what cannot be seen through predictions and making connections between an analogy apparatus and laboratory apparatus sharpened learners’ thoughts from experience (Orgill & Bodner, 2004). In that instance, learners were able to relate air blown into the straw to current flow and the straw was related to electric conductors or connecting wires. The ‘straw electricity’ analogy activity led to the correct conclusion with the use of easily accessible resources (Figure 6). For instance, potential difference is directly proportional to electrical current (see Appendix K). As that was a plausible result, it meant that all learners benefited from the analogy. Such an analogy is referred to as a good analogy, as it was simple, easily visualised and increased self-efficacy towards learning of abstract electricity concepts. Labelling such as a good analogy, was based on the fact that the apparatus used were within the learners’ context (Vosnidou & Orthonoy, 1983; Treagust,

1992; Driver et al., 1994). If an analogy connects context with content and facilitates learning, Glynn (2008) refers to it as good analogy. In the context of my study, the ‘straw electricity’ analogy yielded good learning outcomes. That was seen when learners were able to use words and graphs to synthesise knowledge, indicated as written explanations from worksheets. Later on, Ohm’s law was successfully verified. The most interesting thing was that the incorporation of this analogy was a success even in a multilingual classroom, such as mine where learners communicated in *Sesotho*, *IsiXhosa* and English. Simayi (2014) draws similar results with a research study done in a bilingual classroom.

The other benefits provided by this analogy are that it gave a glimpse into future learning, there were no precautions needed (meaning that there were no risks attached) and it engendered confidence in the designed content and tested thinking. Predictions were in place to test learners’ thinking. When the prediction was incorrect learners were allowed to explain, test and then explain the action outcomes. That is, their change of decision was based on critical thinking and observation (Weick et al., 2005) (see Section 2.3.4). Iding (1997) argues that written analogies should be easy to understand (see Section 2.2.1), but the data that emerged from the interviews was not in unison with that idea. One of the focus group learners indicated that she got confused when trying to follow what was in the textbook. However, she understood the way the ‘straw electricity’ analogy was unpacked, so the practical part of the analogy was accompanied by in-depth thinking, which brought about an understanding of Ohm’s law. This suggested that textbook analogies are understood, but only to a certain extent.

The benefit of verbalisation was that all questions were usually attended to. This might be due to the fact that the data-gathering technique minimised the perception of the LoLT as a threat, since all the learners were not English first-language speakers. Even shy learners got the opportunity to speak in their first language (L1), which was either *Sesotho* or *IsiXhosa*. Observations from all the video-recordings revealed that learners were comfortably constructing science knowledge from L1 (Probyn, 2009).

The learning set-up encouraged learners to engage in dialogue for the mutual construction of knowledge, and active social interaction occurred (Vygotsky, 1978). The social exchange of ideas was observed when learners interpreted questions for one another and checked if all the group members had a shared understanding of the supplied response. Vygotsky (1978) refers to creation of knowledge through such collaboration as social constructivism (see Section

2.3.1). Learners used the language they all understood, and showed that they wanted to make sense of their learning (Shepard, 2000; Probyn, 2009) (see Section 2.3.1).

Verbalisation involves the expression of what one thinks in order to make sense of ideas, as suggested by Weick, Sutcliffe and Obstfeld (2005). Weick et al. (2005) further claim that verbalisation is not about language usage accuracy, but about communicating prior knowledge with regard to the current situation, thus bringing to the fore sense-making. This system of communication is used to reinforce other mediational tools such as the analogy because it involves the conveying of thoughts.

Corresponding with Weick, Sutcliffe and Obstfeld's (2005) notion of the effects of verbalisation, learners were able to mentally picture their ideas then communicate their thinking within their social context (see Figure 18 in Section 4.2.2.1). Additionally, learners were able to picture the nature of the graph before they sketched it.

Firstly, learners were able to tell that the graph was a straight line even if the line of best fit did not show such a conclusion. This demonstrated the effect of prior knowledge about the nature of the relationship between two physical quantities as drawn from some of Newton's laws of motion. Secondly, the graphs drawn from the analogy results led to straight lines. Some learners were tempted to put in some points so as to join them together. This showed that they were not comfortable with drawing a graph without any given points. In verbalising their thoughts, some learners also used gestures (see Figure 8).

Observing gestures in gathering research data provided validation of the data-gathering technique employed, that is, the simultaneous checking of whether verbal, written and body language impacted on the processing of responses. The research findings highlighted the contribution to this impact of the gestures involved in the learners' meaning making. Crowder (1996) argues that gestures shape communication. When learners are organising their thoughts, gestures can be used to convey meaning, before speech or after speech (Crowder, 1996). As the learners were constructing meaning, they made gestures. One of the observed learners appeared to be in the process of thinking, when she mimicked the motion of bubbles being formed when air was blown into the straw (see Section 4.2.2.1). She took some time. The other group members assisted with verbalisation (Vygotsky, 1978). When the relevant words were in place, she was able to verbalise her thoughts. According to Crowder (1996), pauses between gesturing and verbalisation are an indication that learners are making sense

of knowledge. Gesturing followed by verbalisation indicates that sense-making is taking place.

It must be noted, however, that the lack of fixed correspondence between gestures and speech can lead to incorrect interpretation in language. Learners from different contexts may use the same gestures to convey different meanings, as we do not have science gestures as such. This can limit sense making.

To conclude: incorporation of the 'straw electricity' analogy triggered verbalisation among the learners in preparing their written explanations. This allowed them to socially construct new knowledge as proposed by Vygotsky (1978). In this way, the analogy used in this study led to understanding that enabled the assimilation of concepts and graphs in the learning of Ohm's law.

5.3.3 Analytical Statement 3: Conventional practical activity and meaning making of concepts based on Ohm's law

A worksheet was designed to be completed by learners when they were working on the conventional practical activity after the analogy exercise. The idea was that the analogy would serve as a foundation to connect context with the content of the new concepts. The PEEOE approach was adopted in doing the conventional practical activity, as it was in the analogy activity (Maselwa & Ngcoza, 2003). Learners were allowed to use laboratory apparatus such as a circuit board, ammeter, voltmeter, connecting wires, switch, resistor, cells and cell holder among others. The learners' experiences as they engaged in this practical activity will now be discussed, focusing on what went well and what was difficult for them.

Learners were able to identify dependent and independent variables but struggled with the control variable. They had an alternative conception that current, cells and potential difference were controlled, while the temperature remained constant. I had to further explain the control variable with reference to the context of the practical activity. Another problem was that it took a long time for the learners to be able to accurately take down readings from the voltmeter and ammeter, which meant that they had to repeat the process. Lastly, they could not do the activity in the absence of the teacher, as highlighted in the interview transcripts, because precautions and hints needed to be imparted for their understanding.

A straight line graph was drawn using results from the ammeter and voltmeter readings. A problem was that few points (readings) were taken, and that led to a line of best fit which was

not accurately drawn. In formulating their conclusion, one group decided to make two lines of best fit. The explanation was that the first line was not showing the same gradient calculation which was similar to the $\frac{V}{I}$ constant calculated earlier. In the absence of verbalisation, I could have assumed that the learners were doing guess work. But it was revealed through stimulated recall interviews that the exposure to the conventional practical activity assisted the learners to think of applications of electricity out of the classroom context.

Learners highlighted the importance of learning about electricity, especially Ohm's law, with regard to its real-world relevance. This was evident from the mention of careers involving electricity such as electrical engineering. The study also revealed that learners' understanding of the law investigated here could raise awareness of electricity usage at home (Appendix W). For instance, the knowledge acquired here could assist in understanding why we must avoid running many appliances from one adaptor.

The conventional practical activity was of advantage to learners as they were working with concrete materials to understand concepts. They were given the opportunity to test skills like measuring, explaining and drawing conclusions from the demonstrated activity. They were able to sketch graphs using the data from the ammeter and voltmeter readings. The challenges the learners encountered in learning Ohm's law will be discussed next.

5.3.4 Analytical Statement 4: Challenges experienced by learners when learning Ohm's law

Such difficulties as were experienced by learners during the research process are highlighted here. The Multiple Choice Questions (MCQ) in the summative test served as indicators of the level of understanding.

The MCQ which probed for explanations required learners to make sense of their learning, unlike those which were closed ended. The summative assessment test answers revealed that the MCQ with follow-up questions or explanations yielded correct responses, although they required some processing time (Treagust, 1998). This was apparent where explanation was given to learners or learners had to supply explanations. Learners were in a position to detail their justifications (see Appendix OOO).

I think the main reason might be that learners were now used to having to explain their answers. In addition, the system of learning made them aware that processing results was dependent on deeper self-mediation (Anton, 1999; Sofaer, 1999). For that reason, the summative test scores showed improvement over the diagnostic test scores (see Table 4). This indicated that change in learners' conceptual understanding had taken place (Section 2.2.8). Interestingly, one of the passive learners in class managed to achieve an unusually high score difference. The existing literature only maps improved performance with active participation and extensive classroom involvement. This might be a rare case, though. The data from summative test responses revealed that some learners were able to show their understanding by checking their calculations. In another instance, two of the learners did the calculations for gradient twice (see Figure 11 in Section 4.2.1.3). I assumed that both learners were showing understanding in mastering calculations and saw it as improvement in self-efficacy. But only one of these learners proved me right.

Although graphicacy is a challenge, a few learners managed to get correct coordinates that led to correct gradient calculations as revealed in this study and the earlier studies reviewed in this thesis. To be specific, studies by Erceg and Aviani (2014) as well as Anagnostopoulou et al. (2015) show similar findings. Other learners still showed confusion in terms of reading of correct coordinates and assigning a correct scale. This led to two calculations with different answers and swapped numerator and denominator quantities. It was apparent that such learners had only a surface understanding of graphicacy. Another method used to assess the strengths and weaknesses of the learners was the use of reflective journals. Learners were allowed to use journal entries in noting down related concepts in their mind maps and questions where clarity was needed.

According to Walker (2006), learners should be encouraged to note down questions, discussions and doubts about their learning progress. Thus, reflections on daily activities were promoted. The purpose was to create a record of learners' thoughts so as to avoid underestimating or overestimating their levels of understanding. Thinking involves the abstract processing of ideas, so it is not easy to measure.

Carpenter (2003) argues that reflective journals reveal prior knowledge and alternative conceptions (see Section 2.2.7). This is confirmed by Towndrow, Ling and Venthan (2008). The study by Towndrow et al. (2008) in Singapore shows that journal writing promotes reflexive thinking, as new learning is drawn from prior knowledge, to make sense of the

present situation and anticipate the future state. Walker (2006) and Chan (2009) share the same sentiments with Towndrow et al. (2008) around the issue of connecting prior knowledge to future decisions. It is this that enables the application of school-learned knowledge in the real world. Chan (2009) views journal writing from the assessment perspective, but my study used it in the way described by Walker (2006), that is, as a measure of learning progress. It monitored whether learners were making sense of concepts or not. If yes, to what extent? If not, what were the challenges?

Towndrow et al. (2008) stipulate that journal writing can take place in a laboratory or in any classroom setup. The study by Towndrow et al. (2008) took place in a laboratory, suggesting that where learning takes place, reflective journal processing can also take place.

The nature of questions asked by learners signalled their level of understanding and concentration in the classroom activities. The questions appeared in their journal entries as well as in transcripts from lesson observations. One of the learners based her question on the recent learning of Ohmic conductors by thinking about non-Ohmic conductors. It was apparent that prior knowledge was necessary to trigger sense making for new learning (Mezirow, 1990; Walker, 2006; Towndrow et al., 2008; Chan, 2009). Schön (1995) reveals that the nature of questions asked by learners signifies the thinking process as they reflect on prior knowledge. Questions are an aspect of reflection in the quest for deeper understanding. In areas where learners are struggling to make sense of ideas, the questioning technique becomes the bridge to effective learning.

Some of the learners posed questions when they were engaged in scientifically processing knowledge. This was evident when they were surprised by having made a wrong prediction during the analogy activity. The result served as a virtual question that they answered by formulating a new reasoning. There is no doubt that questions encourage scientific reasoning.

Since the focus group comprised of learners from different levels of achievement, it was easy for them to assist one another (see Section 3.2.3). The MKOs such as *Entle* and others were not chosen but they emerged naturally. They assisted the low achievers by guiding them using a question-and-answer technique. Once again, social constructivism in action was observed (Appendix P2).

Social learning means that the MKOs and the assisted learners together experience development with regard to cognitive levels. The data indicated that the MKOs felt happy

about assisting other learners as shown in Figure 16 (see Section 4.2.1.5). This indicates growth in the MKO's self-confidence and efficacy (Bandura, 1993). Learning in such an environment promotes understanding and critical thinking.

The data gathered in my study indicated that learners made sense of the subject when exposed to verbal and non-verbal explanations. Such explanations made use of different symbolic modes, including words, graphs and equations. Learners encountered fewer problems after an analogy was incorporated into their learning prior to a conventional practical activity. Although some learners still showed a lack of understanding of the calculation of resistance at the final lesson presentation, the study revealed that learners managed, to a much greater extent than before, to make sense of concepts and graphs.

5.4 Concluding remarks

This chapter interpreted and discussed the data presented in the previous chapter. The data, gathered through documents, observations and interviews, supplied verbal and non-verbal material. Themes emerging from the data led to discussion of four identified analytical statements.

There were indications that learners did make sense of Ohm's law primarily as a result of the incorporation of the 'straw electricity' analogy. In the next chapter, I present a summary of my findings and draw some conclusions, make recommendations and suggest areas for future research.

CHAPTER 6

SUMMARY OF FINDINGS, RECOMMENDATIONS AND CONCLUSIONS

6.1 Introduction

This chapter provides an overview of the research study as presented in the previous sections from the study context through to the literature that informs the study, the research design and data presentation up to the discussion of findings. This chapter highlights reflections on my personal experience and the nature of themes that emerged from the data. The limitations of the study are described, recommendations made and areas for future studies are also highlighted.

6.2 Summary of findings

The qualitative case study on how Grade 11 Physical Sciences learners made sense of Ohm's law when it was mediated through an analogy responded to challenges in the context of the study, including the high failure rate in the subject in Grade 12. The study goal and research questions pointed to the literature that provided mediational tools and a theoretical framework that guided data discussions. This literature was referred to throughout to check on the study's direction and significance.

Literature consulted in the study pointed to the importance of mediational tools, theory, research design and reinforced data discussions. It assisted me in discussing the emerging themes in the study, which centred on the use of an analogy in the mediation of learning. The study revealed that other concepts and factors, such as prior knowledge, language, practical activities, assessment, graphicacy and concept maps were embedded in the mediation of the 'straw electricity' analogy. All these factors and mediational tools played a role in helping learners to make sense of Ohm's law. The notion of the mediation of learning was informed throughout by the central pillar to my study, the social constructivist perspective.

Literature on the social constructivist perspective and its components was discussed to ground this study. The theory was observed throughout the research design when sampling participants, choosing data gathering techniques, right through to discussion of the research findings.

The quantity of data generated in this study was considerable. Transcripts from observations and interviews as well as learner journals provided data which would have been ignored if I was focusing on either verbal or non-verbal responses only. I learned that verbalisation as well as gesturing revealed important dimensions of how learners made sense of new knowledge. These modes of communication assisted me in organising the data into themes and analytical statements, which showed how the study developed as well as how learners benefited.

Incorporation of the ‘straw electricity’ analogy yielded good results. The analogy was incorporated to give learners experience of a practical activity where scientific procedures were followed. Learners had to predict, explain, explore, observe and explain when doing the analogy activity using easily accessible materials (Maselwa & Ngcoza, 2003). This facilitated their comprehension of Ohm’s law. The hands-on method gave learners an opportunity to experience different learning styles through different mediational tools. This constituted at least some of the study’s significance because an analogy was mediated using different mediational tools from those they were used to. In addition, this analogy addressed all aspects of learning Ohm’s law, in words, symbols, calculations and graphs. Learning such skills is in line with the curriculum and assessment expectations (South Africa. DBE, 2011, 2014).

The study revealed that learners can make better sense of what they are learning if given an opportunity to learn using different mediational tools and presenting their thoughts in different ways. The discussion of the data emerging from the study revealed its value to science learning. The literature consulted together with the data gathered served effectively to answer all the research questions posed by the study (see Section 5.3). However, the study was not without limitations, and these are discussed below.

6.3 Limitations of the study

This case study was learner-focused and qualitative in nature with some observed quantitative aspects. The selected participants and sample size were in conformity with its being a case study of Grade 11 Physical Sciences learners. The focus group comprised of only 12 learners out of a total of 199 in the grade. Because of this, it would be difficult to generalise the study’s findings even if the selection criteria covered a wider spectrum of learners’ abilities. It could be argued that the selection based on diagnostic test results was language limiting.

It was revealed through data gathering techniques such as observation and interviews that learners constructed knowledge more easily when allowed to use their home language. This seems to show that the language used for learning and teaching might have an effect on learners' processing of new ideas and their responses to it. It appears to take some time for them to switch from L1 to L2 (assuming they are able to make the conceptual 'translation' at all). The fact that the duration of examinations is stipulated at school and national level could be a problem with regard to the performance of South African learners, as reflected by TIMSS reports and Examiners' Reports (see Section 1). South Africa mostly has schools where the LoLT is English, whereas most of learners' L1 is an indigenous African language.

The 'straw electricity' analogy could have imposed a limitation on attainment of measurement skills in that it did not lead to visualisation of a complete circuit connection, even though almost all the curriculum expectations pertaining to the learning of Ohm's law were covered.

The timing of the data gathering process was also a limitation. It took place during the holidays, so I was the only tutor. This provided time for data collection which could not be found during normal teaching time. That was an advantage, but more of a disadvantage to the learners' system of knowledge construction. Learners are expected to process their thinking faster in a normal teaching and learning time which was not experienced by the research participants in this project.

6.4 Reflections

The journey of my Master's degree took two years. It involved some interesting and challenging experiences. I will start by sharing the personal background of the study, then look at what went well and later discuss what did not go well. The passion to have a careful look at how learners make sense of Ohm's law when it is mediated through an analogy began when I was doing my Honours degree at Rhodes University.

My engagement with literature and the context during that time made me realise that I had to do a study on electric circuits. The way prior knowledge was embraced in the study of acids and bases using domestic materials encouraged me to explore further. The study on acids and bases was presented by Kuhlane (2011). In such practical activities the 'predict, explain, explore, observe and explain' (PEEOE) approach was promoted as pioneered by Maselwa and Ngcoza (2003). At the beginning of the year 2014, I attended a workshop where easily

accessible materials were utilised to demonstrate science concepts (Grant, 2014, pers. com). It was then that I thought of focusing on Ohm's law within the topic of electric circuits.

That thought was reinforced by my marking experience at the provincial level. I observed that learners were not doing well in electricity, probably because the part of the foundation which is Ohm's law is not well constructed. In Grade 11 textbooks, the presentation of Ohm's law is too short to meet the specified examination guidelines.

In describing what went well during my research journey, I must first acknowledge the support I got from my supervisors, colleagues, parents and research participants. The support I got from my supervisors was revealed when my research proposal was approved. I could not have made it if it was not for their critical eyes on my work. I was then motivated to carry on with my research. Their continuous and motivating feedback made me look at my work from different perspectives. They reminded me of things I would have ignored and kept me focused on the goal of my study. My MEd colleagues have also given me outstanding support by thoughtfully sharing information at any time. That practice kept me motivated.

The data gathering stage took place during the winter school holidays. The parents whose children were part of my study supported me in terms of allowing their children to come to school. There was approximately 100% attendance even though my school is situated in an area where the winters are very cold. Lastly, the learners were all involved in planned activities - there was not a single day when one of them came to class without making a mind map or journal entry. I will now discuss what did not go well on my research journey.

85 out of 199 learners presented themselves for the diagnostic test. The 57% of 199 learners who did not write could have helped to make the emerging themes clearer or provided data for different themes. That high level of absenteeism might have signaled that assessment was negatively interpreted by learners. In interviewing one of them, I discovered that my presentation on the purpose of the study and the composition of the focus group made them aware that the chances of being one of the 12 selected out of 199 were very slim. I felt as if I had failed them. On the other hand, if all of them were there I could not have accurately picked up data through video-taping as the classes would have been overcrowded.

During the research process, I expected learners to come up with concept maps but all of them made mind maps. I think this is due to the fact that not many concepts were dealt with on a daily basis since most of the time was spent in allowing learners to construct ideas (see

Section 2.2.7). Some of the recorded data was lost from the video machine. I am not sure whether this happened when it was transferred to another storage system. Fortunately the important parts were saved and then later transcribed. Another point of regret is that I did not have enough time to participate in the discussions when learners were working in small cooperative groups. I only discovered that I could have assisted a certain group when playing back a video-recording. I felt that trying to give feedback after some time had elapsed assisted few learners since it is not easy to make sense of knowledge when one is out of the zone of proximal development (ZPD) (see Section 2.3.2.2). Time was a problem when the teaching and learning process involved the entire class, so I ended up using afternoon sessions as well to make it up.

I think that my study was balanced in that some things went well and some things did not. However, there are things to be considered if I were to do this study again. They include the following:

- It is important to motivate learners so that they are eager to participate in all types of assessments. I missed a lot of data due to the comparatively low number of learners who turned up for diagnostic assessment. Learners have a tendency to regard assessment as a tool to grade them according to their performance and not as a part of learning;
- I would allow learners to come up with their own analogies relating to electric circuits before my lesson presentations. The purpose would be to check on their mental readiness. That would make them keen to seek connections between an analogy and future learning, since they mostly use easily accessible materials in previous grades (Kasanda et al., 2005). As a result, learners would be motivated throughout the teaching and learning process;
- Mind maps were designed instead of concept maps, as hinted at by Davies (2011). I think that allowing learners to design concept maps after at least five days might help them to identify the connected concepts. Thereafter, they could come up with the expected web-like structures and sense making would be promoted;
- When doing a conventional practical activity I would allow learners to take at least seven sets of points from the voltmeter and ammeter readings in order to show a clear correlation among plotted points. That may eliminate confusion in processing graphical results;

- I would do the research by aligning the contact duration with the normal teaching time. Learners would be used to processing their thoughts within that time. That might possibly help them cope when they are out of the research space;
- Journal writing evoked salient thoughts which provoked reflective learning. If I had requested the participants to continue with journal entries after the research process had concluded, I could have learned about the impact of the study on their future learning;
- The use of more than one video machine would have enabled clearer capturing of data from different angles, given the challenge I had of background noise due to construction. It would also minimise the loss of data when the video recorder faces one group whilst other groups continue with deliberations;
- Lastly, watching the video recordings as lesson presentations continue is important. I attended to the concerns which emerged in the learners' discussions only some time later. So it served as feedback, but it was not of much benefit as the learners were out of their ZPDs.

Some of the study's limitations inform my recommendations for future research.

6.5 Recommendations

The research findings showed that the incorporation of the 'straw electricity' analogy in learning Ohm's law was of benefit. For better results, however, I would like to make some recommendations.

This study has revealed that well-planned analogies trigger a number of modes of sense making in the process of acquiring new knowledge (see Section 5). Therefore, the incorporation of analogies can be recommended for most science topics, because the South African Curriculum does not promote the use of easily accessible resources at the FET phase as proposed by Kasanda et al. (2005). Learning is enhanced when easily accessible resources are utilised, so teachers should take advantage of using such resources in teaching science.

Learning becomes more fruitful when an analogy is used in conjunction with a conventional practical activity. This provides an opportunity to link knowledge from different worlds of understanding, although the two should not be compared with the object of identifying which one brings better understanding. On the other hand, it is equally important to encourage teachers to develop learning and teaching support materials (LTSMs) in the form of units of

work that supplement the content of the textbooks and cater for different learning styles. Throughout the learning process, the skills to formulate hypotheses and provide scientific explanations when processing answers in the science world should be promoted at all times. That has been proved by Maselwa and Ngcoza (2003) to yield good results (Appendix K & N). The incorporation of various mediational tools is encouraged. The mediational tools are not limited to the ones discussed in this study. The participation of teachers in professional development can help endow them with an awareness of the value of using different mediational tools to enhance learning, especially easily accessible resources.

Lastly, issues of ethics in the South African context should be considered with care. For instance, not all parents are formally educated in South Africa. Considering the parents' education status and learners' diverse backgrounds, I would like to suggest that meeting with the parents for the purpose of gaining their trust is of importance. They end up interested in their children's learning, which in turn motivates learners.

6.6 Areas for future research

- A similar study could be done in more under-resourced schools, that is Quintile 1 and Quintile 2 schools. Although it is suggested in this study that the incorporation of an analogy would be of more benefit to under-resourced schools, it would be interesting to get actual findings from more under-resourced schools;
- A similar study could be done with learners whose home language (L1) is their language of learning and teaching (LoLT) in order to check the effect of incorporating an analogy without being influenced by language issues;
- A similar study could be done with teachers to get their views on using the 'straw electricity' analogy. Such a study would be aimed at adding value to the professional development of science educators. It would be interesting to get the teachers' views concerning the value of this analogy in the teaching and learning of Ohm's law.

6.7 Conclusion

This case study using a mixed method approach on how Grade 11 Physical Sciences learners made sense of Ohm's law when it was mediated through an analogy seemed to address the stated goal of the study. I learned that learners might individually learn comfortably using different mediational tools as they participate in small groups. The fact that effective learning takes place in a social context cannot be undermined. This study revealed that the essence of

learning lies in building learners' self-efficacy through engaging learners in social interaction, using verbal and non-verbal communication techniques and allowing them to reflect on their learning through journal entries, mind maps or by simply asking questions.

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APPENDICES

APPENDIX A: Letter to the Subject Advisor

The Subject Advisor

Maluti District Office

Matatiele

4730

Dear Sir/Madam

Re: Request for permission to conduct a research study at Tholang Senior Secondary School

I Lineo Ramasike, hereby request permission to conduct a research study at the above mentioned school from the 29th June to the 10th July 2015. I am a Grade 10 to 12 Physical Sciences teacher at the mentioned school who is also a part-time student at Rhodes University doing a Master's degree in Science Education.

I am interested in a case study of how Grade 11 Physical Sciences make sense of Ohms' law when it is mediated through an analogy. The study will benefit learners in that it will seek to explore how learners make sense of concepts using easily accessible resources. Learners will be the research participants and they will be exposed to written tasks, interviews as well as lesson observations. The data gathered in this study will be kept confidential and anonymity will be observed. The outcomes of this study will also help in professional development of science teachers.

I hope that my request will be valued.

Yours sincerely

Lineo Ramasike (student number: 609R5589)

.....

(083 987 7521 OR lframaside@gmail.com)

APPENDIX AA: Letter from the Subject Advisor



Province of the
EASTERN CAPE
DEPARTMENT OF EDUCATION

MALUTI DISTRICT OFFICE * CURRICULUM * P.O. BOX 1835 * MATATIELE * 4730 * REPUBLIC OF SOUTH AFRICA

Enquiries: **Lurwengu** * Tel: +27 (0)39 256 0111 * Fax: 0866570498 * Cell: 0822535351 *email*
lurwengu@yahoo.com

TO : Ms L.F RAMASIKE
FROM : MSTE SES – MALUTI DISTRICT
SUBJECT : PERMISSION TO CONDUCT A RESEARCH
DATE : 25/05/2015

This is with reference to the request from Ms L.F RAMASIKE to conduct a research for Master's Degree in her school.

I am pleased to learn that you have enrolled with the University of Rhodes for your Master's degree. Rhodes University is one Institution (Where Leaders Learn) that is well recognised across the country for its product. I have no doubt that you have made an informed decision that you won't regret.

In responding to your request, I am excited to inform you that you are granted a permission to conduct the research in your school provided you will adhere to the following conditions:

- Inform the school SMT about your programme, clearly explaining the purpose and how learners will benefit.
- Your programme should not interfere with the teaching and learning process.
- Your programme should be in line with the approved curriculum (CAPS) for your target group/grade.

I know you have it all, what it takes to successfully complete your Master's Degree on record time. I hope that you will be of good inspiration to many other teachers and learners not only in Maluti but across the Province.

Good luck in studies.


MSTE SES

25/05/2015
DATE

APPENDIX B: Letter to the principal

The Principal

Matatiele

4730

Dear Sir/Madam

Re: Request for permission to conduct a research study at Tholang Senior Secondary School

I Lineo Ramasike, hereby request permission to conduct a research study at your school from the 29th June to the 10th July 2015. I am a Grade 10 to 12 Physical Sciences teacher at the mentioned school who is also a part-time student at Rhodes University doing a Master's degree in Science Education.

I am interested in a case study of how Grade 11 Physical Sciences make sense of Ohms' law when it is mediated through an analogy. The study will benefit learners in that it will seek to explore how learners make sense of concepts using easily accessible resources. Learners will be the research participants and they will be exposed to written tasks, interviews as well as lesson observations. The data gathered in this study will be kept confidential and anonymity will be observed. The outcomes of this study will also help in professional development of science teachers.

I hope that my request will be valued.

Yours sincerely

Lineo Ramasike (student number: 609R5589)

.....

(083 987 7521 OR lframaside@gmail.com)

APPENDIX C: Consent letter

0. RIX 321
AT/IBLE
30

TEL: (08) 987 7524
E-mail: lramasike@gmail.co

CONSENT LETTER

This serves as an invitation for YOLANDA a grade 11 Physical Sciences learner to participate in research lessons which will take place at his/her home school. The research practice will take duration of two weeks, starting from the 29th June 2015 to the 10th July 2015. Teaching and learning process will take place during the morning hours of the day, as it will be during school holidays. This letter serves as a follow-up to the discussion around the research outline.

The following research agreement will be considered throughout the research session:

- You are free to withdraw your participation at any time.
- The use of information for research purposes is voluntary.
- Your name will not be used in any research reports, so your responses will always be anonymous. Not unless you give the researcher a permission to use your real name.
- Data gathered will be kept safely to ensure that confidentiality is adhered.

Participants' signature: [Signature]

Date : 29 June 2015

Yours in Education
Ramasike L. F. (the researcher)
Student Number: 09R5589

APPENDIX D: Invitation letter to parents

Dear Parent

Your child is selected to participate in a research study that will take place at school from the 29th June to the 10th July 2015. You are invited to a presentation on the 25th June concerning this research study. Programme and expectations by parents will therefore be discussed on that day. When the research process is complete, you will also be requested to come and watch video-taped lessons of how learners participated throughout the research study.

Yours sincerely

Lineo Ramasike. (Grade 11 Physical Sciences - teacher: 083 987 7521)

[IsiXhosa translation]

Mzali Obekekileyo

Umntwana wakho ukhethiwe uba athabathe inxaxheba kuphando lwezifundo oluzakwenziwa apha esikolweni ukusukela ngomhla wama 29 June ukuya kumhla we 10 July ngonyaka wama 2015. Uyamenywa ukuba uze apha esikolweni ngomhla wama 25 June kobe kusenziwa ingcaciso egcweleyo ngolu phando lwezifundo. Indlela oluzaqhutywa ngayo uphando nezinto ezilindeleke kubazali zoxoxwa ngaloo mini. Xa solugqityiwe uphando uyacelwa uba uze uzobukela ushicilelo olubonisaindlela olwenziwe ngayo olu phando.

Enkosi.

Ozithobileyo

Lineo Ramasike. (Grade 11 Physical Sciences -utitshalakazi: 083 987 7521)

[Sesotho translation]

Motswadi ya ratehang

Ngwana wa hao o kgethilwe ho nka karolo dipatlisisong sekolong sa hae ho tloha mohla la-29Phupjane ho ya ho di-10 Phupu selemong sena. O a mengwa ho tla ba kopanong e lokisetsang dipatlisiso tsena ka la-25 Phupjane 2015. Kopano eo e mabapi le tsamaiso hammoho le ho bontshana ka tse lebelletsweng ho batswadi. Mafelong a phuputso ena o tla kotjwa ho tlatla shebella video-tape ho bona ngwana wa hao ha a nka karolo dipatlisisong tsena.

Ka boikokobetso

Lineo Ramasike. (Grade 11 Physical Sciences - mosuwetsana: 083 987 7521)

APPENDIX E: Invitation letter to a critical friend

Maluti District

Matatiele

4730

Dear Colleague

Re: Request for your assistance during the research study with Grade 11 Physical Sciences learners at Tholang Senior Secondary School

I Lineo Ramasike, hereby request your assistance when conducting a research study at the above mentioned school from the 29th June to the 10th July 2015. The study is in line with requirements for my Master's degree in Science Education as I am a part-time student at Rhodes University.

I am interested in a case study of how Grade 11 Physical Sciences make sense of Ohms' law when it is mediated through an analogy. The study will benefit learners in that it will seek to explore how learners make sense of concepts using easily accessible resources. Learners will be the research participants and they will be exposed to written tasks, interviews as well as lesson observations. The outcomes of this study will also help in professional development of other science teachers.

If my request is successful, we will develop a unit of work together. You are also requested to observe all my lessons and verify if transcripts from videotaped lessons are done well. You are free to withdraw at any time.

I hope that my request will be valued.

Yours sincerely

Lineo Ramasike (student number: 609R5589)

.....

(083 987 7521 OR lframesike@gmail.com)

APPENDIX F: Extract from the Examiners' report 2013

The focus is on electric circuits which is question 9.

Although well prepared learners answered this question well and obtained full marks, it was overall the poorest answered question in this paper.

QUESTION 9 (11,6%)

(a) General comments on the performance of learners in specific questions. Was the question well answered or poorly answered?

This question is the most poorly answered question in the entire question paper.

9.1 This question was poorly answered.

9.2 This question was extremely poorly answered.

9.3 This question was extremely poorly answered.

9.4 This question was extremely poorly answered.

(b) Why was the question poorly answered? Also provide specific examples, indicate common errors committed by learners in this question, and any misconceptions.

Question 9.1: The majority of the learners wrote the definition of emf, instead of explaining the meaning of an emf of 12V, in terms of energy transferred and charge.

Question 9.2: The correct equation $P = I^2R$ was used only by a few learners to calculate electrical current.

Question 9.3: A cognitive demand level 4 question. The majority of the learners could not identify which resistors are connected in series and which are in parallel. The 3Ω and 9Ω resistors which are connected in series inside the parallel combination were not identified by most of the learners. Hence they could not solve the problem appropriately.

Question 9.4: The majority of the learners lack the skill to explain what their understanding of electric circuits is. Learners could not explain the relationship between resistance, current and power correctly.

APPENDIX G: Diagnostic test

Topic: Electric Circuits

Time: 1 hour

Answer ALL the questions

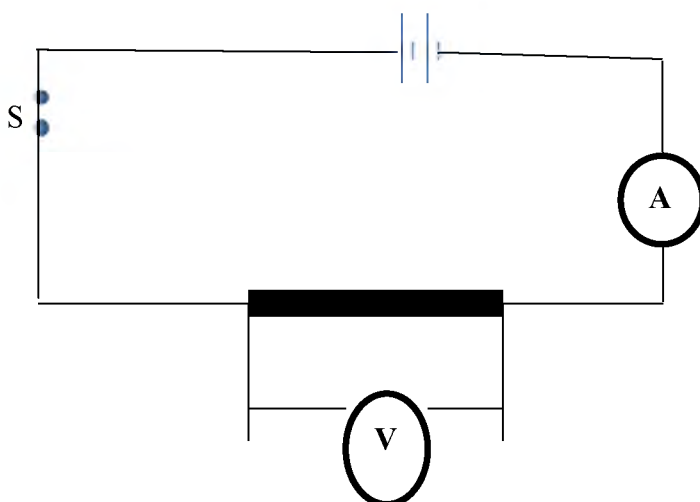
Marks: 48

QUESTION 1: MULTIPLE-CHOICE QUESTION

Four options are suggested as possible answers to each question. Choose the letter that represents the best answer and write it next to the question number (1.1 – 1.2) e.g. 1.2 D. All the multi-choice questions are based on the diagram and/or table below.

In the diagram, a voltmeter measures potential difference across a piece of nichrome wire and the ammeter measures the current through it:

Switch S is closed.



The table below gives readings and calculations (results) for two pieces of nichrome wires:

Measurement	First wire (800 mm x 0,5 mm)	Second wire (1600 mm x 0,5 mm)
Potential difference, V	3.0 V	3,0 V
Current, I	0,6 A	0,3 A
Ratio, $\frac{V}{I}$	5 V.A ⁻¹	10 V.A ⁻¹

1.1 Carefully consider the readings and calculations for the two pieces of nichrome wire.

What is the relationship between the length of the wire and the ratio $\frac{V}{I}$? They are ...

- (i) Directly proportional
- (ii) Indirectly proportional
- (iii) Inversely proportional
- (iv) Constantly proportional

Which one of these explains your choice for the above answer?

- A. the ratio increases as the length of the wire increases
- B. the ratio increases as the current increases
- C. the ratio increases as the current decreases
- D. the ratio increases as the current stays the same (2)

1.2 Which is the ODD one out?

- (i) The type of material the conductor is made of.
- (ii) The temperature of the conductor.
- (iii) The colour of nichrome wire.
- (iv) The thickness of nichrome wire.

Which of the following is the correct justification for the chosen factor?

- A. The pattern of the ratio $\frac{V}{I}$ is studied.
- B. It does affect the readings of both voltmeter and ammeter
- C. It is the only factor which does not affect the ratio $\frac{V}{I}$
- D. It does not affect the readings of both voltmeter and ammeter to a certain degree (2)

[2x2=4]

QUESTION 2

Consider the following terms:

- Electrical current
- Potential difference
- Resistance

2.1 Define each term. (6)

2.2 Identify physical quantities and their units, extracted from each definition. (3)

2.3 Write down equations that originate from definition of each term. (3)

2.4 What is the relationship between any two physical quantities found in each defined term? (3)[15]

QUESTION 3

A group of Grade 11 learners were given the following apparatus to do an experiment to determine the relationship between electric current and potential difference, where current changes after a set of readings was taken. That means a changeable ammeter was used.

- Two cells (connected in series)
- A switch (open)
- Connecting wires
- An ammeter
- A voltmeter
- A resistor

3.1 Draw a circuit diagram that shows a connection of all apparatus, with a voltmeter connected across a resistor. (3)

3.2 When the switch is closed, the readings from an ammeter and a voltmeter were noted as shown in the table below:

Current (I) (in A)	Potential Difference(V) (in V)	$\frac{V}{I}$
0,2	0,4	
0,4	0,8	
0,6	1,2	
0,8	1,4	
1,0	2,0	
1,2	2,4	

- 3.2.1 Predict the next set of points. Justify your choice of answer. (2)
- 3.2.2 Identify the: a) independent variable (1)
- b) dependent variable (1)
- 3.2.3 Use the graph paper provided to plot all sets of points, on the potential difference versus current axis. (4)
- 3.2.4 Join the points and draw the line of ‘best fit’. (2)
- 3.2.5 What is the shape of the graph formed? Choose from:
exponential, parabola or straight line. (1)
- 3.2.6 What is the relationship between current and potential difference? Explain by referring to the table of values and the graph. (2)
- 3.2.7 Copy the ammeter and voltmeter results table. Then complete the last column. (2)
- 3.2.8 What do you observe with regard to $\frac{V}{I}$ values? (2)
- 3.2.9 What scientific meaning is suggested by such a column results? (2)
- 3.2.10 Use the graph drawn in question 3.2.4 to calculate the gradient. (2)
- 3.2.11 What do you observe from your answers to questions 3.2.8 and 3.2.10 above? (2)
- 3.2.12 As a scientist, briefly discuss the conclusion for this experiment. Also argue using a third physical quantity in addition to current and potential difference. (3)

[29]

APPENDIX GG: Diagnostic test Memorandum

QUESTION 1

1.1 A ✓✓ (2)

1.2 C ✓✓ (2)[4]

QUESTION 2

2.1 Electrical current is the amount of charge that flows past a point in every second **or** is the rate of flow of charge through a circuit. ✓✓

Potential difference is the work done (or energy transferred) per charge to move a positive charge from one point to another. ✓✓

Resistance is the extent to which a conductor or a component in a circuit resists the flow of current **or** is the ratio of potential difference across the electric component to current passing through it. ✓✓ (6)

2.2 Electrical current: electric current, electrical charge and time. ✓

Potential difference: potential difference, work done (energy) and electrical charge. ✓

Resistance: Resistance, potential difference and electrical current. ✓ (3)

2.3 From electrical current: $I = \frac{Q}{\Delta t}$ ✓

From potential difference: $V = \frac{W}{Q}$ ✓

From resistance: $R = \frac{V}{I}$ ✓ (3)

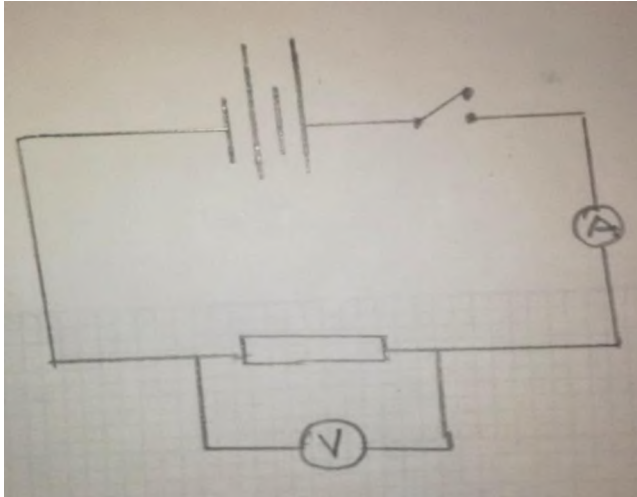
2.4 Electrical current \propto charge **or** electrical current $\propto \frac{1}{\text{time}}$ **or** charge \propto time taken ✓

Potential difference \propto work done (energy) **or** potential difference $\propto \frac{1}{\text{charge}}$ **or** energy \propto charge ✓

Resistance \propto potential difference **or** resistance $\propto \frac{1}{\text{current}}$ **or** potential difference \propto electrical current ✓ (3)[15]

QUESTION 3

3.1



(3)

3.2.1 (1,4; 2,8) ✓✓

(2)

3.2.2 a) Electrical current. ✓

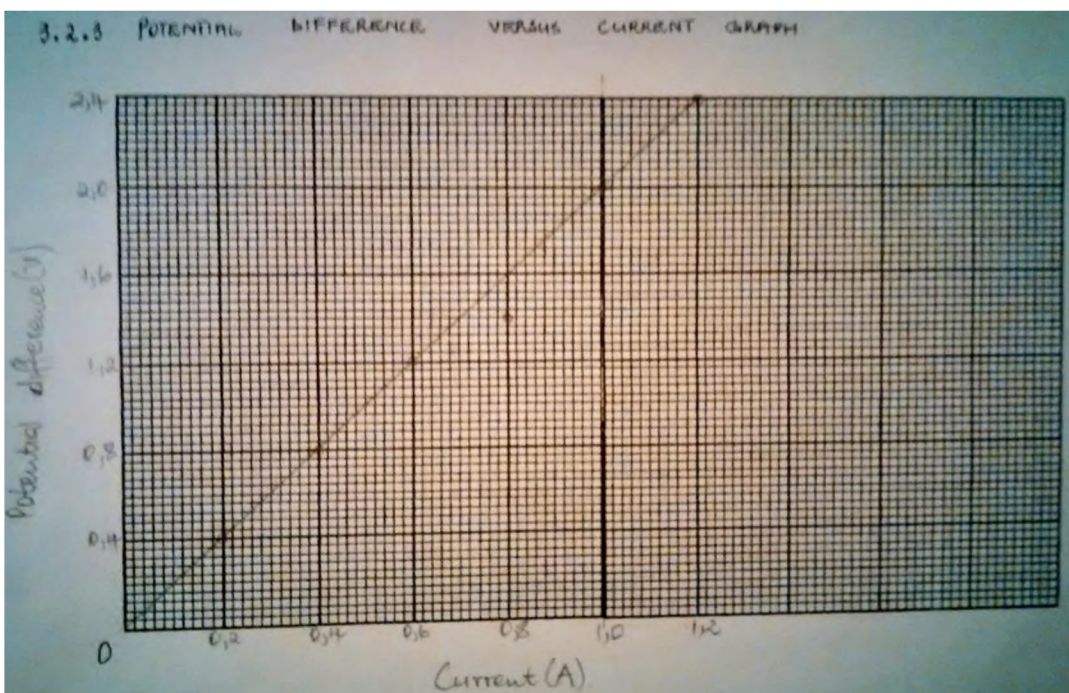
(1)

b) Potential difference ✓

(1)

3.2.3 and 3.2.4 On the graph paper.

(4 + 2 = 6)



3.2.5 Straight line. ✓

(1)

3.2.6 Electrical current is directly proportional to the potential difference. Potential difference increases as electrical current increases. ✓✓ (2)

3.2.7

Current (I) (in A)	Potential Difference(V) (in V)	$\frac{V}{I}$
0,2	0,4	2
0,4	0,8	2
0,6	1,2	2
0,8	1,4	1,75
1,0	2,0	2
1,2	2,4	2

✓✓

(2)

3.2.8 They are the same. $\frac{V}{I}$ is constant. ✓✓ (2)

3.2.9 It is a control variable because it is constant/fixed. ✓✓ (2)

3.2.10 Gradient = $\frac{\Delta V}{\Delta I} = \frac{1,2 - 0,8}{0,6 - 0,2} \checkmark = 2 \checkmark$ (2)

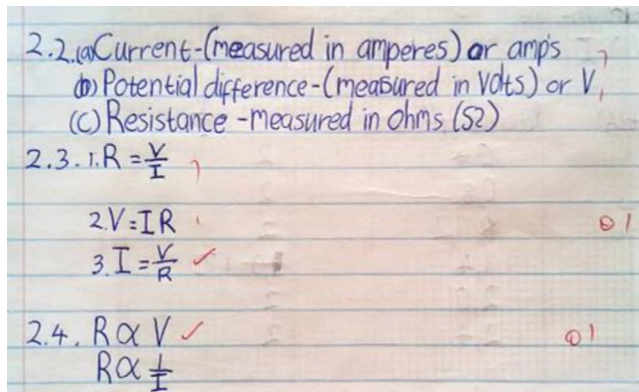
3.2.11 The results are the same. ✓✓ (2)

3.2.12 Electrical current is directly proportional to the potential difference✓ and $\frac{V}{I}$ which is resistance✓ is constant✓. (3)[29]

APPENDIX H: Data on diagnostic test

2.1 Definition of electrical current, potential difference and resistance were provided.

2.2 Identify physical quantities and their units, extracted from each definition.



RI: Electric circuits-amps.

Resistance- Ohms.

R2: V- voltage; W-wire and A-ammeter.

R3: Resistance- Ammeter – A.

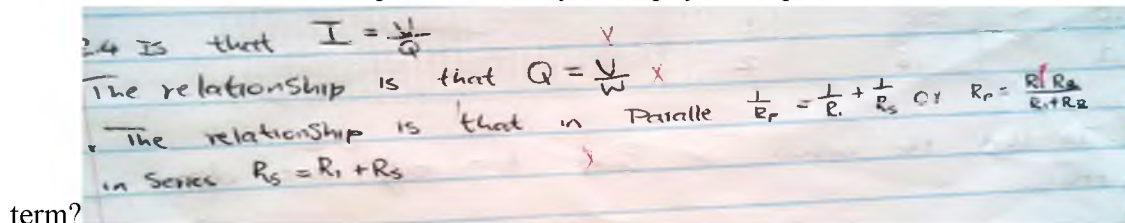
2.3 Write down equations that originate from definition of each defined term.

RI: $I = \frac{V}{R}$; $V_T = V_1 + V$

R2: $R_s = R_1 + R_2$ and $R_p = \frac{R_1 R_2}{R_1 + R_2}$

R3: $V = IR$

2.4 What is the relationship between any two physical quantities found in each defined



term?

RI: The current is directly proportional to the potential difference

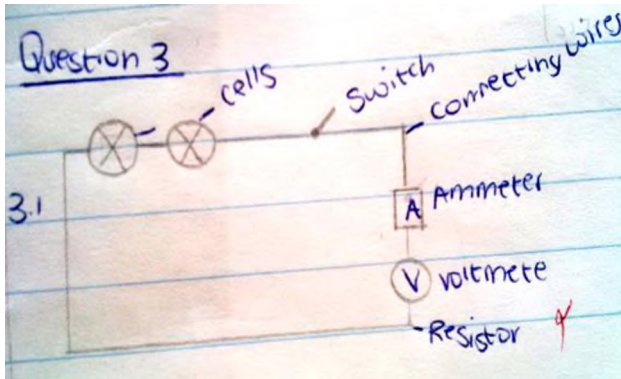
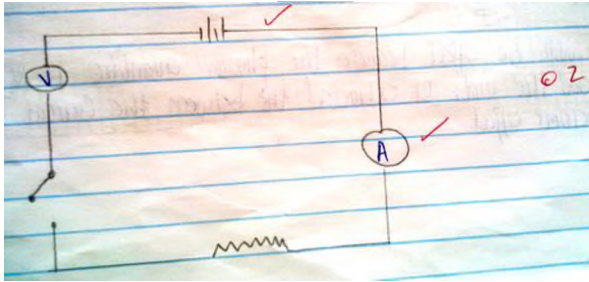
R2: In a series circuit, the resistor is known as the voltage divider. In a parallel circuit, the ammeter is known as the voltage divider.

R3: Is the electric current and resistance

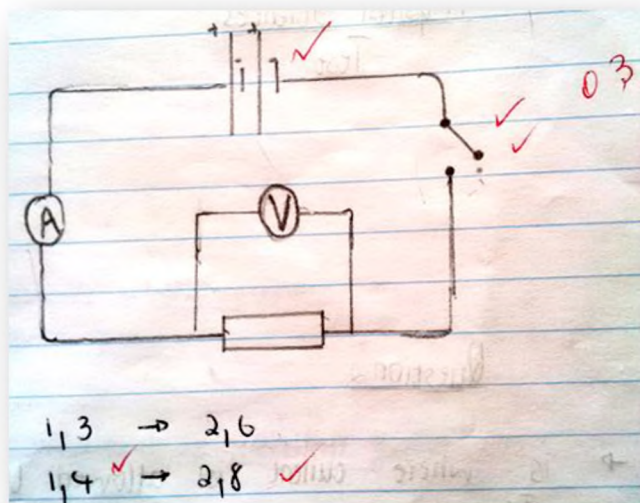
R4: They total up to the voltage of the battery that is given.

R5: $R \propto V$

3.1 Draw a circuit diagram that shows a connection of all apparatus, with a voltmeter connected across a resistor.



3.2.1 Predict the next set of points. Justify your choice of answer.



R1: We can add current and potential difference and give answer of the $\frac{V}{I}$

R2: 1,4 → 2,8. The potential difference increases are the current in ammeter increase.

R3:

Current (I) in (A)	Potential Difference (V)
1,4	2,8

On current we keep on adding 0,2 and on potential difference we keep on adding 0,4.(5 responses)

3.2.2 Identify the:

a) independent variable:

R1: Current in ammeter (5 responses)

R2: Potential difference (2 responses)

R3: Two cells (2 responses)

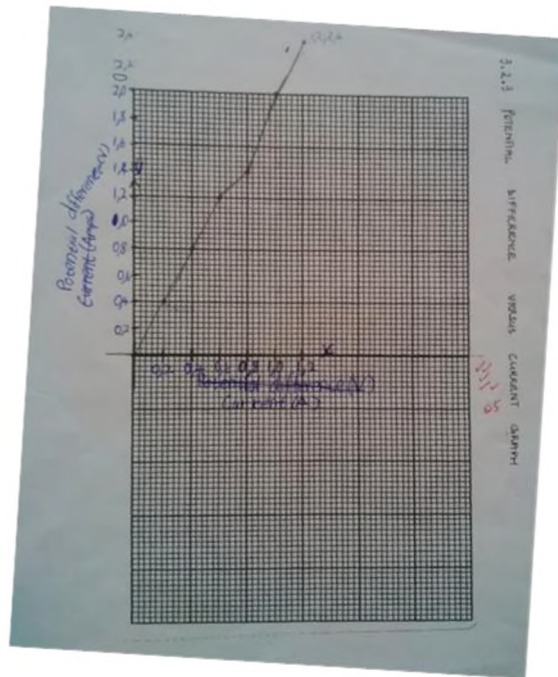
b) dependent variable :

R1: Potential difference (5 responses)

R2: Current (2 responses)

R3: Switch (2 responses)

3.2.3 Use the graph paper provided to plot all sets of points, on the potential difference versus current axis. AND 3.2.4 Join the points and draw the line of 'best fit'.



3.2.5 What is the shape of the graph formed? Choose from:

exponential, parabola or straight line.

R1: Exponential (2 responses)

R2: Straight line (9 responses)

R3: Parabola (1 response)

3.2.6 What is the relationship between current and potential difference? Explain by referring to the table of values and the graph.

R1: current increases as potential difference increases OR $V \propto I$ (5 responses).

R2: The relationship between current and potential difference is the adding of the current and potential difference.

R3: The relationship between current and potential difference is directly proportional, as current increases, the potential difference also increases (4 responses).

3.2.7 Copy the ammeter and voltmeter results table. Then complete the last column.

R2:

Current (I) (in A)	Potential Difference(V)	$\frac{V}{I}$
-----------------------	----------------------------	---------------

	(in V)	
0,2	0,4	2
0,4	0,8	2
0,6	1,2	2
0,8	1,4	2
1,0	2,0	2
1,2	2,4	2

(1 response)

R4

Current (I) (in A)	Potential Difference(V) (in V)	$\frac{V}{I}$
0,2	0,4	0,6
0,4	0,8	1,2
0,6	1,2	1,8
0,8	1,4	2,2
1,0	2,0	3
1,2	2,4	3,6

(2 responses)

3.2.8 What do you observe with regard to $\frac{V}{I}$ values?

RI:

$\frac{V}{I}$ values are remaining constant or are in constant motion.

They results give 2 they are the same but when the potential difference is 1,4 they give different results (4 responses).

The resistance of the circuits were 2Ω because the current was half the voltage. The resistance increased since the current and voltage increased.

They are equal to two

R2: I observe that the values of $\frac{V}{I}$ do not change.

R3: I observe that V is directly proportional to I .

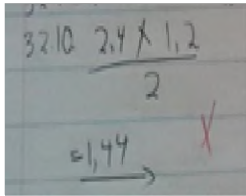
They are equal most of them when you divide values of current by values of potential difference.

R4: To observe with regard to $\frac{V}{I}$ values is to complete the factor of the ammeter and voltmeter.

Observe that the type of material the conductor is made of is the thickness of nichrome wire.

3.2.9 Scientific meaning was suggested by the last a column results

3.2.10 Use the graph drawn in question 3.2.4 to calculate the gradient.



Handwritten calculation: $3.2.10 \frac{2.4 \times 1.2}{2} = 1.44$

$$R1: \frac{0,6}{0,2} = 2$$

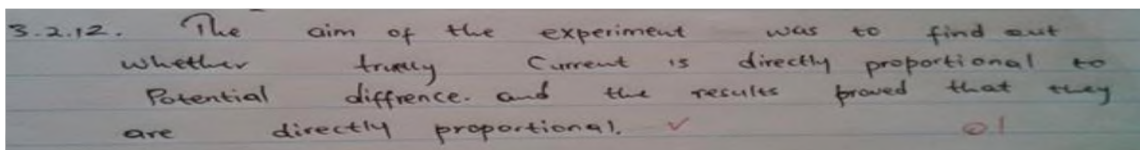
$$R2: G = \frac{y_2 - y_1}{x_2 - x_1} = \frac{2,4 - 0,4}{1,2 - 0,2} = 2 \quad (\text{correct one})$$

$$R4: R_T = R_1 + R_2 = 0,2 + 0,4 = 0,6$$

3.2.11 What do you observe from your answers to questions 3.2.9 and 3.2.10 above?

The current is directly proportional to the potential difference was the common answer provided.

3.2.12 As a scientist, briefly discuss the conclusion for this experiment. Also argue using a third physical quantity in addition to current and potential difference.



Handwritten answer: 3.2.12. The aim of the experiment was to find out whether truly current is directly proportional to potential difference. and the results proved that they are directly proportional. ✓ 01

The aim of the experiment was to find out whether truly current is directly proportional to potential difference and the results proved that they are directly proportional (most responses).

APPENDIX I: Unit of work

Research topic: A case study of how Grade 11 Physical Sciences learners make sense of Ohms' law when it is mediated through an analogy.

TOPIC: Electric Circuits

What you know already:

Grade 8: circuits, resistors and electric circuits.

Grade 9:

- Factors which affect resistance in a circuit.
- Series and parallel circuits: focus on measurements of current and potential difference.
- Cost of electricity.

Grade 10:

- Define potential difference.
- Differentiate between terminal potential difference and emf.
- Calculations using $V = \frac{W}{Q}$
- Define current and use $I = \frac{Q}{\Delta t}$ in calculations.
- Measurement of: current and potential difference.
- Resistance: definition, explanation, unit definition as well as to state and explain factors affecting resistance (the same factors which were dealt with in grade 9).
- Resistors in series and parallel.

General Mathematics concepts:

- Units and their conversions.
- Equations.
- Graphs (functions).

What you will learn about in this topic: Ohms' law:

- State Ohms' law in words.

- Determine the relationship between current, potential difference and resistance at constant temperature.
- Draw and interpret graphs of 'V versus I' and 'I versus V' in relation to gradient and resistance.
- State the difference between Ohmic and non-Ohmic conductors and give an example in each.
- Solve problems using $R = \frac{V}{I}$ for series and parallel circuits (maximum of four resistors).
- Application of Ohms' law in power and energy problems:
- Define power.
- Solve problems using: $P = \frac{W}{\Delta t}$; $P = VI$; $P = I^2R$ or $P = \frac{V^2}{R}$
- Solve circuit problems involving the concept of power and electrical energy.
- Discuss the concept of kilowatt hour.
- Calculate the cost of electricity (as in grade 9).

Topic presentation:

Revision (definitions of some concepts):

Cells or battery: is the source of energy in an electric circuit.

Direct current (DC): is the flow of current in one direction only.

Electric current (I): is the amount of charge that flows past a point in every second **or** is the rate of flow of charge through a circuit. It is measured in Amperes (A), with an ammeter which is connected in series to the circuit. It is connected in series because of its low resistance to current. From the definition, the following equation is determined:

$$\text{current}(I) = \frac{\text{charge}(Q)}{\text{time}(\Delta t)}$$

In symbols: $I = \frac{Q}{\Delta t}$; then $Q = I\Delta t$ or $\Delta t = \frac{Q}{I}$; where current is measured in Amperes (A), charge in Coulombs (C) and time is measured in seconds(s).

Potential difference (V) (between two points in a conductor): is the work done (or energy transferred) per charge to move a positive charge from one point to another. It is measured in Volts (V), with a voltmeter connected in parallel to the circuit. It is connected in parallel to the battery, light bulbs or resistors/rheostat because of its high resistance to current. That

means, if it is connected in series no current can pass through it. Then the circuit would be broken.

From the definition, the following equation is found:

$$\text{potential difference (V)} = \frac{\text{work done (W)}}{\text{charge (Q)}}$$

In symbols: $V = \frac{W}{Q}$; then $W = VQ$ or $Q = \frac{W}{V}$; where potential difference is measured in Volts (V), work done or energy is measured in Joules (J) and charge is measured in Coulombs (C).

Resistance (R): is the extent to which a conductor or a component in a circuit resists the flow of current **OR** is the ratio of potential difference across the electric component to current passing through it. The equation: $\text{resistance (R)} = \frac{\text{potential difference (V)}}{\text{current (I)}}$

In symbols: $R = \frac{V}{I}$; where resistance is measured in Ohms (Ω). This equation can be rearranged as follows: $V = IR$ and $I = \frac{V}{R}$

Resistance is influenced by: the material the conductor is made of; its length; thickness and temperature. Apart from the type of material the conductor is made of, the following relationships do exist:

- The longer the conductor, the greater is its resistance.
- The thicker the conductor, the smaller is its resistance.
- The hotter the conductor, the greater is its resistance.

The following are also important:

- Circuit diagrams.
- Series and parallel resistors (calculations).
- Cost (of electricity) = power rating of appliance \times the number of hours it was used \times the unit price of electricity

Ohms' law:

Electric current, potential difference and resistance are important physical quantities which are related to each other. The 'unit of work' on electric circuits is based on their relationships through Ohms' law.

A 'straw electricity' analogy will be incorporated as well as a conventional practical activity to link prior knowledge to new knowledge (Refer to Appendices D1 & D2).

Ohms' law states that: the potential difference across a conductor is directly proportional to the current in the conductor at a constant temperature.

Graphically:

potential difference versus current

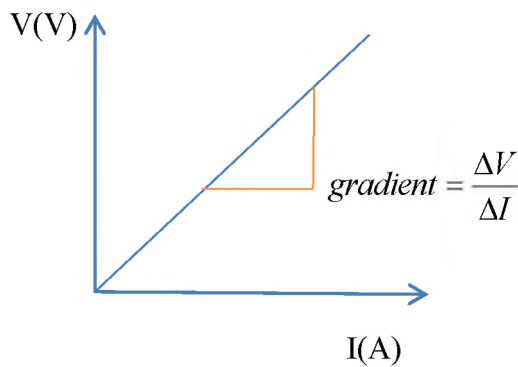


Figure 1

potential difference versus current

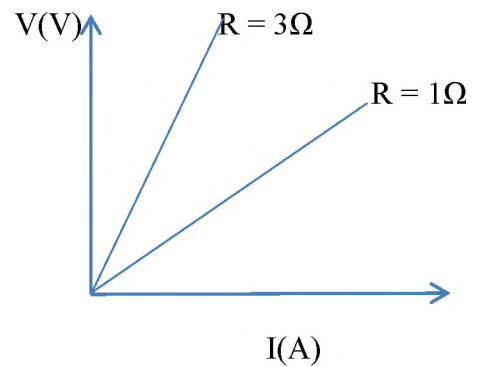


Figure 2

The gradient in 'V versus I' (refer to figure 1): $gradient = \frac{\Delta V}{\Delta I}$

But, $\frac{V}{I} = R$. It means that R is constant. That means temperature is equivalent to resistance.

Resistance is mostly referred to when dealing with Ohms' law equation.

The graph where the gradient is greater (3Ω) is steeper than the one with lesser gradient (1Ω). Thus, the steeper the slope, the higher the resistance (refer to figure 2).

Mathematically (Ohms' law): $V \propto I$

$$V = k I$$

$V = RI$ (constant temperature is equivalent to resistance i.e. $k = R$)

$\therefore R = \frac{V}{I}$ ← this is the gradient

$R = \frac{V}{I}$ is referred to as the Ohms' equation, where the focus on units for the ratio $\frac{V}{I}$ leads to the unit Volts per Amperes ($V.A^{-1}$) since 'V' is measured in Volts and 'I' in Amperes.

The unit for resistance is Ohm (Ω).

Therefore, the unit 'Ohm (Ω)' is equivalent to Volts per Amperes ($V.A^{-1}$). An Ohm is an SI unit and Volts per Amperes is a derived unit. That means, in dealing with calculations, the answers must have an Ohm unit.

An Ohm is defined as: a conductor has a resistance of one Ohm if a current of one Ampere passes through it when a potential difference of one Volt is maintained across i.e. $1\Omega = \frac{1V}{1A}$.

Variables:

For any experiment, there are physical quantities which play a role in verification of a law/principle/theory.

There are three groups of physical quantities which are categorised as variables, namely, independent; dependent and control variables. The stated variables are described below:

Independent variable: is the physical quantity that changes so as to study its effect on the other quantities. Graphically: this variable is put on the horizontal axis.

Dependent variable: it the physical quantity that changes as influenced by the change of another quantity. Graphically: this variable is put on the vertical axis.

Control variable: is the physical quantity that must remain constant throughout the experiment for the purpose of getting a fair test.

Note that: When sketching the graph of potential difference versus current, potential difference should be labelled on the vertical axis and current on the horizontal axis. The rule applies to any graph. For that reason, it is important to supply a heading for any graph, as it suggests the dependent and independent variables.

Ohmic and non-Ohmic conductors:

Conductors which obey Ohms' law, have a constant resistance when potential difference is varied across them or current is varied. Such conductors are known as Ohmic conductors.

Graphs drawn from such conductors form a straight line, as shown below.

potential difference versus current

current versus potential difference

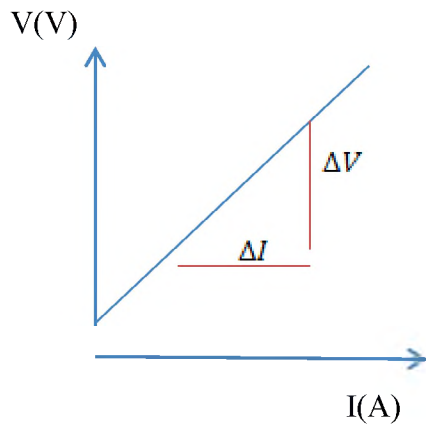


Figure 3

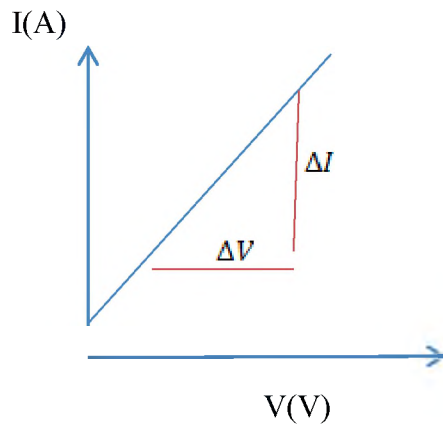


Figure 4

In figure 3: $gradient = \frac{\Delta V}{\Delta I}$

That is: Resistance = $\frac{\Delta V}{\Delta I}$; where the:

- Independent variable is current (current varies)
- Dependent variable is potential difference (changes due to a change in current)
- Control variable is temperature (must be kept constant throughout)

In figure 4: $gradient = \frac{\Delta I}{\Delta V}$

Note that the right hand side is the inverse of resistance equation.

So: $\frac{1}{R} = \frac{\Delta I}{\Delta V}$ (remember that $R = \frac{V}{I}$)

Then: Invert both sides of the equation:

$$\therefore R = \frac{\Delta V}{\Delta I}$$

For this kind of a straight line graph, the:

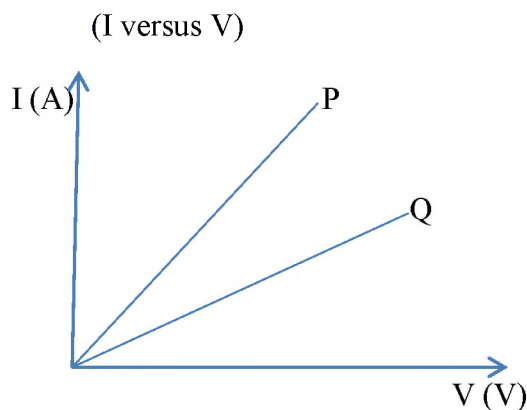
- Independent variable is potential difference (voltage varied)
- Dependent variable is current (current changes as influenced by a change in potential difference)
- Control variable (temperature)

Ohmic resistors are also known as 'linear resistors' because they result in a straight line graph.

Examples of Ohmic resistors are: nichrome wire and circuit resistors.

Apply your skills:(adapted from February/March 2012)

Learners use Ohm's law to determine which ONE of two resistors **P** and **Q** has the greater resistance. For each resistor, they measure the current through the resistor for different potential differences across its ends. The graph below shows the results obtained in their investigation.



The learners are supplied with the following apparatus:

- 6 V battery
- Voltmeter
- Ammeter
- Rheostat
- Resistors **P** and **Q**
- Conducting wires

1. Draw a circuit diagram to show how the learners must use the above apparatus to obtain each of the graphs shown above. (4)
2. Write down ONE variable that must be kept constant during this investigation. (1)
3. Write down the dependent variable. (1)
4. Which ONE of **P** or **Q** has the higher resistance? Give an explanation for the answer. (3)

Non-Ohmic conductors do not obey Ohms' law. For such conductors, the temperature changes as it increases or decreases. So, the graph will not be a straight line. Examples of non-Ohmic conductors are diode, transistor and light bulb.

Current versus potential difference graphs

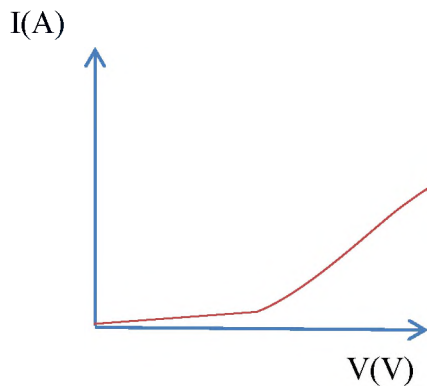


Figure 5

In figure 5: As potential difference increases, current initially increases at a slow rate and later increases at a higher rate. That means temperature increases drastically after some time. This does represent a non-Ohmic conductor, because the graph is not a straight line drawn from the origin. The graph represents a relationship between current, potential difference and resistance in a diode or a transistor.

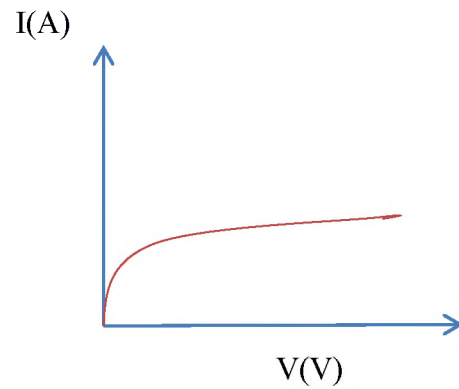


Figure 6

In figure 6: As potential difference increases, current initially increases intensely than towards the end of the experiment. This is also a graph that represents a non-Ohmic conductor because the graph is not a straight line. The conductor gets hot then the temperature does not change after some time. Such a graph represents a relationship between potential difference, current and resistance in a light bulb.

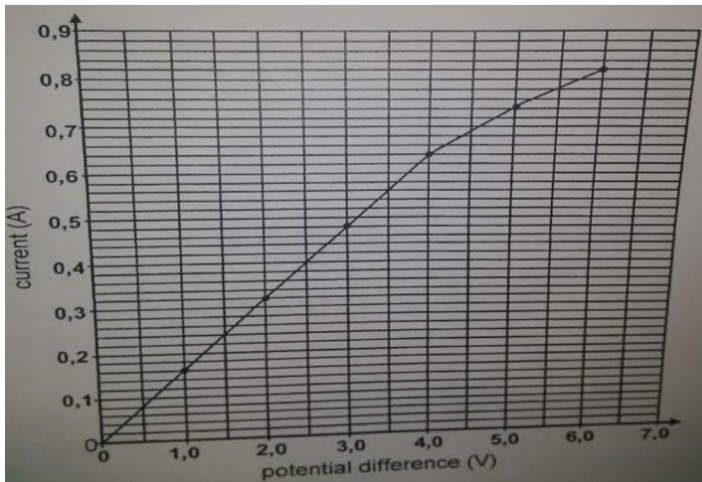
NB 1) Other factors which affect resistance need to be explored. Factors like:

- Length of the conductor (the longer the conductor the greater the resistance)
- Thickness of the conductor (the thicker the conductor the smaller the resistance)

2) Interpretation of graphs is of importance in making meaning of Ohms' law.

Worked example:(Adapted from November 2011)

Learners conduct an investigation to verify Ohm's law. They measure the current through a conducting wire for different potential differences across its ends. The results obtained are shown in the graph below.

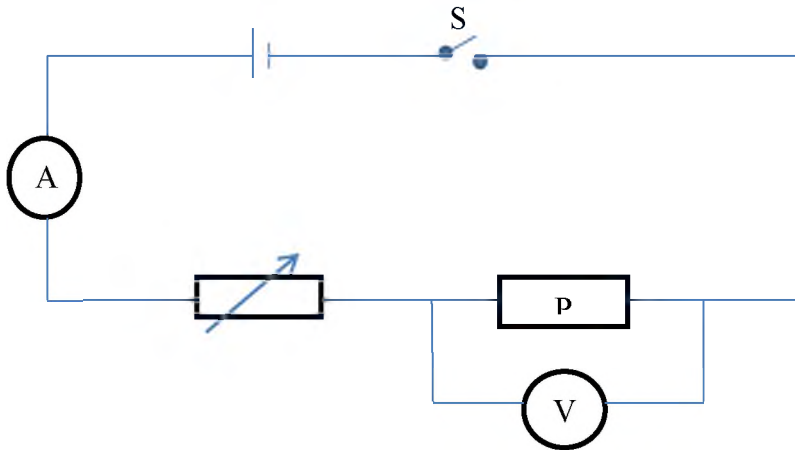


1. Which ONE of the measured quantities is the dependent variable? (1)
 2. From the graph, write down the mathematical relationship between current and potential difference. (2)
 3. State Ohms' law, in words. (2)
 4. The graph deviates from Ohm's law at some point.
 - 4.1 Write down the coordinates of the plotted point on the graph beyond which Ohm's law is not obeyed. (2)
 - 4.2 Give a possible reason for the deviation from Ohm's law as shown in the graph. Assume that all measurements are correct. (2)
 5. Calculate the gradient of the graph for the section where Ohm's law is obeyed. (4)
- Use this to calculate the resistance of the conducting wire. (4)

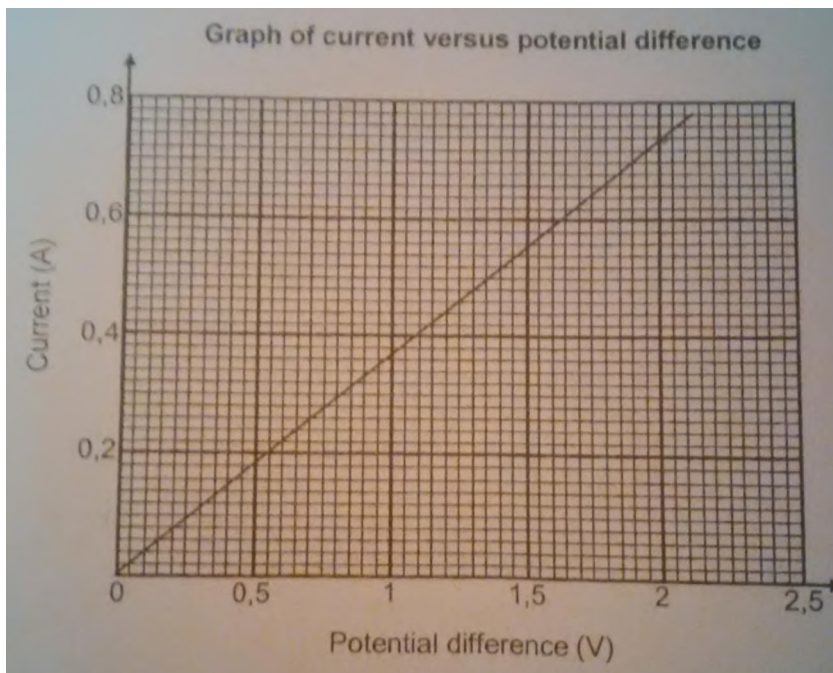
[13]

Apply your skills: (Adapted from February/March 2013)

The circuit represented below is used to investigate the relationship between the current passing through and the potential difference across resistor P



The results obtained are used to draw the graph below.



1. Suggest TWO other factors that should be considered to ensure a fair test when choosing which wire to use. (2)
2. Write down the independent variable. (1)
3. Which variable must be controlled? (1)
4. Formulate an investigative question for the above investigation. (2)

5. What conclusion can be drawn by looking at the nature of the graph? Briefly justify your answer. (3)
6. Which scientific law is investigated here? (1)
7. Using the gradient of the graph, calculate the resistance of resistor P. (4)[14]

APPENDIX J: Analogy worksheet

Research topic: A case study of how Physical Sciences learners make sense of Ohms' law when it is mediated through an analogy.

Name of an analogy: 'Straw electricity'

Work in groups of threes

Objective: This practical is designed to give you a mind model for basic electricity with focus on Ohms' law.

Apparatus: glass (half filled with water); drinking straw and clothes peg.

What previous knowledge is needed to study 'electricity' in a grade 11 Physical Sciences class?

PART 1: Getting current to flow in a conductor (using an analogy)

Predict what will happen when you blow through the straw that is inserted in a glass of water? _____

Explain. _____

Now, take a straw and blow gently into it. Feel the air coming out of the other end. In order to see the air coming out of the other end, dip the end into a glass of water while blowing gently.

Think of the following relations to electricity set-up and complete:

A straw relates to _____

The air blown into the straw relates to _____

PART 2: Getting air current to flow through a resistor

Predict what will happen when you blow through the straw with a peg on it?

Explain: _____

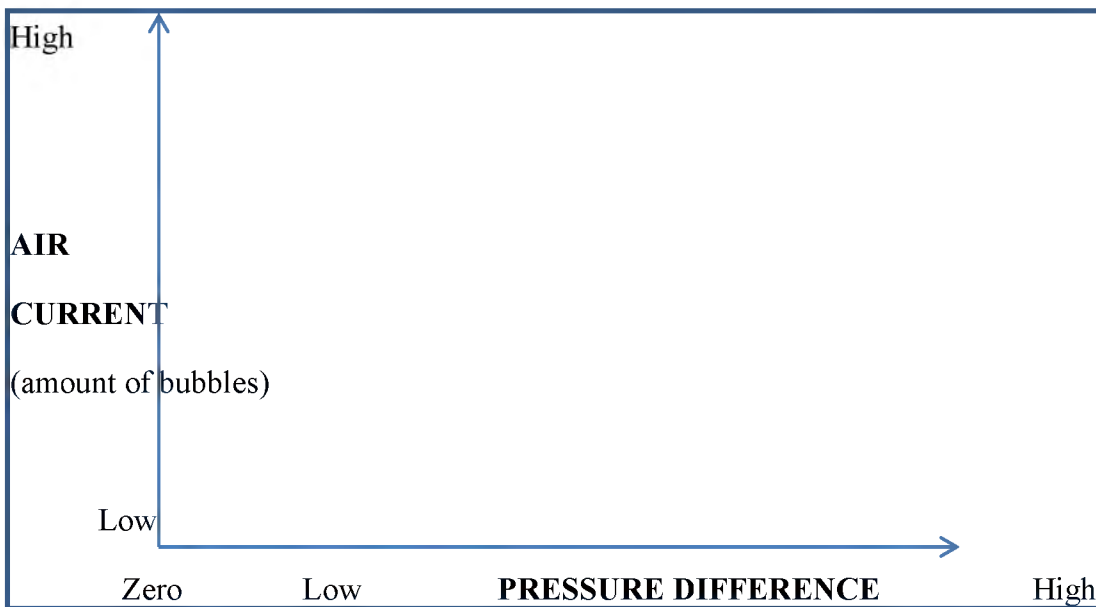
Now place a clothes peg on the straw so that the straw is squashed almost flat. Try blowing air through the straw. Does any air go through or not? _____

Place the other end of the straw in the glass of water to verify your answer.

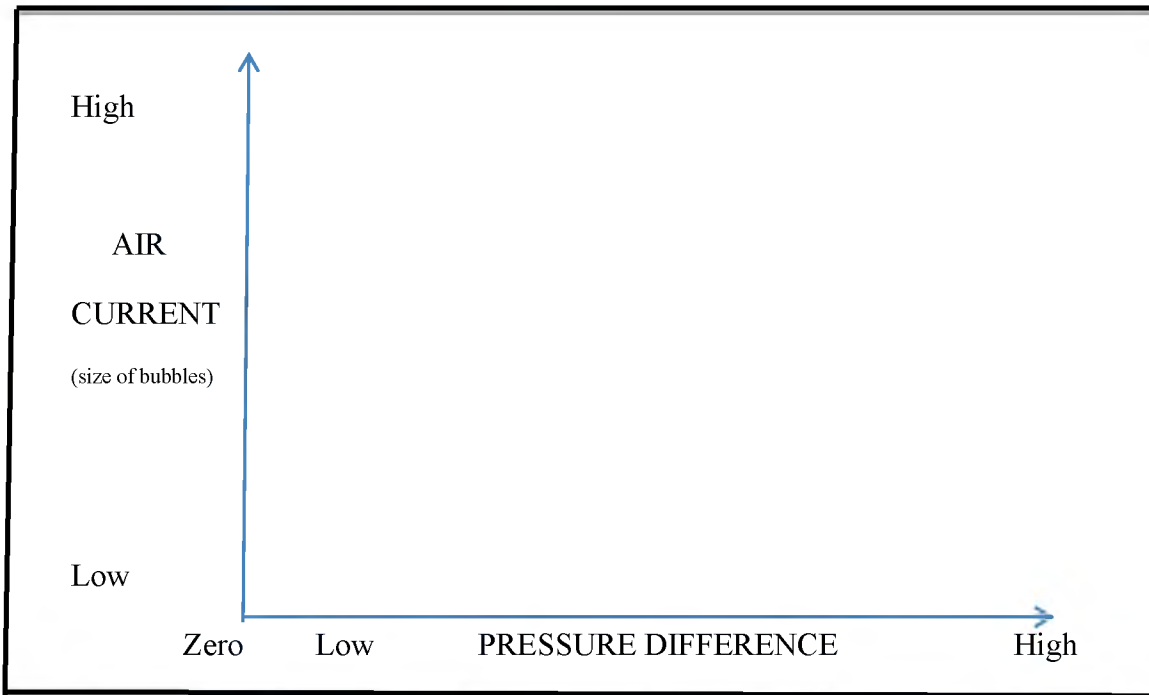
Does air still go through the straw? Explain the choice of your answer

When air is flowing through the squeezed straw, what can you say about the air in the straw between your mouth and the peg, and the air in the straw on the other side of the peg?

Try blowing through the straw with varying amounts of pressure and see how the air current changes. Then sketch a line on the graph axes below to illustrate what you have discovered.



Carefully observe the size of bubbles as the pressure difference increases. Then sketch a graph to show what you have discovered in the next set of axes.



Look at the sketched graphs (on pages 2 and 3) and answer the following questions:

Are there any similarities and/or differences between the two graphs? _____

If any, briefly discuss them below.

Similarities: _____

Differences:

Is the graph of Air Current (amount of bubbles) versus Pressure Difference, straight or curved? _____

What is the relationship between 'air current' and 'pressure difference' (refer to the first graph to make your decision)? _____

Explain the choice of your answer:

A conventional practical activity can be done and yield the same results. The apparatus to be used are: four cells; switch; conductors; ammeter; voltmeter and a resistor or light bulb.

Comparing ‘straw electricity’ analogy and conventional practical activity:

In an electric circuit, the current is made to flow through devices in its path, such as bulbs and motors, by creating an electrical pressure difference between one side of the device and the other. No pressure difference, no current. Pressure difference (potential difference) is measured in volts and examples of devices which supply an electrical potential difference are cells, batteries, generators and power supplies.

Addition of one cell at a time after readings are taken, leads to _____ being the independent variable and _____ the dependent variable (choose between current and potential difference).

Now, rewrite the relationship using ‘current’ and ‘potential difference’ variables in comparison with the results from ‘straw electricity’ analogy.

That relationship between current and potential difference leads to Ohms’ law.

State Ohms’ law, in your own words: _____

APPENDIX K: Data on ‘straw electricity’ analogy (AG)

Key: The normal writing is extracted from worksheet template and italic writing represents the group’s responses. In addition, abbreviations ‘AGA to AGD’ characterise Analogy response for group A up to group D.

What previous knowledge is needed to study ‘electricity’ in a grade 11 Physical Sciences class?

- *Electric components should be known, their use and connections.(AGA & AGB)*
- *Know how to draw circuits in parallel and series connection. Know factors affecting resistance. How to calculate electric components and how to state Ohms law. (AGC)*
- *How to differentiate between potential difference; resistance and current. How to draw a graph of potential difference and current. How to calculate components in a circuit. (AGD)*

PART 1: Getting current to flow in a conductor (using an analogy)

Predict what will happen when you blow through the straw that is inserted in a glass of water?

Bubbles will be formed or produced. (ALL GROUPS)

Explain:

- *When blowing through the straw that is inserted in a glass of water is not dense, so the air that you are inserting easily penetrate water and forms bubbles. (AGA)*
- *Because of air that you use and insert in into the straw which makes bubbles inside the water and the particles or a liquid are far apart which makes it easier to move around in a glass. (AGB)*
- *Because the air that is blown through the straw will be exerted by the force because the water is less than the air hence the bubble will move up.(AGB)*
- *When you push air through the straw into the water, water will open space for air therefore causing air bubbles, the bubbles will rise because air is less denser than water.(AGA)*

Now, take a straw and blow gently into it. Feel the air coming out of the other end. In order to see the air coming out of the other end, dip the end into a glass of water while blowing gently.

Think of the following relations to electricity set-up and complete:

A straw relates to:

Three groups indicated that it relates to a conductor (AGA; AGB & AGC) and one group indicated that it relates to a cell or battery (AGD).

The air blown into the straw relates to: *current (from all groups).*

Carefully observe the size of bubbles as the pressure difference increases. Then sketch a graph to show what you have discovered in the next set of axes.

Does air still go through the straw? Explain the choice of your answer
Yes because of the big hole on a vertex that doesn't allow the air to flow through it will not blow.

When air is flowing through the squeezed straw, what can you say about the air in the straw between your mouth and the peg, and the air in the straw on the other side of the peg?
The air between the mouth and the peg is blowing through very little and the air between straw and the other side of the peg is blowing with the blowing of mouth.

Try blowing through the straw with varying amounts of pressure and see how the air current changes. Then sketch a line on the graph axes below to illustrate what you have discovered.

Carefully observe the size of bubbles as the pressure difference increases. Then sketch a graph to show what you have discovered in the next set of axes.

Look at the sketched graphs (on pages 2 and 3) and answer the following questions:
 Are there any similarities and/or differences between the two graphs? *They are similar.*
 If any, briefly discuss them below.
 Similarities: *They are both straight line graphs. They are both showing a directly proportional relationship.*

Differences:
There are no differences.

Is the graph of Air Current (amount of bubbles) versus Pressure Difference, straight or curved? *It's straight.*

What is the relationship between 'air current' and 'pressure difference' (refer to the first graph to make your decisions)? *It is directly proportional.*

(All groups sketched straight line graphs from the origin for both set of axes, although some groups attempted to plot some points).

Look at the sketched graphs (on pages 2 and 3) and answer the following questions:

Are there any similarities and/or differences between the two graphs?

All groups indicated that there are similarities and there are no differences.

If any, briefly discuss them below.

Similarities:

- *They are both straight line graphs. They are both showing a directly proportional relationship. (AGA)*
- *The graphs are straight lines and they are directly proportional. (AGB)*
- *When pressure is low the bubbles are also low and when pressure is high the bubbles will also increase and give a straight line graph. (AGC)*
- *They are straight line graphs. They are increasing as the pressure difference increases and when the pressure difference decreases the bubbles also decrease. (AGD)*

Differences: *On the first graph we wanted the bubbles on the second graph we wanted size of bubbles.(AGD)*

Is the graph of Air Current (amount of bubbles) versus Pressure Difference, straight or curved? *It gives a straight line (same response from all the groups).*

What is the relationship between ‘air current’ and ‘pressure difference’ (refer to the first graph to make your decision)?

- *It is directly proportional. (AGA)*
- *As the pressure difference increase the air current also increase.(AGB)*
- *The air current is directly proportional to pressure difference. (AGC)*
- *The relationship is directly proportional.(AGD)*

Explain the choice of your answer:

- *As the air current increase, the pressure difference also increase.(AGA)*
- *The amount of bubbles that were observed causes the pressure difference to be the same as the air current.(AGB)*
- *Because when air current is high the pressure difference is also high and when air current is low the pressure difference is also low which makes it directly proportional.(AGC)*
- *Because as pressure difference increases the amount of bubbles also increasing.(AGD)*

A conventional practical activity can be done and yield the same results. The apparatus to be used are: four cells; switch; conductors; ammeter; voltmeter and a resistor or light bulb.

Comparing ‘straw electricity’ analogy and conventional practical activity:

In an electric circuit, the current is made to flow through devices in its path, such as bulbs and motors, by creating an electrical pressure difference between one side of the device and the other. No pressure difference, no current. Pressure difference (potential difference) is measured in volts and examples of devices which supply an electrical potential difference are cells, batteries, generators and power supplies.

That relationship between current and potential difference leads to Ohms’ law.

State Ohms’ law, in your own words:

- *For conductor at a constant temperature, the current in a conductor is directly proportional to potential difference across it (AGB; AGC & AGD).*
- *When potential difference increases, the current increase when the temperature of the conductor is kept constant.(AGA).*

APPENDIX M: Conventional practical activity worksheet

Experiment: on Ohms' law

Objective: This practical activity will give you an understanding of Ohms' law

Apparatus: four 1,5 V cells; a switch; an ammeter; a voltmeter; connecting wires and a resistor.

Set up all the apparatus such that the voltmeter is connected across the resistor.

Draw a circuit diagram to show how you are going to set up the apparatus. Use the space provided below:

Start by using one cell for the first readings.

Close the switch for a moment and measure the current through the resistor and the potential difference.

Note well: Only close the switch while you are taking the readings, otherwise the resistor may get hot and your readings will change.

Record your readings in the table below:

Number of cells	Potential difference, V (V)	Current, I (A)	$\frac{V}{I}$
1			
2			
3			
4			

Add a second cell in series with the first one. Record the values of potential difference and current.

Add a third cell in series to the first two. Record the values of potential difference and current.

Add a fourth cell in series with the first three. Record the values of potential difference and current.

All the last three set of readings should also be recorded in the table above.

Predict the next set of points. Justify your choice of answer:

Identify and give a reason for your choice of the:

1) Independent variable

2) Dependent variable

3) Control variable

Explain in each case what happens to the:

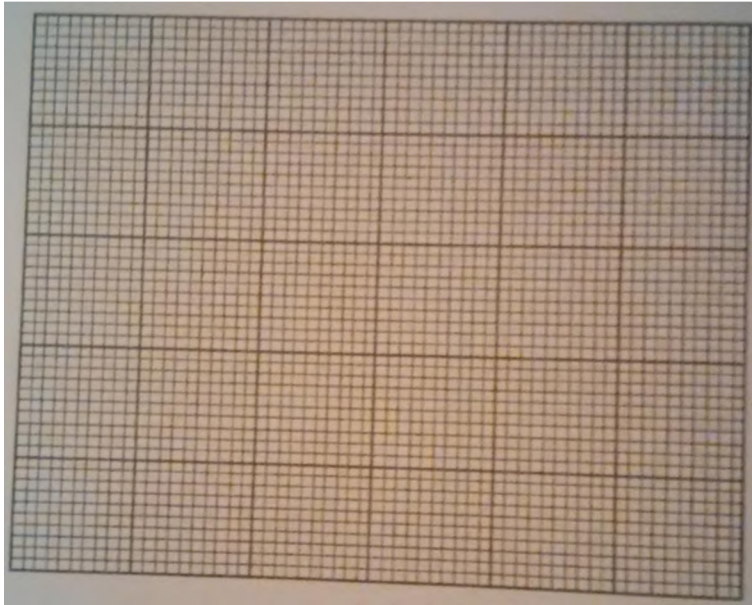
1) Potential difference as the number of cells are added in series

2) Current when the number of cells increase from one to four

3) Ratio $\frac{V}{I}$ when the number of cells increase from one to four

State the relationship between potential difference across the resistor and current in the resistor (by referring to the record of readings)

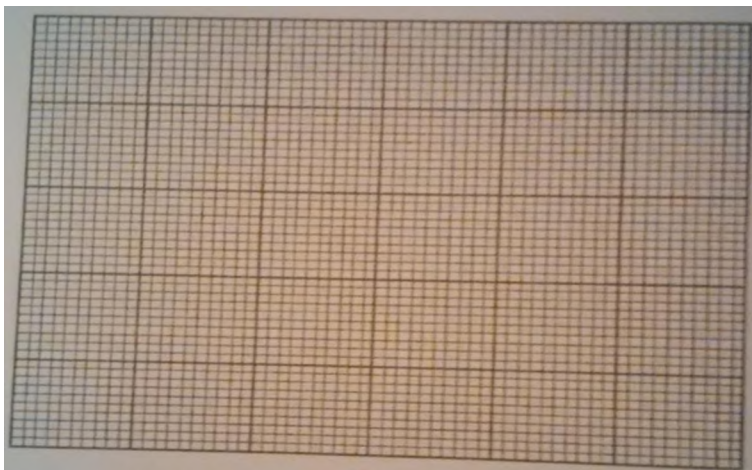
Plot the set of points and draw the line of 'best of fit' for current versus potential difference, on the Cartesian grid below.



Describe the shape of the graph:

Assume that the independent and dependent variables are swapped, but readings are still the same.

Use the Cartesian grid below to sketch the graph of potential difference versus current.



Describe the shape of this graph

The following questions are based on the second graph:

Mark off two points in you graph and label them as **A** and **B**.

Use the two marked points to calculate the gradient of the graph:

Compare then discuss about the gradient results and the last column on the record values for potential difference and current:

What do we call the ratio $\frac{V}{I}$? _____

What unit is derived from the ratio $\frac{V}{I}$:

Conclusion: State the relationship between potential difference and current, include the quantity represented by the ratio $\frac{V}{I}$

Comment on the findings from the 'straw electricity' analogy and this experiment, with reference to Ohm's law:


APPENDIX N: Data on conventional practical activity (EG)

Key: The normal writing is extracted from worksheet template and italic writing represents the group's responses. In addition, abbreviations 'EGA to EGD' characterise Experiment response for group A up to group D.

Experiment: on Ohms' law

Apparatus: four 1,5 V cells; a switch; an ammeter; a voltmeter; connecting wires and a resistor.

Set up all the apparatus such that the voltmeter is connected across the resistor.
Draw a circuit diagram to show how you are going to set up the apparatus. Use the space provided below:



Start by using one cell for the first readings.
Close the switch for a moment and measure the current through the resistor and the potential difference.
Note well: Only close the switch while you are taking the readings, otherwise the resistor may get hot and your readings will change.
Record your readings in the table below:

Number of cells	Potential difference, V (V)	Current, I (A)	$\frac{V}{I}$
1	1,5	0,12	12,5
2	3,0	0,2	12,5
3	4,5	0,3	12
4	6	0,4	12,5

Add a second cell in series with the first one. Record the values of potential difference and current.

Add a third cell in series to the first two. Record the values of potential difference and current.

Add a fourth cell in series with the first three. Record the values of potential difference and current.

All the last three set of readings should also be recorded in the table above.

Predict the next set of points. Justify your choice of answer:

- *The potential difference will be 6 and the ammeter will be 0,5 because the ratio $\frac{V}{I}$ will give us 12.(EGB)*
- *6 Volts and 0,5 amperes, because the potential difference increases as the current increases.(EGC)*

- $V = 6,25 \text{ V}$, $I = 0,5 \text{ A}$, $\frac{V}{I} = 12,5 \Omega$. Since $\frac{V}{I}$ is constant, its equal to 12,5. $I = 0,5$
because the common difference of $I = 0,1$ therefore when determining V , you will multiply $\frac{V}{I}$ with current which will be $V = 6,25$. (EGD)

Identify and give a reason for your choice of the:

4) Independent variable:

- Potential difference, because it always change. (EGA)
- Potential difference because it makes the current to change and is directly proportional. (EGB)
- Potential difference. Because the independent variable is not influenced by other variables meaning it does not depend on others. (EGC)
- Potential difference because it doesn't depend on anything for it to change. (EGD)

5) Dependent variable:

- Current, because it is influence by independent variable as it change. (EGA)
- Current because it depends on the potential difference. (EGB)
- Current. Because it is influenced by the potential difference or any independent variable to change. (EGC)
- Current because it depends on potential difference for it to change. (EGD)

6) Control variable was identified but one group did not provide a correct variable.

Explain in each case what happens to the:

4) Potential difference as the number of cells are added in series:

- As adding the number of cells, the potential difference also increase. (EGA)
- The potential difference increases as the number of cells are increased. (EGB)
- As the number of cells are added in series the potential difference increases. (EGC)
- Potential difference also increases. (EGD)

5) Current when the number of cells increase from one to four:

- It ways increase when the number of cells are added. (EGA)
- The current also increases. (EGB)
- As the current increases when the number of cells increases from one to four that means current increases. (EGC)
- Current also increases. (EGD)

6) Ratio $\frac{V}{I}$ when the number of cells increase from one to four:

- The ratio of $\frac{V}{I}$ are the same. It's only that difference from others. EGA

- When the number of cells increases the amount of the ratio $\frac{V}{I}$ remain constant. (EGB)
- The ratio $\frac{V}{I}$ when the number of cells increase from one to four remains constant. (EGC)
- $\frac{V}{I}$ also increases. (EGD)

State the relationship between potential difference across the resistor and current in the resistor (by referring to the record of readings):

- The relationship is directly proportional because they are increasing. (EGA)
- Potential difference across the resistor is directly proportional to the current in the resistor. (EGB)
- The relationship between potential difference and current is directly proportional. (EGC)
- It is directly proportional. (EGD)

Plot the set of points and draw the line of 'best of fit' for current versus potential difference, on the Cartesian grid below.

The graphs are straight lines for all the groups.

Describe the shape of the graph:

- Straight line. (EGA)
- The shape of the graph is a straight line. (EGB)
- It is a straight line. (EGC)
- It's a straight line. (EGD)

Assume that the independent and dependent variables are swapped, but readings are still the same.

Use the Cartesian grid below to sketch the graph of potential difference versus current.

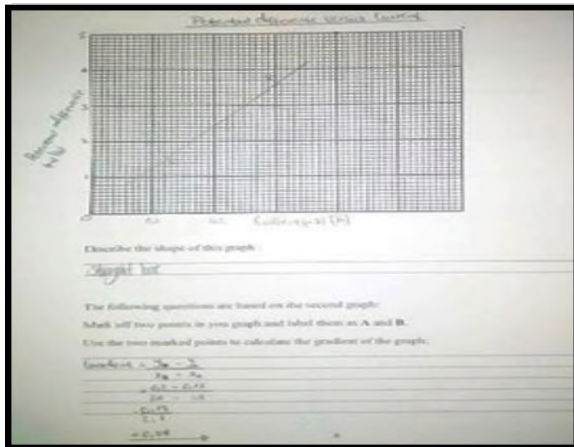
The graphs are straight lines for all the groups.

Describe the shape of this graph:

- Straight line. (EGA)
- The graph is a straight line. (EGB)
- It is a straight line. (EGC)
- It's a straight line. (EGD)

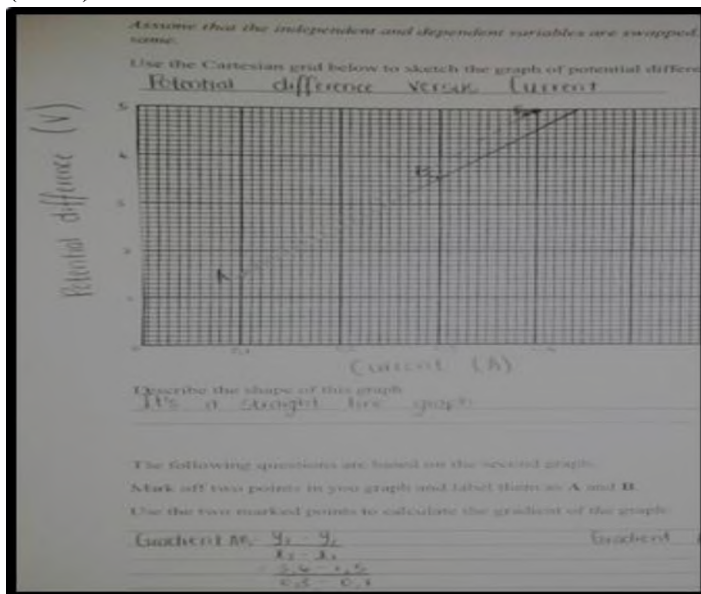
The following questions are based on the second graph:

Mark off two points in you graph and label them as **A** and **B**.



Use the two marked points to calculate the gradient of the graph:

- $Gradient = \frac{y_2 - y_1}{x_2 - x_1} = \frac{0,3 - 0,12}{3,6 - 1,5} = \frac{0,18}{2,1} = 0,09$ (EGA)
- $Gradient = \frac{y_2 - y_1}{x_2 - x_1} = \frac{2,5 - 3,6}{0,3 - 0,12} = \frac{5,1}{0,42} = 2,14$ (EGB)
- $Gradient = \frac{y_2 - y_1}{x_2 - x_1} = \frac{2,5 - 1,5}{0,2 - 0,12} = 12,5$ (EGC)
- $Gradient = \frac{y_2 - y_1}{x_2 - x_1} = \frac{3,6 - 1,5}{0,3 - 0,1} = 10,5$ OR $Gradient = \frac{y_2 - y_1}{x_2 - x_1} = \frac{5 - 1,5}{0,4 - 0,12} = 12,5$ (EGD)



Compare then discuss about the gradient results and the last column on the record values for potential difference and current:

- *Potential difference and current it was increasing and the gradient decrease. (EGA)*

- *When we calculate the amount of potential difference we got 12,6 V and when we calculate the amount of current we got 0,694 that tells us that it is ohmic. (EGB)*
- *The results of gradient and last column for potential difference and current are constant.(EGC)*
- *The first gradient doesn't satisfy the theory that says the gradient must be equal to the resistance. The second gradient satisfies it. The results from $\frac{V}{I}$ revolves around the second gradient. (EGD)*

What do we call the ratio $\frac{V}{I}$?

- *$\frac{\text{potential difference}}{\text{current}}$. (EGA)*
- *This is resistor where $I \propto V$. (EGB)*
- *Potential difference over current. (EGC)*
- *Resistance. (EGD)*

What unit is derived from the ratio $\frac{V}{I}$:

- *Ohm's. (EGA)*
- *Resistor is measured in Ohms. (EGB)*
- *Ohms (Ω) (same response for two groups). (EGC & EGD)*

Conclusion: State the relationship between potential difference and current, include the quantity represented by the ratio $\frac{V}{I}$

- *The relationship is inversely proportional since the potential difference divided by current. (EGA)*
- *The potential difference is directly proportional to the current as the one increases the other one also increases. (EGB)*
- *The potential difference is directly proportional to current at constant temperature (EGC).*
- *The relationship between potential difference and current is directly proportional. Resistance is inversely proportional to current and directly proportional to potential difference. (EGD)*

Comment on the findings from the 'straw electricity' analogy and this experiment, with reference to Ohm's law:

Compare then discuss about the gradient results and the last column on the record values for potential difference and current:
When we calculate the amount of potential difference we got 136V and when we calculate the amount of current we got 0.69A that tells us that it is ohmic.

What do we call the ratio $\frac{V}{I}$? This is the resistance where $I \propto V$

What unit is derived from the ratio $\frac{V}{I}$:
Resistor which is measured in ohms

Conclusion: State the relationship between potential difference and current, include the quantity represented by the ratio $\frac{V}{I}$:
The potential difference is directly proportional to the current as the voltmeter measures the better one also increases

Comment on the findings from the 'straw electricity' analogy and this experiment, with reference to Ohm's law:
The analogy showed non electrical connections and it was not real but it made us to sense what is going on in the Ohm's law. The experiment was connected electrically and we were able to see that the connection was good or bad. The analogy made us to know what is going to happen based on the electric circuit and how to set up the apparatus in the circuit. The analogy based on the straws didn't have the gradient value we have it in the graph.

Compare then discuss about the gradient results and the last column on the record values for potential difference and current:
Gradient AB_1 doesn't satisfy the theory that says the gradient must be equal to the resistance. Gradient AB_2 satisfies it. The results from $\frac{V}{I}$ results around gradient AB_2 .

What do we call the ratio $\frac{V}{I}$? Resistance

What unit is derived from the ratio $\frac{V}{I}$:
Ohms (Ω)

Conclusion: State the relationship between potential difference and current, include the quantity represented by the ratio $\frac{V}{I}$:
The relationship between potential difference and current is directly proportional. Resistance is directly proportional to current and directly proportional to potential difference.

Comment on the findings from the 'straw electricity' analogy and this experiment, with reference to Ohm's law:
On straw electricity the conclusion was that potential difference is directly proportional to current if resistance is kept constant. On the experiment, the conclusion is that potential difference is directly proportional to current if temperature is kept constant. Both the analogy and the experiment obeyed Ohm's law because it says that resistance is directly proportional to potential difference and inversely proportional to current.

APPENDIX O: Summative test

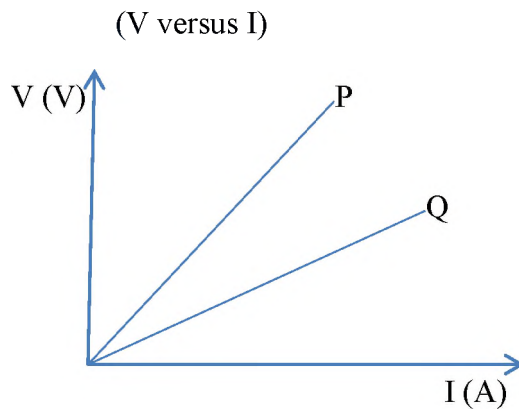
Time: 1 hour

Answer ALL the questions

Marks: 44

QUESTION 1: MULTIPLE-CHOICE QUESTION

Four options are suggested as possible answers to each question. Choose the letter that represents the best answer and write it next to the question number (1.1 – 1.2) e.g. 1.2 D. All the multi-choice questions are based on the diagram below.



1.1 Which resistor has a higher resistance?

1. P
2. Q

An explanation for the choice of a resistor with higher resistance is that...

- A. has a high current
- B. has a high potential difference
- C. P is longer than Q
- D. The gradient of P is steeper than that of Q

(2)

1.2 Analysing the graph, one can observe that the following set of terms has the same scientific meaning:

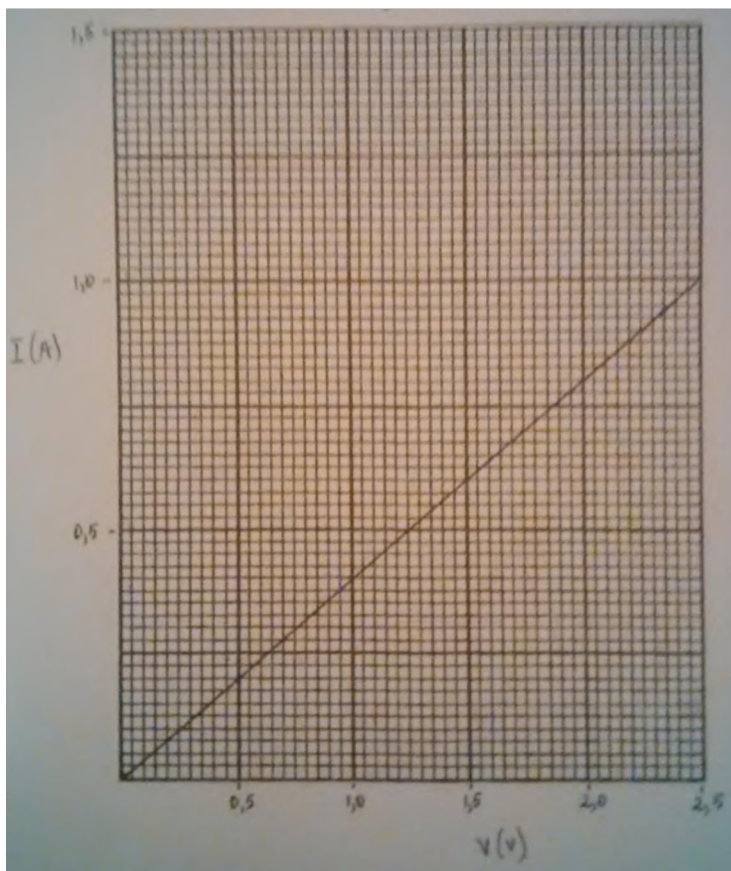
- A. Thickness of a conductor, gradient and temperature.
- B. Gradient, resistance and temperature.
- C. Current; potential difference and resistance.
- D. Potential difference, voltage and gradient.

Explain the choice of your answer.

(2)

QUESTION 2

A group of grade 11 learners were eager to do an experiment in order to determine the relationship between current and potential difference. They connected a battery (where after a continuous addition of a cell at a time to the existing one, led to set of readings taken), an ammeter, a voltmeter and a resistor. The results obtained were used to draw the graph shown below. Study the graph and answer the questions that follow:

Graph of current versus potential difference

- 2.1 Which one is the independent variable? (1)
- 2.2 Formulate an investigative question for this experiment. (2)
- 2.3 From the graph, write down the mathematical relationship between current and potential difference. (1)
- 2.4 Explain your answer to question 2.3 above. (2)

2.5 Name and state the law which is verified here. (3)

2.6 Calculate the gradient of the graph. Then use the calculated gradient to find the resistance. (4)

[13]

QUESTION 3

Grade 11 learners were given the following apparatus to do an experiment to determine the relationship between electric current and potential difference, where current changes after a set of readings was taken. That means an adjustable ammeter was used.

- Two cells (connected in series)
- A switch (open)
- Connecting wires
- An ammeter
- A voltmeter
- A resistor
- A rheostat

3.1 Draw a circuit diagram that shows a connection of all apparatus, with a voltmeter connected across a resistor. (4)

When the switch is closed, the readings from an ammeter and a voltmeter were noted as shown in the table below:

Ammeter reading (A)	0,3	0,9	1,2	1,5	1,8
Voltmeter reading (V)	0,5	1,9	2	2,5	3

3.2 Predict the next set of points. Explain how you arrived at your answer. (4)

3.3 Which variable must be controlled? (1)

3.4 Discuss the effect on experiment results if the switch is closed for a long time when taking readings on the ammeter and voltmeter. (3)

3.5 Suggest TWO other factors that should be considered to ensure a fair test when choosing which resistor to use. (2)

3.6 Use the graph paper provided to plot all sets of points, on the potential difference versus current axis. (4)

3.7 Join the plotted points and draw the 'line of best fit'. (2)

3.8 Use the graph to answer the following questions:

3.8.1 Is the resistor Ohmic or non-Ohmic? (1)

3.8.2 Explain your choice to the answer for question 3.8.1 (above). (2)

3.8.3 Calculate the resistance. (4)

[27]

APPENDIX OO: Summative test Memorandum

QUESTION 1

1.1 B. ✓ (2)

1.2 B. The same physical quantity (gradient, resistance and temperature) relative to the study of Ohms' law but it has different representation. ✓✓ (2)

[4]

QUESTION 2

2.1 Potential difference. ✓ (1)

2.2 What effect does potential difference has on current? ✓✓

OR What is the relationship between potential difference and current? ✓✓ (2)

2.3 $V \propto I$ ✓ (1)

2.4 As potential difference increases, current also increases. ✓✓ (2)

2.5 Ohm' law ✓. Potential difference across the conductor is directly proportional to the current when temperature is kept constant ✓✓. (3)

$$2.6 \ m = \frac{\Delta I}{\Delta V} \checkmark = \frac{0,2 - 0}{0,5 - 0} \checkmark$$

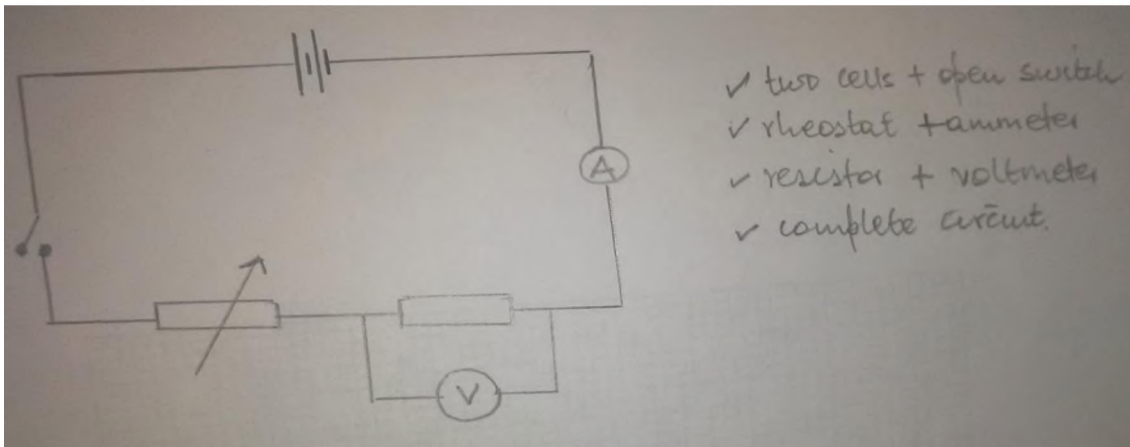
$$\frac{1}{R} = \frac{0,2}{0,5} \checkmark$$

$$\therefore R = \frac{0,5}{0,2} = 2,5\Omega \checkmark \text{ (accept any correct set of point)} \quad (4)$$

[13]

QUESTION 3

3.1



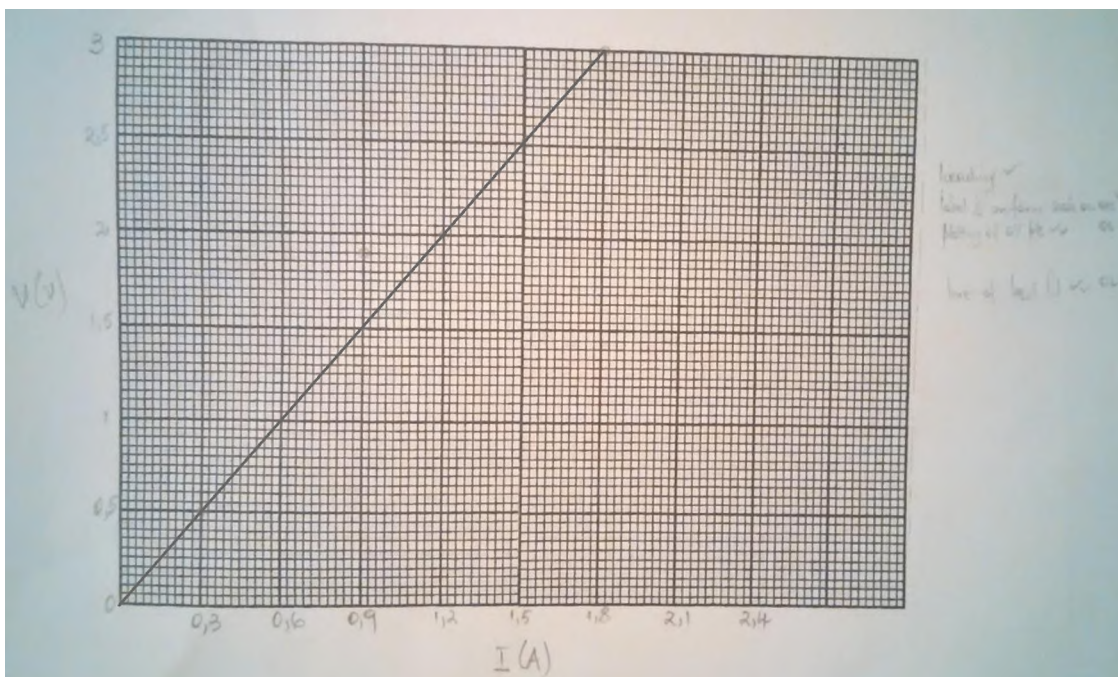
3.2 (2,1; 3,5) ✓✓. Current increases by 0,3 A ✓ and potential difference increases by 0,5 V ✓ (4)

3.3 Temperature. ✓ (1)

3.4 The resistor becomes hot ✓, meaning that its temperature increases ✓. Ohm' law will no longer be obeyed when temperature is not constant. ✓ (3)

3.5 The thickness ✓ and length ✓ of a resistor. (2)

3.6 and 3.7



3.8.1 Ohmic ✓ (1)

3.8.2 Straight line graph from the origin. $V \propto I$ ✓✓ (2)

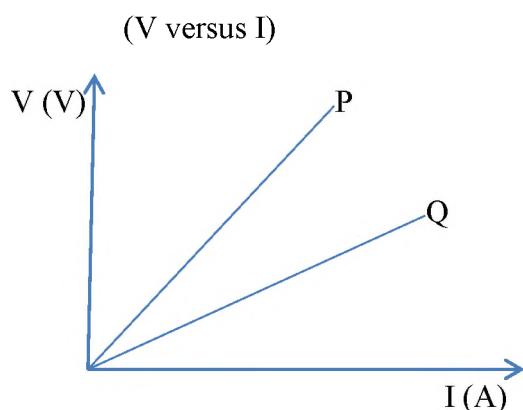
$$3.8.3 \quad m = \frac{\Delta V}{\Delta I} = \frac{0,5 - 0}{0,3 - 0} \quad \checkmark\checkmark = 1,67\Omega \quad \checkmark\checkmark$$

$$\text{Or} \quad = \frac{1,5 - 0,5}{0,9 - 0,3} \quad \checkmark\checkmark = 1,67\Omega \quad \checkmark\checkmark$$

$$\text{Or} \quad = \frac{3 - 2,5}{1,8 - 1,5} \quad \checkmark\checkmark = 1,67\Omega \quad \checkmark\checkmark \quad (4)$$

[27]

APPENDIX OOO: Data on summative test (DST)



1.3 Which resistor has a higher resistance?

3. P

4. Q

An explanation for the choice of a resistor with higher resistance is that...

E. has a high current

F. has a high potential difference

G. P is longer than Q

H. The gradient of P is steeper than that of Q

R1: D (12 responses)

1.4 Analysing the graph, one can observe that the following set of terms has the same scientific meaning:

E. Thickness of a conductor, gradient and temperature.

F. Gradient, resistance and temperature.

G. Current; potential difference and resistance.

H. Potential difference, voltage and gradient.

Explain the choice of your answer.

R1: A. The graph is a straight line graph. If the thickness of a conductor and temperature were not kept constant, the graph would have deviated at some point or it wouldn't be a straight line graph. Since it is a straight line graph, it means its gradient is constant throughout OR because the more the current increase the potential difference increases/the steeper of P is greater than of Q.

R2: B. Because the gradient of the graph is equal to its resistance if temperature is kept constant. (3 responses)

R3: C. They are directly proportional ($\therefore R = \frac{V}{I}$) OR you can use current vs potential difference to calculate the resistance OR the steeper the slope the higher the resistance.

R4: D. Because potential difference is a measure in volts and voltage is use to measure potential difference.

a. Which one is the independent variable?

R1: Voltage/potential difference (8 responses)

R2: Current (4 responses)

b. Formulate an investigative question for this experiment.

R1: What is the relationship between current and potential difference? (11 responses)

R2: What is the relationship between current and potential difference when temperature remains constant?

2.3 From the graph, write down the mathematical relationship between current and potential difference.

R1: $I \propto V$ (12 responses)

c. Explain your answer to question 2.3 above.

R1: Because they make up a graph of a straight line.

R2: When current is directly proportional to potential difference in Ohms' law it is always a straight line and temperature constant and it also verifies that Ohms' law is obeyed.

R3: It is because as potential difference increases the current also increases (4 responses).

R4: Because we want to calculate mathematics.

R5: It's because the current is in the dependent and potential difference is in the independent variable.

R6: Is because current is directly proportional to the potential difference in the graph (4 responses).

d. Name and state the law which is verified here.

All learners were able to name and state the law.

2.6 Calculate the gradient of the graph. Then use the calculated gradient to find the resistance.

$$m = \frac{I_2 - I_1}{V_2 - V_1} = \frac{0,6 - 0,4}{2,0 - 0,5} = \frac{0,2}{1,5}$$

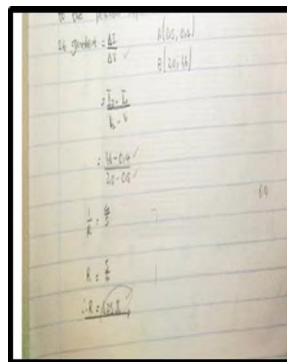
R1: $\therefore \frac{1}{R} = \frac{1,5}{0,2}$
 $\therefore R = 7,5\Omega$

R2: $Gradient = \frac{\Delta I}{\Delta V} = \frac{I_2 - I_1}{V_2 - V_1} = \frac{1,0 - 0,5}{2,5 - 1,25} = \frac{0,5}{1,25}$
 $\therefore \frac{1,25}{0,5} = 2,5$
 $\therefore R = 2,5\Omega$

(5 responses)

R3: $m = \frac{\Delta I}{\Delta V} = \frac{I_2 - I_1}{V_2 - V_1} = \frac{0,2 - 0}{1,5 - 0} = \frac{0,2}{1,5}$
 $\therefore \frac{1,5}{0,2} = 7,5$
 $\therefore R = 7,5\Omega$

R4: $\frac{\Delta I}{\Delta V} = \frac{I_2 - I_1}{V_2 - V_1} = \frac{1,0 - 0,5}{2,5 - 1,25} = \frac{0,5}{1,25} = \frac{1,25}{0,5}$
 $\therefore R = 2,5\Omega$



3.1 Draw a circuit diagram that shows a connection of all apparatus, with a voltmeter connected across a resistor.

Almost all learners managed to provide correct circuit diagrams.

3.2 Predict the next set of points. Explain how you arrived at your answer.

R1: In $I(A)$ it is 2,1 and in $V(V)$ it is 3,5 because in ammeter I added 0,3 and in voltmeter I added 0,5.

R2: The ammeter reading (A) it is increasing by 0,3 and the voltmeter reading(V) it is increasing by 0,5 (9 responses).

R3: Ammeter reading will be 2,7 A it increases by 0,0. Voltmeter reading will be 4 V it increases by 1 after increased by 0,5.

R4: In current the next set point is 2,1 because of the number on the table that are given in potential difference is 3,5 because of the set point.

3.3 Which variable must be controlled?

R1: Constant variable.

R2: Temperature (10 responses).

R3: Temperature or resistance.

3.4 Discuss the effect on experiment results if the switch is closed for a long time when taking readings on the ammeter and voltmeter.

Scientific reasoning using electricity concepts were used for the discussion.

3.5 Suggest TWO other factors that should be considered to ensure a fair test when choosing which resistor to use.

R1: Thickness and material.

R2: The length of the conductor and the thickness of the conductor (8 responses).

R3: Temperature and length/thickness of the conductor (2 responses).

R4: The watt (W) of a resistor and the resistance of a resistor (Ω).

3.6 Use the graph paper provided to plot all sets of points, on the potential difference versus current axis.

3.7 Join the plotted points and draw the 'line of best fit'.

Most of the learners were able to sketch the graph and come up with the line of best fit.

3.8 Use the graph to answer the following questions:

3.8.1 Is the resistor Ohmic or non-Ohmic?

R1: Ohmic (11 responses)

R2: Non-Ohmic.

3.8.2 Explain your choice to the answer for question 3.8.1 (above).

R1: Because the result of the graph is a straight line (4 responses).

R2: It is because it obeys Ohms' law and the graph is a straight line (3 responses).

R3: It obeys Ohms' law.

R4: It is non-Ohmic because it is a straight line graph, even if there some points are out of line.

R5: Because current is directly proportional to potential difference and they give out a straight line meaning Ohms' law is obeyed and the resistor is Ohmic.

R6: I chose Ohmic because most of the points are touched by the line of best fit and they result in a straight line (obey Ohmic law).

R7: Because it is a straight line graph and the point (0,9; 1,9) is not in the line of best fit because there was a change in temperature.

3.8 3 Calculate the resistance.

24 Gradient = $\frac{\Delta V}{\Delta I}$ A(0,5) / B(2,0,5)

$= \frac{2-0,5}{0,9-0,5}$

$= \frac{1,5}{0,4}$

$R = \frac{1,5}{0,4}$

$\therefore R = 0,43 \Omega$

393 $\Delta V = V_2 - V_1 = 0,5 - 0,3$

$\Delta I = I_2 - I_1 = 1,8 - 1,2$

$= \frac{0,2}{0,13}$

$R = 1,5 \Omega$

R1: Gradient = $\frac{\Delta V}{\Delta I} = \frac{V_2 - V_1}{I_2 - I_1} = \frac{1,9 - 0,5}{0,9 - 0,5} = \frac{1,4}{0,6}$

$\therefore \frac{0,6}{1,4} = 0,43$

$R = 0,43 \Omega$

R2: $\frac{\Delta V}{\Delta I} = \frac{V_2 - V_1}{I_2 - I_1} = \frac{3 - 0,5}{1,8 - 0,3} = 1,67$

$\therefore R = 1,67 \Omega$

$m = \frac{\Delta V}{\Delta I} = \frac{V_2 - V_1}{I_2 - I_1} = \frac{0,3 - 0}{0,5 - 0} = \frac{0,3}{0,5}$

R3: $\therefore \frac{1}{R} = \frac{0,5}{0,3}$

$\therefore R = 1,67 \Omega$

APPENDIX P: Journal entry template

JOURNAL ENTRY CONTENTS

Date:

What I have learned today:

.....

Some exciting learning moments in class today:

.....

Area that needs more clarity:

.....

Questions I have about today's lesson:

.....

Comments:

.....

APPENDIX Q: Interview schedule

1. (a) What do you think made it easy for you to answer to some of the diagnostic test questions?
(b) Why was it difficult for you to answer to some of the diagnostic test questions?
2. What could have led to a difference in your performance between the diagnostic test and a summative test?
3. (a) What do you think are the benefits of using an analogy in learning of Ohms' law?
(b) What do you think are the challenges of using an analogy in learning of Ohms' law?
4. (a) What do you think are the benefits of using a conventional practical activity?
(b) What do you think are the challenges of using a conventional practical activity?

APPENDIX S: Lesson observation transcript 1

Learners predicted, observed and provided reasons as air was blown through the drinking straw which was inserted into glass with water.

L3: Ok.

L4: Volume *ine-space andithi*? If *uthi*... 'volume of the straw is reduced ...' (Volume has a space, right. If you say, volume of the straw is reduced ...)

L3: *Andi-understandi* [Shaking her head]. (I do not understand)

L4: *Awu-anderstandi*? Hmm ... If *i-peg i-squeeza i-straw*, the volume of the straw will be reduced ... the volume ... *i-volume ine-space andithi*? So, *i-air* ... Yhooo! ((You do not understand? Hmm ... If the peg squeezes the straw, the volume will be reduced. Volume has a space, is that so? So, the air ... yhoool!)).

After blowing air through the straw inserted in water:

L1 and L2: *Hayi angeke! Aa*. How come? [Amazed by the outcome](No).

L9: It is true.[Referring to their prediction].

T: Does air still go through a peg-clipped straw?

L1; L2; L8; L9 and L10: Yes.

T: Explain.

L10: Because the particles are free to move.

L9: *Kungoba umoya awuphumi wonke; qha iya ... ke hoba ...* (It is because not all air comes out, but ... because).[Started in IsiXhosa then changed to Sesotho].

L11: *E o dumelletse ho tswa* (It allowed it to pass through).

L9: *Ja* (Yes).

T: Squash the straw so that it is almost flat. Does the air still go through when blowing?

L3; L4 and L7: Yes

T: Verify and explain your answer by placing the other side of the straw in water.

L4: *Sithi*, 'yes it does'. Then... *ha hothwe 'explain' ho lebeletswe reason*. (We say, 'yes it does'. Then... when it is said 'explain', a reason is expected)

L7: Why?

L1: *Sawuthini?* (What to say?) Ok. When you blow, ok! When we were blowing, neh! The air we were blowing ... ok ... the air that I was blowing was ... *kanene xa into inintsi sithini?* (How do we put it, if something is more?)

L2: More ... was more.

[L3 and L4 had individually taken their straws and clothes pegs]

L4: *I-air* that is blown ... *eh* ... (The air that is blown)

L3: The amount of air between your mouth and a peg is greater than the amount of air [Hand gesturing].

L2: But the peg reduced ... reduced ... *u-reduced kukuhlisa*, reduced air then transferred to ...

[Blowing air through a straw clipped with a peg, whilst the other straw side is inserted in water]

L4: *Ha ntse ke nyolla pressure le tsona di ba ngata*. (When increasing the pressure they also increase [Smiling whilst taking the straw out of water]).

L3: Directly proportional [Sketching the graph].

L4: It is straight line. *Izanyuka kanje* (It will go up like this).

L3: It is a straight line ... a straight line graph.

L4: Yes [Nodding her head]. *Zibancinci ziye zibankulu, di ba kgolo ha moya o le mongata. Xa kunyuka i-pressure nazo zibankulu* (They are small then become bigger. They become bigger as a result of more air [later translated some Sesotho parts to IsiXhosa]).

L3: *Sizokwenza i-straight line kwakhona* (We are going to make a straight line once more).

L4: *Ja* (Yes).

[L3 sketching a second graph].

L1: *Ziya-increasa* (They are increasing)

L2: At first it is low. *Iya-increasa, isuka ku-low iya ku-high* (It is increasing from low to high).

L1: *Uza kwenza i-line. Siza kwenza kanje* (You will make a line. We will do it like this [showing her]).

L2: *Ii-points zakho zawunyuka until when?* (How far are your points going to be?)

L1: Points? *Wenza ntoni?* (What are you doing?)

L4: I-shape of graph?

L3: Curve.

L4: *Sibuzwa kwezi andithi. So, ngeke uthi 'curved' kodwa sine-straight lines* (We are asked from those, so we cannot say 'curved' whereas we have a straight lines).

L2: *Ziqale zabancinci i-bubbles zaya zi-increasa* (The bubbles started small then increased).

L1 So

L2: *Kanje* (Like this [Showing her]).

L1: *Andazi kaloku* (I do not know).

L2: *Isafana* (It is similar [Takes the worksheet and puts a ruler on the second grid]).

L1: *Jonga, andithi yi-size of bubbles ngapha xa u-blowe kancinci and xa bendi-blowe kakhulu nama-size ama-bubbles amakhulu. Okutshoyo izobanje* [pointing with a finger].
Ayiz 'utshintsha. Qha ngalena kuthethwa nge-amount (Look, we have size of bubbles this side. When there is little blow, if there is high blow even the bubble sizes are big. Meaning that it will be like this. But, that side they talk about the amount).

L1: *Ii-similarities zikhona* (There are similarities).

L1: *Sithi* (We say), on the first graph ...

L2: We want the amount.

L1: On the first graph we wanted the amount. The amount to *ntoni*? (The amount to what?).

[L2 looks at a previous page].

L1 and L2: Amount of bubbles.

L1: On the first graph we wanted the amount of bubbles and on the second graph we wanted *ilanto*(this) ... size of bubbles.

L2 and L1: Relationship.

APPENDIX T: Lesson observation transcript 2

L1: *E qadile ho 25.*(It started at 25 [Reading from the ammeter]).

[The teacher explains that if the signal is beyond zero, it means the connection is wrong. The teacher swaps the connecting wires again].

[Learners had to go to their groups and complete the worksheet. One group requested to verify the last two readings].

[Learners were working in pairs to complete the worksheet]

L1: *I-current iya-increasa from 1 to 4, uyabo?* (Current increases from 1 to 4, do you see?)

L2: Hmmm

L3: *Ha re tjho hore* (Let us say)...current ... current increases and at a certain stage there is a little ... change. *Sheba mona* (Look here - Looking at the table of results) ... *e theoha mona qetellong* ... (It decreases at the end).. the current increases with the number of cells ... after ... when we have four cells then the current drops. Hm! [Shaking his head]. *Ha re zame tsela yah o e beha* (Let us try to put it right) ... current increases with the number of cells up to a certain point where it decreases.

L4: ... when it decreases

L6: *x-axis zi-independent variables andithi? Then kwi y-axis i-dependent variables* (x-axis are independent variables and y-axis are dependent variables. Is that so?)

L5: It is current.

L6: It is potential difference then current [Pointing at the grid]. *I-indepdent yi-potential difference then ke ngoku ... i-dependent variable ... yi-current. Uyabo*, its current versus potential difference. Meaning, *kukhona i-current kwi y-axis* then its potential difference (The independent is potential difference then the dependent is current. You see, it is current versus potential difference. Meaning, there is current in y-axis then is potential difference).

L7: Hmm ... *I-scale sawusebenzisa esiphi?* (Which scale are we going to use?)

L5: Join the points.

L6: *Ubuyise kaloku umgca* (Extend the line. [Pointing towards the origin and extending the line towards the origin]). *Iphi laa reason?* (Where is that reason?)

L5: *Nantsi ithi, 'directly proportional'* (Here, it says, directly proportional [Then she extends the graph to the origin]).

L6: *I-voltage ne current* (Voltage and current)

L7: *Yinto eyi-ONE leyo. Voltage beyi-increasa* (That is ONE thing. Voltage is increasing)

L6: *Ne-current i-increasa.* (Also current increases).

L7: *Uyigqibile ...okanye ...kutheni ingenz'i-sense?* (You said a mouthful ... or ... why it does not make sense?)

L6: *Yenz 'isense.* (It makes sense).

L1: *Se se s-six.* (The sixth one).

Learners were observed helping one another especially to sketch graphs using a graph paper. They assisted each other to understand the question when the one give help seemed not to make sense of what is expected.

APPENDIX U: Group interview transcript

Interviewees were: Yolanda; Oyintando; Faith and Cozmo.

[Teacher (T) goes through introduction on the purpose and the scope for interviews]

Faith: We did in in Grade 10.

T: Remember the first test was diagnostic test and the last one was summative test. What has led to the difference in the marks you got?

Oyintando: *Besititshiwe* (We were taught).

Faith: *I*-diagnostic test we did not have much information about them. *Besi-depende kwi*-previous work (we depended on previous work) then *masiphinda kwi*-summative (coming back to summative) test it was not that hard to answer some questions we were taught.

Advantages of incorporating an analogy were discussed the challenge of not having an opportunity to take reading was pointed. Then, application of Ohm's law to out of class situation was discussed.

T: Ok. It means now we have to be aware of dangers which are still applicable to our home set-up or out of class situation. So, our questions were just four and we attended all of them. Do you have any comments? Anything that you would like to share?

Cozmo: I think next time; we have to continue using analogies in other things to help us to understand better.

T: I also think that it would be easy for you when you think of something you can just make your own analogy so that it helps ... not that someone comes and impose it on you.

Remember, what we did in class where there was that part of the graph where Ohms' law was not obeyed. With the help of an analogy we were able to make sure that everyone understood.

Thank you. End.

APPENDIX V: Individual interview transcript 1

[Interview with Boithabiso]

[T goes through introduction on the purpose and the scope for interviews]

Boithabiso indicated that she did not know the answers so she left blank spaces on her diagnostic test script.

T: What do you think are the benefits of using an analogy in learning Ohms' law?

Boithabiso: Analogy is is easy to understand ... because you .. you the things that you do .. you see them .. you understand.

T: Ok. Ok. Remember we had an analogy then at a later stage we had actual practical experiment using eh..... using apparatus like voltmeter, ammeter, connecting wires and others. Then, what do you think are the benefits of using that experiment?

Boithabiso: Because [I was unable to capture what was said at the start. Towards the end, the voice was a bit audible] *Tsona ke mete.*(They are real).

T: They are more real than an analogy.

Boithabiso: An analogy [Finishes simultaneously with the teacher]. Yes miss.

Boithabiso indicated that the challenge of using a conventional practical activity was that she was unable to connect the apparatus and she was unable to record the readings from measuring instruments.

APPENDIX W: Individual interview transcript 2

[Interview with Zodiac]

T: That is why *mhlawumbi* (maybe) you were unable to get scores for them ... marks for them. Why was it difficult for you to answer some of them?

Zodiac: There was misunderstanding *ezinye iianswer ndizibhidanisile mem.* (There was misunderstandingI exchanged some of the answers).

T: You exchanged answers. Like, in which question? Just make an example, if you can.

Zodiac: Like *kwi-potential difference* and current. (Like with potential difference and current)

T: I have seen that. Instead of putting V over I.

Zodiac: Yes mem

T: Now, after that diagnostic test, there was teaching which took place. Then at a later stage we had *i*-summative test. When we compare the two, we found that *i*-scores or *i*-performance is not the same. What could have led to the difference *kwi*-performance *yakho*? (When we compare the two, we found that the scores or performance is not the same. What could have led to the difference in your performance).

Zodiac: *Ianalogy brought i-difference kakhulu ne-experiment. Zenze izinto zibe easy.* And the way *besifunda ngakhona.* (The analogy together with experiment brought a big difference. They made things easier. Also the way we were learning).

Zodiac: It makes things easy to understand and answer questions. Comparing one thing and another, mem (referring to an analogy).

T: Ok. It means it brings excitement to... to be hands-on *kwi*-practical activity than just learning what is in the textbook.

T: Can you think of challenges of practical activities?

Zodiac: You have to be careful because ... *kungaba ...zingatshokha* sometimes, *kufuneka ube-careful kakhulu.* (You have to be careful ... it can be ... they can choke sometimes, you must be careful). *Ne cells zicontaina i-acid.* So, you have to be very careful of those things.

(Also cells contain acid. So you have to be careful of those things). *And nendlela esizibamba ngayo zingafi.* (Even the way we handle them). Thank you. End.

APPENDIX X: Individual interview transcript 3

[Interview with Lizzy]

T: Some of the questions. But with some of the questions seemingly it was difficult ... why was it difficult to answer them?

Lizzy: Because, mem I think I was never taught to I was taught gradient [Shaking her head] *e ne e le problem*. (Gradient was a problem).

T: Gradient was a problem.

Lizzy: Yes. And to plot ... and coming with the scale, that's where I had a problem.

T: Oh. Your main problem was with the gradient.

Lizzy: Scale.

Lizzy: Some formulas. *Eh* (Yes), mem.

Lizzy indicated that analogy assist learners to understand as learning are based on things they see on daily basis. An analogy also gives them an overview of Ohms' law.

Lizzy identified an inability to work on their own when doing a conventional practical activity as a disadvantage.

T: As a result your performance in the summative test improved.

Lizzy: Yes mem.

Thank you. End