THE ROLE OF SYMBOLS IN LEARNERS' UNDERSTANDING OF DIRECT CURRENT RESISTIVE ELECTRICAL CIRCUITS IN RURAL AND PERI-URBAN SCHOOLS

by

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DISSERTATION

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DECLARATION

I declare that **THE ROLE OF SYMBOLS IN LEARNERS' UNDERSTANDING OF DIRECT CURRENT RESISTIVE ELECTRICAL CIRCUITS IN RURAL AND PERI-URBAN SCHOOLS (**dissertation) hereby submitted to the University of Limpopo, for the degree of Master of Science (MSc Physics) has not been previously been submitted by me for a degree at this or any other university; that it is my work in design and in execution, and that all material contained herein has been duly acknowledged.

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Mautjana, R. T. (Mr) Date

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CONFERENCES

Part of this work has been presented orally at the annual South African Institute of Physics Conferences with one paper peer reviewed.

1. Entitled: "Learners understanding of Ammeter and Voltmeter in a direct current schematic circuit", In Proceedings of SAIP2011, the 56th Annual Conference of the South African Institute of Physics, edited by I. Basson and A.E Botha (University of South Africa, Pretoria, 2011), pp. 602-607. ISBN: 978-1-86888-688-3. Available online at http:\\www.saip.org.za (Peer reviewed)
2. Entitled: "Do Learners understand the role of symbols in DC circuits?" The 53rd Annual Conference of the South African Institute of Physics, University of Limpopo, Turfloop Campus, 2008.

ABSTRACT

This study investigated the extent to which learners from rural and peri-urban areas understand what the symbols represent and their roles in simple direct current resistive electrical circuits. The emphasis was on simple direct current resistive electrical circuits that consist of batteries and bulbs.

The study was carried out with Grade 12 learners at high school level in the Limpopo Provincial Department of Education. It used both qualitative and quantitative data collection methods to investigate learners' understanding of direct current resistive electrical circuits at rural and peri-urban schools. It used questionnaires and structured interviews to collect the data so that the results could provide in-depth understanding and generalizability.

The results revealed that learners knew the symbols used in direct current resistive circuits, however, when the circuit was populated with a number of known symbols it became complex to such an extent that some learners struggled to identify the symbols. As it appeared, learners could not conceptualize the role played by a battery, conductor, ammeter and voltmeter in direct current resistive electrical circuit. In addition, the study also revealed that learners experience difficulties when translating a real circuit to a schematic circuit. This study suggests that deeper focus has to be directed towards developing leaners' understanding of the working and role played by each symbol in a schematic circuit. Learners were operating at far lower conceptual basis and thought of conductor as a hollow pipe like material. Results were also compared in terms of geographical location of the school, and findings indicate that the rural school was performing better than peri-urban school.

The results highlight a number of the frequently encountered alternative frameworks which learners come across when they are faced with schematic circuit diagrams. Most of the alternative frameworks found are well documented in literature (for example current consumption, difficulty with understanding electric concepts, difficulty with concept differentiation, and no firm alternative frameworks).

The participants in this study were not exposed to practical work. This suggests the results might be different with learners exposed to practical work. It is therefore recommended that future studies look at the understanding of the role played by individual electrical components with learners who had practical experience with real electrical circuits**.**

Majority of learners in this study could not communicate their scientific conclusions using English, as the English is their second language.

Key words: Role of Symbols, Schematic Circuits, Alternative Framework, Rural and Peri-urban

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CHAPTER I: INTRODUCTION AND BACKGROUND TO THE STUDY

Numerous studies have revealed conceptual difficulties learners face in trying to learn physics (McDermott and Redish 1999, Driver 1989). Generally, learners have difficulties in understanding physics concepts, using operational definitions of concepts and connecting physics concepts (e.g., unable to see physics as a collection of related concepts and formulae). Although research has been done elsewhere on conceptual understanding, for example on formulae and graphs (Caillot 1997), little research has focused on African learners, especially, the effects of geographical location on learners performance. The available literature on science learning concerning learners in Africa is according to Baker and Taylor (1995), descriptive and problematic. In addition, where real life examples exist, those based on the African context that allow for first hand experiences are inadequate. Hence, it is advisable not to assume that insights from European and Western research studies can be easily transferred to different geographical locations (Lewin 1993).

In South Africa, electricity is introduced to learners for the first time at primary school level. However, physics is formally taught from Grades 10 (14 -15 years) to 12 (17 – 18 years) as an elective subject. The electricity topic is introduced through simple experiments, and it is treated through algebra-based approach, with emphasis mainly on solving numerical problems. At a university level, the approach is usually a much formalized calculus-based.

In the past few years, especially 2005 and 2006, South Africa's national matric pass rates in Physical Science (HG papers) have been a cause for concern, were in most cases less than 40% of those who obtained matriculation exemptions (Taylor 2007). The electricity topic on average comprise about 40% of Grade 12's Physical Science paper 1 (Department of Education, RSA, Physical Science P1, 2006 and 2005). In addition, a survey by Khumalo and Naidoo (1996) on Physical Science educators in KwaZulu-Natal found electricity to be one of the most difficult sections for both educators and learners in Grade 12. Shipstone (1985) found similar results. Mahapatra (2006) also found that Indian high school educators with post graduate (masters) degrees in physics and long teaching experience held alternative frameworks on simple direct current resistive electrical circuits. Educators where found to have mental models like current consumption, constant current-source model and universal applicability of Ohm's law.

1.1 THE STATE OF PHYSICAL SCIENCE EDUCATION IN SOUTH AFRICA

There is a direct relationship between a country's wealth and its mathematics, science and technology capacity (DoE 2008). Currently, there are many people who live below the poverty line. South Africa has since made promotion of mathematics, science and technology an area of focus as a means of improving living standards in particular, given the high level of poverty in rural areas. This is more pertinent when considering that forty six percent of South African citizens live in rural areas (DoE 2008). In order to effectively realize the country's growth vision, learners have to be encouraged to pursue mathematics, science and technology related careers after matriculation. The country needs qualified individuals who will use their skills to enable it to compete internationally. Hence, a good quality education system is required to realize the envisaged dream.

The Department of Education initiated Curriculum 2005 (C2005) which was based on the principles of Outcomes – Based Education (OBE). The goal of the curriculum was to undo the legacy of apartheid. It was envisioned to introduce new skills, knowledge, values and attitudes for both learners and educators. Moreover, it was expected that it would make physics teaching more interactive and inquiry based (DoE 2001). However, South Africa still has some schools which do not have well-trained (and qualified) science educators and or teaching resources including laboratories. As a result, some learners are subjected to learn science and technology in talk and chalk. In some instances, educators rarely conduct practical demonstrations or experiments with the learners. These factors adversely affect the learning process of learners entering the mathematics, science and technology field at institutions of higher learning (James *et al.* 2008).

There is an inadequate number of learners matriculating with mathematics, science and technology from public schools (DoE 2008). In fact, the quality of general matric pass rate for school leavers in mathematics and science has not been improving since 2004. About 45% of the Grade 12 learners who wrote physical science in 2008 did not achieve the required pass level of 30% and above (DoE 2008a). This figure increased to about 63% in 2009 (DoBE 2010). Reports also show that only 21% and 30 % of learners achieved a pass level of 40 % and above in 2009 and 2010, respectively (DoBE 2011). In addition, Limpopo province achieved 16% and 24% for a pass level of 40% and above for 2009 and 2010, respectively. Studies on learners' performance at matric level have shown huge inequalities with a wide range of scores (DoE 2008). This has been identified as one of the constraints to achieving the required economic and technological growth of the country. This resulted in initiatives that seek to improve the quality of education in schools, especially in previously disadvantaged communities. In addition, there is an assertion that learners in rural areas perform poorly as compared to those in urban areas; however there is no indication that learners from peri-urban (towns) performs better than those in rural areas (van den Berg 2005). One of the many initiatives identified by Department of Education (now Department of Basic Education) in collaboration with the Joint Initiative on Priority Skills Acquisition (JIPSA) is the Dinaledi (Stars in Sotho) Schools Project.

1.1.1 Dinaledi Schools Project

The Dinaledi Schools Project is an intervention by the National Department of Education in collaboration with JIPSA to increase the number of learners studying mathematics and physical science in Grades 10 to 12, especially females and former disadvantaged learners. In addition, the project was intended to increase the pass rate and achievements in mathematics, science and technology in these grades. The Dinaledi Schools Project was established in June 2001, aiming to improve the quality of mathematics and science in public schools through education (JIPSA Annual Report 2008). As Nelson Mandela stated:

"*Education is the most powerful weapon which you can use to change the world"*.

As a result of this project, 102 (in 2002 to 2004) high schools were selected nationally to be centres of excellence for the development of mathematics, science and technology. The aim of the project was:

- to increase the number of learners studying mathematics, physical science and technology in Grades 10 to 12.
- to increase the number of learners with good results in these subjects – especially girls and former disadvantaged learners.
- to increase the pass rate and achievement in mathematics science and technology in these grades

- to develop capacity of the mathematics, science and technology educators.

The selected schools were already performing reasonably well in mathematics and physical science, and they were equipped with a range of resources such as scientific equipment, learning and teaching material, qualified teachers etc. (DoE 2004). In 2003, the number of learners passing mathematics and physical science increased by about 15% amongst African learners in public schools but was still not satisfactory (Surty 2008). Within the Dinaledi schools, a good progress made led to the number of schools being increased to 500 in 2008 (Surty 2008). Limpopo had a total of 51 from the country 500 schools of which 27% and 73% are from the peri-urban and the rural area, respectively. Despite this project, research shows that the mathematics, science and technology education system is still failing to deliver sufficient numbers of school leavers equipped with mathematics, science and technology skills to meet the country's needs.

1.2 STATEMENT OF THE PROBLEM

Most physics textbooks use a lot of schematic diagrams, particularly so, for basic electricity, where a high level of abstraction is involved, e.g. current, voltage, positive and negative charges etc., which cannot be directly observed (Ogunniyi 2005). In the electricity section, one is likely to find a diagram of an ammeter, voltmeter or a symbolic representation of these devices (i.e. circles with capital A or V inside them). Moreover, one would find symbolic drawings of wires (straight lines), resistors (zigzag lines/rectangular blocks) and a battery (two parallel lines, one shorter than the other), etc.

All of the diagrams and symbols above have different roles in physics teaching. Schematic circuit diagrams involving current and voltage differ noticeably from real circuits. They are controlled by rules which are not necessarily taught in schools (Caillot 1997 and Ogunniyi 2005). As a result, learners are not able to transfer concepts they have successfully learned in classroom physics to the context of everyday life to make it a living subject and fun to learn.

Electrical circuits whether complex or simple, can be presented in various ways. Drawings provide a quicker mental picture of the actual circuit. In drawing such circuits, special symbols are used to represent components of the circuit. Such circuits are called schematic circuit diagrams (Engelhardt and Beichner 2004). Engineers and Electricians draw circuit diagrams to help them design real circuits. The important thing to note on a circuit diagram is what each symbol represents.

Moreover, Braden (1994) believes that diagrams enable learners to understand concepts associated with objects which are too small, too big or too complex to be readily visible. Reid (1984) refers to the benefits derived from learning diagrams as 'the picture superiority effect'. In addition, Crowford and Cullin (2004) reported that relationships between objects are more easily visualized from illustrations than from text only. This suggests that information is better understood when presented in both visual and verbal formats. Although diagrams help learners in understanding new concepts, research indicates that some learners have difficulties with understanding the diagrams. Caillot (1997) showed that:

"The figures themselves bring geometric information which competes with Physics information".

Caillot (1997) also reported that when learners were given circuit diagrams they opted for closeness of two components or their parallelism. It was then concluded that learners did not have the meaning of what a diagram was and suggested that educators should teach the role and the meaning of diagrams used in Physics.

Learners' difficulty related to diagrams and symbols are best cited below:

> *"Physicists use schematics diagrams to represent circuit elements and examine their behaviour. Learners' recognition of what these diagrams represent is an important aspect of their understanding of circuits*" (Engelhardt and Beichner 2004: p. 98).

This study as its primary focus investigates the role of symbols in learners' understanding of direct current resistive electrical circuits in rural and peri-urban schools. The study also investigates the extent to which geographical location had on knowledge of symbols and their role in direct current resistive electrical circuits. It explores learners' ideas about the symbols in simple direct current resistive electrical circuits that consist of batteries and bulbs. The study focuses on Grade 12 learners because they have been previously introduced to electricity topic in their lower grades of schooling, and they were about to matriculate and enter institutions of higher learning where their prior-knowledge of basic concepts is crucial in mastering electricity.

Literature review often reveals learners' incorrect notions about how the world operates (Hendricks 2002). This is particularly true for electricity concepts. According to Ogunniyi (1999), Osborne and Freeman (1989) and McClelland (1984), a number of challenges and conceptual difficulties which learners experience in learning electric circuits, are due to the learners' 'alternative frameworks'. The term 'alternative frameworks' will be used to refer to learners ideas which contradicts the scientific accepted ideas (Netshisaulu 1996). These 'alternative frameworks' are often believed and used to explain natural phenomena incorrectly. It is therefore, important that learners overcome these alternative frameworks to have a clear understanding of the world. Learners' views on electrical concepts are essential, if one is to instill culture of scientific understanding in this area of study. This will form a secondary focus area of this study.

1.3 THE PURPOSE AND OBJECTIVES OF THE STUDY

The main purpose of this study was to investigate the extent to which learners per geographical school location understand what the electrical symbols represent and what the role of symbols is in simple direct current resistive electrical circuits.

The objectives of the study are as follows:

- to assess Grade 12 learners' knowledge and understanding of symbols representation in Direct Current (DC) Resistive electrical Circuits.
- document alternative frameworks that learners hold in electrical circuits
- to determine the effects of geographical location on knowledge of symbols and their roles.

1.4 SIGNIFICANCE OF THE STUDY

This study has implications on performance of physical science in Direct Current Resistive electrical Circuits of learners from various backgrounds and contexts (rural and peri-urban) within which teaching and learning take place. It would highlight the overlooked challenges which learners encounter when they are faced with schematic circuit diagrams. According to Caillot (1997), construction of circuit diagrams is governed by a set of rules that are not taught in schools. Learners are expected to learn to read, draw and understand diagrams on their own. The study therefore would enhance learners' basic understanding of the working of electrical circuit. It will also contribute to the improvement of Grade 12's physical science pass rates in both rural and peri-urban areas. In addition, the study will guide future research projects in the field of electricity.

1.5 RESEARCH QUESTIONS

The study sought to answer the following specific research questions:

(1) What do learners from rural and peri-urban schools know about symbols used in direct current resistive electrical circuits?
(2) What do learners from rural and peri-urban schools understand about the role of symbols used in the direct current resistive electrical circuits?
(3) How does adding or changing circuit component affect the circuit?
(4) What alternative frameworks do learners in rural and peri-urban hold in electrical circuits?

1.6 LOCATION OF RESEARCH

The research was carried out at two public high schools in the Limpopo Provincial Department of Education at the Mankweng Circuit of the Capricorn District. Limpopo has a large rural population of about 87%. Mankweng has peri-urban - rural split of 28% and 72%, respectively (http://en.m.wikipedia.org/wiki/polokwane_local_municipality).

1.7 STUDY LIMITATIONS

The study focused only on the Grade 12 physical science learners. The sample was derived from the two public high schools one from the rural and the other from the peri-urban area within the proximity of the researchers learning institution. The focus was on understanding symbols in circuit diagrams and the alternative frameworks thereof. Data were collected on a once off basis rather than longitudinally and identified challenges were not addressed.

1.8 DEFINITION OF TERMS

The following terms are defined to give the reader a better understanding of the study as they might be different from everyday use.

- **Alternative frameworks** refer to learners' ideas which contradict the accepted scientific ideas (Netshisaulu 1996).
- **Electricity** Some reports such as (Beaty 1999) refers to electricity as the substance that flows along the inside of a wire, however, in this study it refers to the topic or subject or section of the Physics curricula (Psillos 1998).
- **Learning difficulty** refers to issues related to skills, for example, where learners are unable to interpret experimental data, and/or are unable to manipulate circuit diagrams and/or laboratory equipment and/or numbers (Netshisaulu 1996).
- **Schematic circuit diagram** is defined as a circuit diagram where symbols are used to represents components of the circuit (Engelhardt and Beichner 2004, Caillot 1997).
- **Scientific concept** is defined as the scientific idea as perceived by the scientific community (Bryan and Stuessy 2006).
- **Peri-urban** refers to the underdeveloped urban living area or a township.
- **Rural area** is Traditional Authority (TA) areas, primarily 'community owned' land in the former 'homelands' and commercial farms in former 'white' areas of South Africa (census 2001 as cited in DoE (2005))

1.9 ASSUMPTIONS

Ideal schematic circuits were used for the purpose of probing learners understanding. However, in a real laboratory environment ideal electrical circuits are not possible. The results of ideal schematic circuits are well-ordered and follow the equations from the textbooks. For example potential drop across identical light bulbs in series should be the same. Whereas, with real equipment the results will be slightly different due to internal resistance of the components (including the wires) and also normal light bulbs do not follow Ohm's law as their temperature increases. Suppose one were given Circuit 12 as in Appendix A, where one has a 6V battery connected to two identical light bulbs in series together with 2 ammeters and 2 voltmeters across the bulbs. In an ideal situation the 2 voltmeters would each read 3V while in a real laboratory environment voltmeters might read 2.5 volts and 2.3 volts, respectively. Some learners may not recognize that the two results are similar and might had difficulties in realizing that the sum of the 2 voltmeters should equal to the total potential difference of the battery.

The study also assumed that the respondents would have had adequate knowledge of circuit diagrams as they have encountered them before in their lower grades. Learners would be able to read and write in English language, to be able to understand the questions and articulate the answers to the questionnaire.

1.10 STRUCTURE OF THE DISSERTATION

The dissertation comprises of five chapters as follows:

CHAPTER I

The chapter introduces the topic of direct current resistive electrical circuits and contains the significance, purpose and goal of the study.

CHAPTER II

The chapter provides the previous work on direct current resistive electrical circuits and identifies related gaps.

CHAPTER III

The chapter presents an overview of the methods used to collect data. It also provides a brief summary of the advantages and disadvantages of the said methods. The rational for the chosen data collection method is discussed. A description of the study process (sample and questionnaire developments) is provided. Finally, data analysis methods are discussed.

CHAPTER IV

The chapter provides the results of the study and deliberates on the interpretation of the findings. It also presents a summary of what emanated from the study, i.e., whether all research questions are answered or not.

CHAPTER V

This chapter presents the conclusion made on the basis of the study findings and makes recommendations for further research.

CHAPTER II: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter outlines some previous studies which the researcher considered to be relevant to this investigation (i.e., those which report the ideas learners have about electrical concepts and their role in understanding simple direct current resistive electrical circuits). Factors (including geographical location) which were found to have an effect on learners understanding were extracted in relation to this study.

Electricity is a common science topic at high school and tertiary levels. Currently, much of people's lives are centred on electrical applications. Electrical circuits can be found everywhere, (i.e., in our cell phones, digital watches, calculators, televisions, computers, etc.) Unfortunately understanding electricity is challenging and difficult to both learners and educators at high school level (Jaakkola and Nurmi 2004). This could be attributed to its abstractness because current, voltage and energy cannot be directly observed. What is observed is not electrons or current but an indirect occurrence by either the brightness of a bulb or a reading of a meter. An ammeter reading indicates the intensity of the current and a voltmeter reading indicates voltage/potential difference between two points.

Electricity forms an integral part of the examination at the end of high school education (matric level). However, numerous studies revealed several difficulties that learners encounter while studying electricity (Frederiksen *et al.* 2000). Some of the documented difficulties are: inability to relate to theoretical models of electricity to real circuits, incomplete understanding of basic concepts, inability to reason about the behaviour of electric circuits, problems with conceptual differentiation, linking different models, developing systemic reasoning, identifying series and parallel connections, current consumption and a battery is a constant source of current, etc. (Jaakkola and Nurmi 2004, Engelhardt and Beichner 2004, Frederiksen *et al*. 2000).

There are studies which investigated how learners develop their understanding of related concepts whilst learning electricity at school level (Sacate 2005). These studies reaffirm the long-held view that learners experience difficulties in understanding electrical concepts due to alternative frameworks that they bring into the classroom (Sacate 2005). Every learner brings to class a system of beliefs about the physical process. These systems of beliefs are acquired through interactions with the environment and from personal experiences. The pre-knowledge and understanding of concepts that learners bring to classroom mostly impacts negatively on their learning as some of these alternatives frameworks have conflicting positions to established theories in the discipline. Literature indicates that interpretations arise from interplay of existing understandings (Bryan and Stuessy 2006).

It has been established in the literature that difficulties in recognizing and interpreting information may be due to lack of knowledge about the topic. It is, therefore, important for educators to assess their learners' prior knowledge and to establish which alternative frameworks they are operating with to enable proper planning and structuring of lessons.

According to Carstensen and Bernhard (2007), one of the possible reason learners are unable to differentiate conceptually between concepts such as current, potential difference, power and energy is that they are interdependent. The confusion is said to arise as a result of not relating them properly to each other, for example: no current implies no voltage, i.e. voltage is seen as a property of a current, battery supply a constant current and current is consumed. The researchers indicated that learners see concepts as isolated items and not as being inter-related. They pointed out that learning concepts one by one is troublesome and therefore suggested that they should form an integrated whole. It is therefore difficult for learners to view electrical circuit as a whole system, and to understand and appreciate that making changes at a particular point would affect the whole circuit. As a result, learners focus their attention on a single point in a circuit *(local reasoning*), and a change in the circuit is thought to affect only current and or potential difference where a change is made. Also a change in the circuit is thought to affect current and or potential difference in elements located after the place where the change was made (*sequential reasoning)* (Carstensen and Bernhard 2007).

Planinic *et al*. (2006) found that current is a central concept that learners use to explain phenomena in a circuit. They found that learners thought current is consumed by circuit's elements, and therefore intensity diminishes after passing through such elements. However, potential difference is poorly understood and is usually identified with current. Also in their study they investigated and compared the strength of learners' alternative frameworks regarding topics of Newtonian dynamics and direct current resistive circuits using learners' confidence levels. The study further reports that Newtonian dynamics had higher learners' confidence levels, whereas a direct current resistive circuit had low learners' confidence levels. This was observed even after exposure to direct current resistive electrical circuit lessons where learners were providing scientifically acceptable ideas but they were observed to be lacking confidence. The explanation for this was suggested to be lack of firm conceptual models regarding direct current resistive circuits and few everyday experiences which allowed learners to question what happens in wires of electrical circuits.

Beaty on his website (http://amasci.com/miscon/whatdef.html 2009) listed a number of contradictory definitions of electricity. He observed that there are number of physics textbooks which have confusing definitions of electricity. Some of the definitions are as follows:

- Electricity is a form of energy, therefore invisible and moves with the speed of light.
- Electricity is a flow of current.
- Electricity means electric current, which implies that electricity appears whenever there is a flow of electrons within a metal wire and when the flow stops, electricity vanishes, even though the electrons are still there in the metal wire.
- Electricity is a flow of a charge, and the flow of a charge in a conducting wire is very slow.

From the above definitions it is clear that electricity is difficult, challenging and confusing to most people. In this study the term 'Electricity' refer to the learning area or a field of study.

2.2 FACTORS THAT HAVE AN EFFECT ON LEARNING ELECTRICITY

There is literature on conceptual difficulties which once identified, could improve instruction (McDermott and Shaffer 1992). There are five models that learners use to represents direct current resistive circuits: unipolar, clashing currents, attenuation, sharing and scientific model. The unipolar model refers to the view that electrical charges flow from one terminal of the battery to the bulb, where it is consumed by the bulb. In the clashing current model, the current leaves the battery through both terminals and meet at the bulb where it is used. With the attenuation model, the view is that electrical charges flows around the circuit in one direction, however, more charges flow from one terminal of the battery than they return to the other. In the sharing model, (current) charges flows around the circuit in one direction but it is shared equally among a series of identical bulbs. Lastly the scientific model, electrical charges flows around the circuit in one direction and current is conserved in the circuit (Fleer 1994).

2.2.1 Effect of geographical location on learning electricity

The terms ‘urban’ and ‘rural’ have complicated history in South Africa and there is still no agreement about what constitutes urban and rural areas (Gardiner 2008). Cities and towns were declared by apartheid to be whites dominated whereas blacks were located either in townships (peri-urban) near urban centre or in rural areas. Apartheid insisted that all blacks belonged to “homeland” some distance away from the urban center. According to Statistics South Africa census 2001 as cited in DoE (2005) “rural” is a spatial definition identifying Traditional Authority (TA) areas, primarily 'community owned' land in the former 'homelands' and commercial farms in former 'white' areas of South Africa. International literature defines 'rural' as a space where human settlement and infrastructure occupy only small patches of the landscape, and economic activity is dominated by primary production (DoE 2005).

The Department of Education established a ministerial committee on rural education in 2004 to report on practical recommendations to help the department to develop an integrated multifaceted plan of action for improving quality of education in rural areas. The committee recommended an expansion of the rural definition, to capture diversity of locations by including the following: distance to town, topography (conditions of the roads, bridges etc.), settlement patterns, access to communications and information technologies, transport infrastructure, access to services (electricity, water, sanitation), health, educational and economic status and social conditions etc. (DoE 2005).

Not many studies have been done on learners understanding of science concepts in urban and/or peri-urban against learners in rural areas. The few studies which have been carried out were not with South African learners. Internationally, rural schools are classified to be smaller in size with coherent communities, with limited resources, and poor school conditions. Learners in rural areas are said to be falling behind their urban counterparts in mathematics and science performance (Canadian Council on Learning 2006). However, studies done in Australia indicated that rural school learners were achieving at comparable levels to their urban counterparts at year 12 using scores for tertiary entrance (ACER 2002).

A study by Dzama (1997) investigated possible sources of errors on electricity made by Malawian (African - predominantly rural) high school learners compared with British (Western - urban) learners because some studies have shown that there were differences between western and non-western ‘alternative frameworks’ which are due to traditional beliefs. The researcher administered a test with open-ended questions to two samples from different high schools in Malawi during 1994 and 1995 school sessions. In London, the test was administered to two high schools during 1995 school sessions. Open-ended questions are questions which require explanations or reasons for their answers. This was necessary as it was believed that they would enable the researcher to gain some underlying thinking of the learners. The results indicate that there was little difference in the performance of learners of different cultures, background and socio-economic status. Dzama suggested that differences were not caused by traditional beliefs but experience. He argued that if learners had experience with electrical phenomena they were unlikely to make certain mistakes such as stating that increasing the resistance of a circuit would lead to an increase in the brightness of the bulb.

A study by Ogunniyi (2005) investigated whether or not the South African learners’ understanding of electricity was influenced by their age, gender, language, career interest or geographical location. He developed an instrument known as ‘Student’s Conceptions of Electricity’ (SCOE). This was a content instrument, which was used to assess different conceptions held by Grades 7 to 9 learners. He took a random sample of Grade 8 learners from nine provinces of South Africa. The results of the research showed that, learners held inadequate conceptions of electricity. Their conceptions of electricity were related to their gender, age, language, career choice and geographical location. It was recommended that the nature of instruction to which the learners were exposed be examined, as the researcher suspected the educator to be part of the problem (Ogunniyi 2005). The issue of educator quality is central to learners’ understanding of electricity as educators have a significant impact on learners’ achievements. The findings are in contrast to observations made by Dzama with

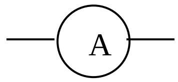
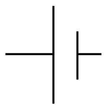
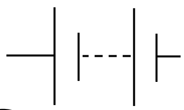
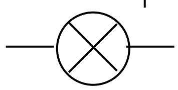
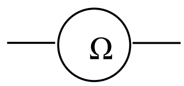
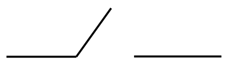
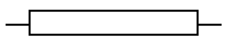
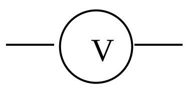
Malawian and London learners who concluded that most of the differences in conceptions are due to lack of experience. Moreover, Alokan (2010) also found that sex and geographic location has no effect on the negative relationship between learners' problems and academic performance.

2.3 UNDERSTANDING SCHEMATIC DIRECT CURRENT RESISTIVE CIRCUIT DIAGRAMS

Schematic circuit diagrams are of interest in this study because they are often found in physics textbooks. They are preferred in textbooks as they are said to be much easier to draw. They use special standard symbols for various components; therefore knowledge of symbols is important to understand schematic circuit diagrams. A schematic circuit diagram is an abstraction of a real circuit. It uses symbols to represent electronic components and straight lines to represent the connections. It therefore contains only information about the components and their connections. The actual layout of the components is usually quite different from the circuit diagram (http://hop.concord.org/el/elps.html). A real circuit is a collection of electronic components (e.g. bulbs, cells/batteries, resistors, meters, etc.) connected together with wires. Representing a real electrical circuit on paper can be complex and might take long and different people might use different symbols which might be very confusing.

For one to understand circuit diagrams it is important to understand individual components as well as their role in the circuit. This is at odds with Hall *et al.* (1987) who indicated that understanding the function of the whole by understanding the parts is difficult. It is acknowledged that both approaches are important and needed. The researcher in this study focuses on understanding individual components which will make it easier to understand the whole circuit. Table 2.1 below indicates some selected basic electronic components that are of interest in this study, their functions and symbols as used in direct-current resistive electrical circuit diagrams.

Table 2.1 Basic components, symbols and their functions

Component	Circuit Symbol	Functions of the Component
Ammeter		A device used to measure flow of charges (current).The ideal ammeter has zero internal resistance, for it to drop as little voltage as possible as charges pass through.
Cell and Battery	 & 	Supply electrical energy to the circuit (Large terminal is positive). (A battery is more than one cells connected together)
Lamp (light bulb)		A transducer which converts electrical energy to light. The thin wire within the bulb, allows the charges to move, as the charges passes through, it gets heated and glows by giving light off.
Ohm-meter		A device used to measure the resistance in a circuit diagram.
On-off switch		It allows charges to flow only when it's in the closed (on) position.
Resistor		Resist the flow of charges
Voltmeter		A device used to measure the potential difference (voltage). The ideal voltmeter has the highest resistance possible so that no or few charges can pass through (little current).
Wire		To pass current from one part of a circuit to another.

Braden (1994) in support of the use of circuit diagrams presented that diagrams enables learners to understand concepts associated with objects which are too small, too big or too complex to be readily visible. Reid (1984) refers to the benefits derived from learning diagrams as 'the picture superiority effect'. In addition, Crawford and Cullin (2004) reported that relationships between objects are more easily visualized from illustrations than from text only.

The above suggests that information is better understood when presented in both visual and verbal formats. Mosoloane and Sanders (2007) argue that although diagrams help learners in understanding new concepts, some learners have difficulties with interpretation of diagrams.

2.3.1 Understanding key electrical concepts

Duit and Rhöneck (1997) investigated learners' learning and understanding of key concepts in electricity namely: current, voltage and resistances. They looked at high school learners' pre- and post-instructional conceptions in the area of electricity, where they compared the everyday meaning of concepts and a physicist meaning of concepts. It was found that there were significant differences between the two. For example, it was found that in everyday language the meaning of current in European languages is closer to the meaning of energy than to current as used in physics. Therefore a conceptual change from existing knowledge (the knowledge accumulated from previous experiences) is required from learners for them to fully understand electricity.

2.3.2 Interpretation of key electrical concepts

Engelhardt and Beichner (2004), looked at how high school and university learners interpreted current and voltage by using two circuits, each with a light bulb and two batteries arranged differently in series or parallel. Learners were expected to predict the resulting voltage and current. The results showed that learners had difficulties predicting the voltage and current. They also had difficulties with term confusion. This was apparent as learners were assigning properties of energy to current, to voltage and also to resistance. Moreover, voltage and resistance were thought to occur in the presence of a current. The researchers also found that learners were able to translate easily from a realistic circuit to a corresponding schematic diagram, but had difficulty in translation from schematic circuit diagram to realistic circuit. It was also apparent that learners did not have firm alternative conceptualizations as they had different alternative conceptions for each question presented. Therefore, understanding of any sort (scientifically correct or alternative) may be lacking.

2.3.3 Concepts differentiation

Carstensen and Bernhard (2007) indicated that learners who cannot differentiate between voltage and current tend to struggle in connecting their measuring instruments. They presented that learners would try to connect current measuring instruments in the same way as the potential difference measuring instruments. This means they would connect an ammeter in parallel instead of in series. The above indicates lack of understanding of the underlying mechanism of electrical circuits.

2.3.4 Manipulation of equations

High school instruction in electrical circuits is centred on manipulating algebraic equations (Frederiksen *et al.* 2000). Learners are not shown how circuit theory is related conceptually to a casual model of what is happening in the circuit. Instead, abstract concepts such as voltage are often used as variables in an equation (e.g. 'V' in Ohm's law) (Frederiksen *et al.* 2000). A learner is therefore left with the notion that a physical system can only be understood through mathematical equations, and these equations cannot be understood in terms of any underlying physical mechanism. Instead of considering what is happening within a circuit, learners learn to use circuit diagrams as clues to access formulas which they use to manipulate equations to solve the required result (Frederiksen *et al.* 2000). Bernhard and Carstensen (2002) cautioned that physics is not just applied mathematics since interpreting physics equations requires understanding of the phenomena represented and knowledge of the symbols used in the representation. Thacker *et al.* (1999) indicated that learners who are exposed to teaching methods where equations and mathematical formulations were used did not have robust mental models of the physical situations. Moreover, when they are confronted with new situations they did not have tools to analyze them. Therefore, understanding of what is happening within the circuit is not realized, as the emphasis is on manipulating equations.

2.3.5 Basic Rules of Direct Current Resistive Circuits

A circuit with some components in parallel and series have certain characteristics and basic rules as summarized below.

The total resistance in series is equal to the sum of the individual resistances while the total resistance in parallel is equal to the reciprocal of the sum of the reciprocals of the individual resistances of the circuit. Potential difference in parallel branches remains the same as the battery while current in the parallel branches add to equal the total current of the circuit. At any node the sum of currents into that node is equal to the sum of currents out of that node. The potential difference across each element in series adds to equal the total input from the battery while current remains the same (http://www.tpup.com/neets/book1/chapter3/1-45.html). In addition the directed sum of potential difference around any closed loop is zero. If the circuit is broken at any point (excluding capacitors) no electrical charges will flow. Understanding the basic rules and the ability to apply them in simple circuits is critical for understanding the concepts.

2.4 ROLE OF REPRESENTATIONS/MODELS

Representation plays a critical role in learning, as one has to understand both what is represented and the representation or notation itself. According to Belski and Gray (2007) the more representations we grasp the deeper our understanding of the system. A real system can be simplified by using models or representation and models can be represented mathematically, graphically, or diagrammatically, etc. Each representation provides only a part of the whole picture. Usually models have incomplete details as they characterise the system from different aspects, however, they have some information to enhance our understanding of the real system.

A study by Frederiksen *et al.* (2000) investigated sources of difficulty in learners understanding casual models for physical systems. The researchers illustrated how knowing the reasons for using models is crucial for understanding. It is believed that helping learners to understand that models are not direct descriptions of physical reality will enable learners to understand physical systems better. Some of the difficulties found were abstractness of objects, multiple purposes of the models and linkages and relationships among models. Their findings indicate that enabling learners to construct linkages among models enables them to understand the origins of circuit theory. They also indicated that learning to represent and reason about the behaviour of circuits helps learners learn the steady-state circuit relationships. Moreover, learners developed a general understanding of the forms that models of a single physical system may take, focusing on different objects and interactions. The underlying cause of the conceptual difficulties learners face in understanding science is said to lie in the disjunctions in the multiple representations and models. Electrical circuits are composed of connected components. The system can only be understood by describing and modeling the system components and their interactions, and reasoning using such models to explore the behaviour of the systems (Frederiksen *et al.* 2000).

At school level, learners are taught important laws, rules and models as separate but expected to see a 'whole picture' and to comprehend the interrelationship between various representation. Circuit learning provides learners with different views and has been so for years (Belski and Gray 2007).

These views look very different and tend to be presented separately. As a result, learners tend not to relate them and thus lack the necessary skills to convert from one view to the other. The researchers relate the above-mentioned to asking a viewer to analyse an activity in a busy street viewing through different windows, without providing help in establishing relationships between the views. They said whatever is clearest, nearest, brightest and facing the viewer would become center of attention. However, what is distant, blurred which is gaining less attention might contain important information. In their study, they adopted a four-screen representation, which allowed learners to simultaneously view system behaviour through different windows. Learners were expected to view all four screens together and establish a unified picture. They were asked while looking at 1 screen to develop the other 3 in their minds. It is said that the mental images and their interrelationships helped in comprehending the whole, which ensured understanding of both representations and the relationships between them (Belski and Gray 2007).

2.5 MEASURING INSTRUMENTS

Research has shown that learners fail to treat meters as circuit elements and to recognize the implication for their connections. Some studies presented that learners believed that an ammeter would consume current for it to function (Planinic *et al.* 2006**)**. Learners do not understand that an ideal ammeter simply allows the charged particles to move through it easily and therefore has a negligible effect on the circuit. In addition Taber *et al.* (2006) showed that, to learners an ammeter complicates the circuit diagram. Understanding of meters in DC circuit will be investigated further in this study.

One of the basic properties of any electrical device is the amount of electrical charges which flows (current) when a known voltage is applied (Gilbert 2009). The plot of current as a function of voltage is usually called ‘I-V characteristic’ of the devise. An I-V characteristic is usually a curve, which may change as the temperature of the device changes. Whatever the I-V curve looks like, it defines the ratio V/I as the resistance, R, of the device at a particular current. There are situations where the curve I-V is a straight line through the origin, $V = IR$, where R is a constant. Such devices are said to obey Ohm’s law or to be Ohmic (Gilbert 2009). Potential difference (voltage), current and resistance can be measured with voltmeter, ammeter, and ohmmeter. Learners are expected to understand the role played by these meters in a circuit, however, from our observations there are no formal lessons about understanding each component in circuit theory.

2.5.1 What is a Meter?

> 'A *meter* is any device built to accurately detect and display an electrical quantity in a form readable by a human being. Usually this 'readable form' is visual: motion of a pointer on a scale, or some sort of display composed of numerical figures. In the analysis and testing of circuits, there are meters designed to accurately measure the basic quantities of voltage, current, and resistance' http://www.allaboutcircuits.com/vol_1/chpt_8/1.html.

There are different types of meters but this study will focus on those used to measure the two basic concepts of electricity namely voltage and current. Most of the modern meters are digital, meaning their display is in the form of numerical digits. Older versions of meters also known as mechanical meters use a pointer to show quantity measured. The pointer moves along a calibrated scale so that a measured value could be read. However, the principles applied in either display are the same. Most mechanical meters movements are based on the principle of electromagnetism that the current through a conductor produces magnetic field perpendicular to the axis of electron flow. The greater the flow the stronger the magnetic field produced. If the magnetic field interacts with another magnetic field a force will be generated between the two sources. If one of the sources is free to move with respect to the other, it will move as charges (electrons) passes through the conductor and the motion will be proportional to the strength of the current (http://www.allaboutcircuits.com/vol_1/chpt_8/1.html).

In connecting meters such as ammeter and voltmeter to a circuit, their roles should be understood and taken into consideration. When connected into the circuit either in parallel (voltmeter) or in series (ammeter), they are not necessarily part of the circuit. Their presence to a good degree should not affect the functioning of the circuit (Habash 2002).

2.5.2 How are Meters Connected?

Current is defined as the amount of charge that pass a particular point in a specified time. To measure the current, one therefore needs to break the circuit and insert the ammeter at the point where current is to be measured. It could be thought of as charges flowing in the original circuit up to the desired point, through the ammeter and being returned to the original circuit. An ammeter is therefore connected in series because it must be part of the circuit. It is desirable for an ammeter to have a zero resistance so that it does not change the properties of the circuit. However, a real ammeter does not have zero resistance but has as little resistance as practical (Gilbert 2009). As a result an educator sees an ammeter as an invisible component in the circuit and the focus is on the meaning of the reading given (Taber *et al.* 2006).

Potential difference or voltage is defined as the difference in electrical potential between two points in the circuits. A voltmeter must therefore be connected between two points of the circuit. It is not necessary to break the circuit to connect the voltmeter. It connects two parts of the circuit which were not joined. This type of connection is referred as parallel. A voltmeter must therefore have infinite resistance to avoid disturbing the flow of charged particles in the circuit. The ideal voltmeter can only be approximated. If the voltmeter was to be connected in series, a circuit will not work, because the high resistance in the meter will prevent flow of charges in the circuit (Gilbert 2009 and Habash 2002).

The other instrument for basic concepts which can be of interest but not investigated in this study is the ohmmeter. The ohmmeter is used to measure resistance directly. It consists of ammeter, voltmeter and an energy source connected to a pair of external terminals. When the terminals are connected to an unknown resistance, the meter measures the ratio of voltage to the current and displays the result. It is important to remove components from the circuit to measure their resistance, as the ohmmeter measures the effective resistance of individual components. Moreover, any voltage source connected to the terminals of the ohmmeter must be disconnected before using the ohmmeter as it may damage or confuse the meter (Gilbert 2009).

2.6 DIFFICULTY IN UNDERSTANDING DIRECT CURRENT RESISTIVE CIRCUITS

Frederiksen *et al.* (2000) also reported that learners found difficulty in understanding the behaviour of electrical circuits. Understanding circuits containing batteries, wires, and light bulbs requires learners to reason about electrical potentials (voltages) at different locations within a circuit and also about the flow of charges caused by the differences at those electrical potentials. Learners should realize how changes in any of circuit component will affect other components. It was found that learners turn to focus their attention on one point and ignore what is happening elsewhere. It is important to realize that changing potential difference in a circuit produces changes in current flows in different circuit branches.

2.7 TEACHING APPROACHES

A study by Taber *et al.* (2006) looked at teaching approaches involving introducing ideas about electrical circuits at high school level in and around England (United Kingdom). They had a case study with two trainee-educators who used models and analogies to introduce electrical concepts to lower high school learners. Their view was that the role of the educator was to help learners acquire conceptual resources suitable for later use in building their own models. However, it was acknowledged that the use of analogies has limitations and thus needs to be carefully presented. It has been found that appropriate models will support developing understanding of what is happening in the circuit. The study recommended that a combination of practical work and modeling strategies will help learners to understand the circuit phenomena. Mental images which are developing will be the foundation for progression in learning. The findings were confirmed by Sacate (2005) who found that a combination of teaching methods improves learners' understanding of concepts. Taber *et al.* (2006) also indicated that educators introducing electrical ideas to lower high school learners need a way to entice learners to engage with the topic at a theoretical level.

2.7.1 Collaborative versus individual learning

Gokhale (1995) examined the effectiveness of individual learning versus collaborative learning in enhancing factual knowledge and critical thinking. Collaborative learning refers to an instruction method in which learners work together in small groups towards a common goal (Gokhale 1995). The study used both series and parallel direct current resistive circuits. Participants were undergraduate urban university students enrolled for basic electronics course at Western Illinois University during 1993. The findings were that collaborative learning promotes the development of critical thinking as it provides learners with opportunity for discussions, clarifications of ideas, learn about themselves, interpersonal skills and evaluations of others ideas. Both learning approaches were found to be equally effective in gaining factual knowledge. However, for the purpose of enhancing critical thinking collaborative learning was found to be more beneficial.

2.7.2 Simulation versus Laboratory Work

Bryan and Stuessy (2006) investigated an alternative conception for the observed differences in light bulbs brightness, where participants where middle Grade educators teaching mathematics and science at school level. The study used physical electrical components and computer simulation program. The participants were asked to explain what happened to the brightness of the identical light bulbs in direct current resistive circuits as more bulbs were (a) added in series (b) added in parallel and then to explain how relative brightness of multiple bulbs could be determined when they were connected in combination circuits. The results presented ‘brightness’ to be a property of an electrical circuit that depended only on the power supply. Thus the total ‘brightness’ in a circuit remains constant as bulbs are added to or taken from the circuit. How much brightness any single bulb gets depends on its arrangement within the circuit. This discovery led to researchers developing an alternative conception which they called the ‘Brightness Rule’ for light bulb circuits.

A study by Nurmi and Jaakkola (2004) investigated whether combination of a simulation and laboratory work can improve learners understanding of simple direct current resistive circuits. In their study they had three working groups:

1. The laboratory group - where learners worked in a classroom and had to build real circuits with bulbs, wires, switches and batteries. They also had to measure current with a multimeter.
2. The simulation group - where learners used online computer simulations ‘Electricity Exploration Tool’ which allowed them to build simple direct current (DC) circuit with bulbs, wires, switches and batteries on a diagram level. The simulation allowed learners to observe the behaviour of their circuits by running the model built and measured the voltage with a multimeter.
3. And lastly the mixed group - where both online computer simulation tool and real circuits were used. They started with simulation followed by real circuits.

Their results showed that simulation can help learners to understand the theoretical principles of electricity by revealing the behaviour of electrical circuit and visualizing the flow of charge in the circuit. It also provides immediate feedback to learners about their actions and errors. It was reported that after understanding the basics of electricity on a theoretical level, it made it easier for learners to transfer acquired knowledge into the laboratory exercises with real circuits. However, the laboratory group had a hard time working with bulbs and wires and also had difficulties in understanding the principles of direct current resistive circuits at a theoretical level. Tarekegn (2009) reported a similar finding with the Ethiopian Grade 12 learners (predominantly rural) where the researcher also used three groups namely the laboratory group, the learner centred simulation group and educator centred simulation group. The laboratory group worked with real laboratory equipment, while learner and educator centred simulation groups replaced the laboratory equipment with computer simulations. The laboratory group and learner centred simulation group performed the experiment themselves while the educator centred simulation group only made observations while the educator was performing the experiment. The results showed that in either setting the use of simulations can enhance learners' achievement.

2.7.2.1 PLAB

Hendricks (2002) investigated whether or not using a computer as a tutor could enhance students' conceptual understanding of electrical concepts. They used intervention software program called 'The Intervention Process' (PLAB) to provide students with an opportunity to investigate a number of pre-designed electrical circuits in which they could test their knowledge about electrical concepts. Participants were first year students at the Cape Peninsula University of Technology. The majority of the students were found to be computer illiterate at the start of the study. Their prior knowledge about electrical concepts was also found to be generally poor. PLAB exposure was one of the processes of intervention decided upon. There was hope that the program would extend the learners' senses (visual and perceptual) and thus facilitate their conceptual understanding of electrical concepts. Learners had to make predictions and verify them with the PLAB program. The program provided immediate feedback on circuits measurements. The results showed that the effectiveness of the computer program was statistically insignificance. The researcher (Hendricks 2002) concluded by saying:

> "*I have come to appreciate a computer as a tool. We cannot expect a computer to teach any more than we expect a pencil to teach a child how to write*" (p II - 52).

However, the University of Colorado in Boulder through their Physics Education Technology (PhET) project developed interactive and animated simulations for learners to explore scientific concepts in an open-style play area, where learners are able to manipulate electric components such as resistors, light bulbs, wires and batteries. The results indicated that simulations promoted higher mastery of electrical concepts such as current and voltage than students who did laboratory exercises with real electrical equipment (Finkelstein *et al.* 2005).

2.8 PRESENT STUDY

At the end of high school education learners are expected to have developed mental models of what takes place in electrical circuits, which should enable them to demonstrate an understanding of key concepts like current, potential deference and resistance. It is expected of learners to appreciate the difference between series and parallel circuits and to appreciate how making changes like adding more batteries or bulbs in series would affect the performance of a circuit. Moreover they should be able to offer explanations in terms of scientific principles. It is therefore important for educators to have knowledge about alternative frameworks which learners have in DC circuit to confront them, through experiments, computer simulations and discussions. However, to achieve all the above it is important for learners to understand the symbols and their role as used in schematic circuits. Learners need to understand roles played by each individual component to be able to resolve difficulties like current consumption model on their own. The current teaching approaches that learners are exposed to create confusions as in most cases basic concepts are introduced without much discussions and the emphasis being on solving numerical problems, rather than understanding the concepts.

The present study investigates learners' understanding (per school location) of individual components and the role they play in electrical circuits. It is believed that a number of alternative frameworks are due to not understanding the role played by each component in an electrical circuit.

There is extensive literature on electricity (Sacate 2005, Taber *et al.* 2006, Engelhardt and Beichner 2004, Ogunniyi 1999, 2005, Hendricks 2002, Duit and Rhöneck 1997, 1998, McDermott and Shaffer 1992). However, majority focused on the role of alternative frameworks in learning electricity. Most of the studies documented a variety of difficulties which learners experience in learning electricity. Others used analogies to assist learners to develop mental models of a flow of charge. Some presented proposed diagnostic remedies to the prevalent difficulties, such as using simulations to visualise the abstract conceptions. However, very few looked at learners' difficulties in graphs and physics drawings. Very few investigated learners' knowledge of symbols used in schematic circuits and none investigated the role of symbols in understanding electric circuit diagrams. In addition very few looked at the effect of geographical location in learning electricity.

CHAPTER III: RESEARCH DESIGN AND METHODOLOGY

3.1 INTRODUCTION

The main purpose of this study was to investigate the extent to which learners per school location understand what the electrical symbols represent and what the role of symbols is in simple direct current resistive circuits.

This chapter presents the sample, procedures used for collecting the data, data analysis, validity and reliability issues, study limitations and ethical considerations.

3.2 DATA COLLECTION METHODS

The most commonly used data-collection instruments in the study of learners' understanding of science concepts are: Observations, Interviews and Questionnaires (Driver and Erickson 1983). However, each method has its advantages and disadvantages. For example, observations require the researcher to interact with the subjects in their environment where data is to be collected. The strategy involves looking, listening, enquiring and recording data which would be a challenge to an inexperienced researcher. According to Nisbet (1977) (as cited in Bell 1995), observations are highly skilled activities which require extensive background knowledge, understanding and ability to spot significant events. They are, therefore, not easy but once mastered, can reveal characteristics of groups or individuals which would have been impossible to discover by any other method (Bell 1995). Moreover, they provide first-hand information unlike inferential methods. The researcher has an opportunity to witness what people do, rather than what they say they do (Bell 1995 and Cohen *et al*. 2007). However, there are challenges with the technique as the reliability of observation protocols across observers can be questionable (Bell 1995).

Interviews in educational research recognize that humans are not just manipulable subjects but conversations between humans also generate data. They enable participants to discuss their interpretations and express how they regard situations from their own point of view (Cohen *et al.* 2007). The interviewer can follow up responses to obtain in-depth information (Netshisaulu 1996).

Data is generated and collected through various ways: verbal, non-verbal, spoken and heard. On the other hand, they are time-consuming, open to interviewer bias and therefore result in relatively small numbers of people being involved in the study (Cohen *et al*. 2007).

Questionnaires enable the researcher to collect information quickly and yield data from a broader range of people than interviews (Bell 1995). They are structured and standardized to reduce bias and to ensure reliability, generalizability and validity. Every respondent is presented with the same questions and in the same order as other respondents (Oatey 1997 and Weinreich 2006). However, they are also riddled with disadvantages such as incomplete returns as a result of those who might not be willing to write everything they are thinking about (Lawrenz and Gray 1995). They require extensive preparations to get clear, unambiguous and relevant questions.

The methodology used in this study involved a combination of two techniques, namely, questionnaires and structured interviews. Questionnaires data were gathered prior to conducting interviews thereby validating responses from questionnaires. In this study data were collected on a 'one shot' basis rather than longitudinally.

3.3 REVIEW OF QUALITATIVE AND QUANTITATIVE METHODS

There is a variety of techniques to investigate learners' understanding of science concepts. The techniques can be grouped into two main categories quantitative and qualitative (Bell 1995). Qualitative techniques use smaller samples than in quantitative methods. The former see an individual as unique and more interested in the depth of the data rather than the breadth (Oatey 1997 and Weinreich 2006). In science education, qualitative research is concerned with understanding people's behaviour, their knowledge, attitudes, beliefs, etc. The focus is on the processes and reasons why, in this case data is therefore rich and detailed (Weinreich 2006). However, it is often difficult to draw definitive conclusions from the findings and to generalize them to the larger group because of smaller and often unrepresentative samples. On the other hand quantitative technique aim to obtain information which can be statistically analyzed, patterns extracted and compared (Bell 1995 and Weinreich 2006). The method ensures objectivity, generalisability and reliability.

3.3.1 Qualitative Methodology

3.3.1.1 Written responses

Qualitative methods generate data which needs to be coded before being analyzed. The data is broken down into parts in order to establish the similarities and/ or differences in learners' responses. Similar ideas are grouped together to form categories. Once the categories have been established, there could be other groups of concepts which could be put together to form sub-categories. The name of the category/code would mainly come ideas used by respondents (Corbin and Strauss 2008).

3.3.1.2 Interviews

Interviews are an example of qualitative methodology. They are normally used to gain information on a particular topic or area to be researched. They can either be structured (closed-ended) or unstructured (open-ended) (Cohen *et al*. 2007). The unstructured interviews are defined by Oatey (1997) as informal, without a list of standard questions, where an interviewer is free to deal with the topic of interest in any order and to phrase their questions as best as they think. The questions are asked in any order as the interview develops. It allows the interviewer an opportunity to question deeper into the initial response of the respondent to gain more detailed answers to the question (Cohen *et al*. 2007). The richness of the data is dependent on the interviewer, as they must judge how much or little they should question. Freedom for the respondent to answer how they wish to is important as it gives them a feeling of control in the interview situation (Oatey 1997). However, this approach is time consuming because of the varied nature of responses. Moreover, it is difficult to generalize and the interviewer tends to be bias.

Structured interviews are said to be a social survey where a range of possible answers could be known in advance (Oatey 1997). Usually the responses are listed on the form so that respondent can simply mark appropriate responses. There is little freedom or flexibility in this approach because the order of the questions is fixed and there could be a standard list of answers for the respondent to choose from. It is therefore uniform as each person is given the same set of questions. Some advantages are that the information is easy to quantify and the responses can be compared.

However, some people may feel that their responses do not fit any of the provided answers on the list (Oatey 1997). This study used structured interviews with a standard list of possible answers however, learners were encouraged to come up with alternative options if they felt their views were not represented.

Interviews as used in research may take two forms namely: face to face interviews (Oatey 1997) and focus group interviews (Cohen *et al*. 2007). Face to face interviews normally result with small samples and usually last for several hours. The focus is generally on open-ended questions allowing the respondent to answer freely. Follow-up questions are based on how the respondent answers the questions. Questions are therefore not standardized.

The Focus group interviews require members of the group to know each other, so that they can feel at ease with each other. Discussions are guided by the interviewer while respondents discuss and express opinions with each other. However, there are possibilities of influence by one or two respondents on the other members of the group. Research indicates that a dominant respondent can negatively affect the outcome of the group and group pressures may influence the comments made by individuals (Oatey 1997). Although, it is possible for one respondent to dominate, it is also possible that other respondents' ideas may spark new ideas from other members. Research indicates that 'extended focus groups' helps in avoiding influence by dominant respondents. In extended focus group each respondent fills a questionnaire prior to the focus group interview expressing their own personal views (Oatey 1997). In this study structured interviews were used with two focus groups of learners to validate the questionnaire responses. The participants were selected based on the pattern of their responses from the questionnaires and questions were selected from the questionnaire and used for the interviews with emphasis on the reasoning behind the chosen options.

3.3.2 Quantitative Methodology

A quantitative methodology collects facts and explores the relationship of one set of facts to the other. The method uses techniques that produce quantifiable and generalizable conclusions (Oatey 1997 and Hopkins 2008). It is concerned with counting and measuring, producing estimates of averages and differences between groups (Bell 1995). The technique covers: the way participants are selected randomly from the population in an unbiased manner, the standardized questionnaire or intervention they received and the statistical methods used. The researcher is considered external to the actual research and the results are expected to be replicable no matter who conducts the research (Weinreich 2006). Questionnaires are a good example of quantitative methodology. However, they may also be qualitative with open-ended questions. Advantages of using questionnaires are that all respondents are asked the same questions. They produce quantifiable, reliable data that are usually generalizable to the larger population. They enable the researcher to obtain answers to the same questions from larger group quicker. However, it is not possible to explain points in the questions that participants might misinterpret. Open-ended questions also generate large data that takes long time to process and analyze. Respondents may answer superficially especially if the questionnaire is taking long to complete. Finally, respondents may not be willing to answer the questions, as they might think they will not benefit from the exercise (Milne 1999).

3.4 DATA COLLECTION METHODS USED IN THE PRESENT STUDY

3.4.1 Research Design

This study followed a descriptive method, which describes the data and characteristics of the population without influencing it in any way (Hopkins 2008). Data was collected from learners, in their unchanged environment. The description of data was factual and systematic but did not describe the cause. The description was used for counting frequencies of occurrence (of ideas, themes, trends or patterns), and other statistical investigations. Data analysis was concerned with what the data suggested (Cohen *et al*. 2007). The results could not be used as definitive answers (Shuttleworth 2008). However, the method was useful in studying abstract ideas like learners' knowledge and understanding of concepts. Data was gathered and organized into patterns that emerged during the analysis. Tables and graphs were used to describe collected data.

The present study used both qualitative and quantitative methods so that the results provide depth of understanding and generalizability. Questionnaires and structured interviews were used to collect the data. The decision to use questionnaires was based on the researcher's quest for representativeness of a wider population (Bell 1995). Two focus groups of six to seven learners from each school were interviewed to validate the questionnaire's responses. Focus groups were used to create an atmosphere for discussion amongst interviewees to assess in-depth knowledge and to reveal their understanding of electricity concepts. Selection of interviewees was based on the alternative frameworks that emerged from their written responses to the questionnaire. With consent of learners an audio recorder was used to capture the learner's responses during the interviews. In addition, the researcher made notes, where necessary. During the data transcription, the researcher did not change the nature and the meaning of the respondents' contributions.

3.4.2 Questionnaire Development

The researcher conducted literature review prior to the construction of the questionnaire to gain insights into learners' mastery of concepts. This activity enabled the researcher to identify gaps which formed the basis for this study. The items were organized such that each item could not influence responses to subsequent items. In addition, items required minimal mathematical competency, but focused more on knowledge, understanding and application of concepts.

Most items in the questionnaire were drawn from diagnostic instrument on conceptual difficulties developed by Engelhardt and Beichner (2004) which were developed to evaluate learners' understanding of a variety of direct current resistive circuits' concepts. The internal consistency of the instrument was estimated to be above 0.70 by the developers. In the present study, underlying thinking was elicited by asking learners to give reasons for their choices.

Some items were drawn from a workshop guide developed by Grayson (1994) entitled, 'A guided inquiry approach to teaching science, using electrical circuits as an example'. Grayson developed the guide to help high school educators in learning circuit theory. Other items were taken from Wolff (1987) article entitled 'Basic mechanics and simple electric circuits'. Items in the questionnaire were re-phrased and converted into a multiple-choice with an additional part that required learners to give reasons for their choices.

A free response draft questionnaire was also given to 19 high school educators to elicit on anticipated learners' alternative frameworks in a multiple-choice test. The educators were all science majors registered in the Department of Mathematics, Science and Technology Education (DMSTE) for an Advance Certificate in Education (ACE) at the University of Limpopo, Turfloop Campus. The predominant responses given by educators to each of the questions were used as alternatives to multiple-choice questions together with the ones from literature. According to Tamir (1971) ready-made multiple-choice questions have to be adapted to local conditions because test constructors follow their own thought patterns which quite often differ from learners.

Figure 3.1 below outlines the sequence or steps followed in questionnaire development

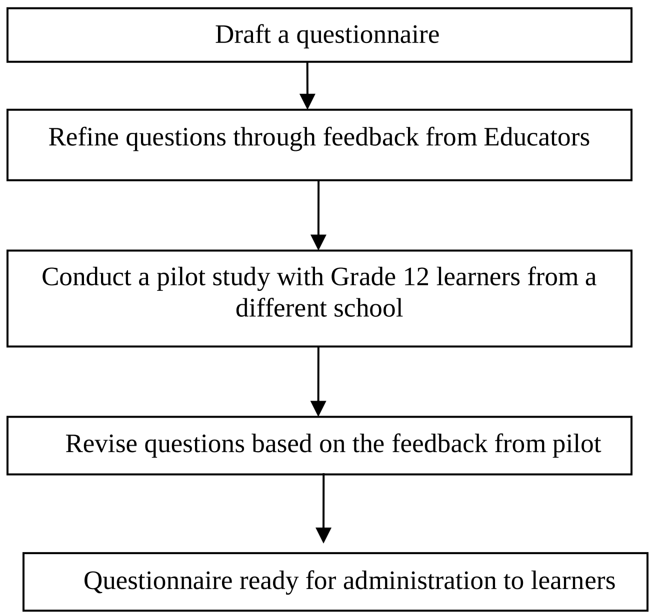


Figure 3. 1: Sequence of questionnaire development stages

3.4.2.1 Questionnaire Format

The final questionnaire had 26 questions with five options to choose from. The questionnaire (see appendix A) contained both closed (multiple-choice) and open–ended forms. Closed-ended questions required the respondents to choose one of the five possible responses, while the open-ended questions required respondents to explain their choices. Multiple-choice type questions were used to assess learners' knowledge of schematic symbols and concepts.

The questionnaire was divided into two sections: A and B see Appendix A. Section A of the questionnaire consisted of 5 multiple-choice questions, 2 where on identification of symbols and 3 on conceptual knowledge. The first 2 questions (1 and 2) required learners to match symbols with their names and/or photographs, to enable the researcher to assess learners' factual knowledge of symbols. Questions 3, 4 and 5 had three sub-questions each with 4 to 5 options to select from. The questions focused mainly on knowledge of concepts. Four to 5 options were adopted to reduce the chances of guessing.

Section B of the questionnaire focused on symbols identification, roles of components and applications of concepts in circuit diagrams. The latter was used to assess learners' level of understanding concepts in circuit diagrams. The section contained 7 main questions, each (except for questions 2 and 7) with an average of 3 multiple-choice sub-questions of which 8 required learners to provide explanations for their choices. This enabled the researcher to explore learners' knowledge, understanding and their underlying thinking. Each question in the questionnaire had an objective and these are listed in Table 3.1 below.

Table 3.1: Objective(s) of each question in the questionnaire

Objective	**Question number**	
	Section A	**Section B**
Knowledge of symbols		
Identify and apply knowledge of photographs, symbols and associated names.	1 & 2	2
Role of a battery		
Understand the role of a battery in a circuit.	3a	
Conductor		
Understand the concept of conductor	3b	
Explore learners knowledge that conductor has free charges inside ready to move	3b	
Measuring instruments		
Understand the role of measuring instruments in a circuit.	5a, 5b	6a, 6b, 6c
Identify and apply knowledge of measuring instruments symbols.		6a, 6b, 6c
Apply the knowledge of how measuring instruments are connected.		2, 6a, 6b, 6c
Power	4c	5c
Understand the concept of power and interpretation of its values		
Comparison between real and schematic diagrams		2

Use circuit skills to move from pictorial (real) to schematic		
Current		
Understand and apply conservation of current.		1a, 6c
Understand the concept and interpretation of the microscopic aspect of flow of charge.	4a	7
Understand that current split in parallel and combine to pass through a series branch.		1b, 5a
Potential difference (voltage)		
Understand the concept and interpretation of its values	4b	
Apply the knowledge that p.d. in series circuit sums and while in parallel remains the same.		4a ,4b, 4c, 4d 5b, 6a, 6b
Resistance		
Apply the concept of resistance.	3c	
Apply knowledge that in series resistance increases and in parallel it decreases.		3a, 3b

3.4.3 Research population and Sample

3.4.3.1 Population

The study was carried out at high school level in the Limpopo Provincial Department of Education: Capricorn District, Mankweng Circuit. The number of learners in each of the schools ranged from 7 to 163 as shown in Table 3.2 below.

Table 3.2: Summary of Grade 12 Physical Science entries 2007, Mankweng Circuit

Number	**Name of School**	**Physical Science HG**	**Physical Science SG**	**TOTAL**
1	Bjatladi	5	16	**21**
2	Ditlalemeso	10	61	**71**
3	Hwiti	18	10	**28**
4	Makgoka	119	44	**163**
5	Makgongoana	6	6	**12**
6	Mamabudusha	28	14	**42**
7	Marobathota	84	0	**84**
8	Mountainview	41	64	**105**
9	Mphetsebe	0	26	**26**
10	Ramashobohle	0	0	**0**
11	Sekitla	7	0	**7**
TOTAL		**318**	**241**	**559**

Table 3.2 shows that Mankweng circuit had 11 high schools of which 10 offered physical science at Grade 12. The circuit had a population of 559 learners enrolled for Physical Science during the year 2007. From the 10 schools offering physical science, 7 were in a rural area while 3 were in a peri-urban area. From the 3 peri-urban schools, 1 was used as a pilot and therefore excluded from the main sample. The actual number of learners enrolled for physical science in each school was used to select the sample. Within the 7 rural high schools 1 was among the Dinaledi schools project. However, the school was not sampled for this study.

Mankweng Circuit was chosen by the researcher because of its proximity to the researcher's learning institution. The 2 participating schools were within a 10 kilometer radius from the researcher's learning institution.

The study focused on the Grade 12 learners as they had been introduced to the topic of electricity in their earlier lower grades of schooling. They were on the verge of entering higher institutions of learning where their prior-knowledge of basic electrical concepts is crucial in mastering electricity.

3.4.3.2 Sample

A chosen sample had to be representative of the population for the results to be generalizable otherwise selection would be bias (Hopkins, 2008). According to Hopkins (2008) the safest way to ensure that the sample is representative of the population is to use the random selection procedure. The current study used cluster sampling technique due to its advantage in giving a manageable group (Cohen *et al.* 2000). With cluster sampling the researcher randomly selects a number of groups from the whole population and decides to randomly or systematically select the subjects or use the whole group. In this study the researcher randomly selected 2 schools and tested all physical science learners in the selected schools. Two African mixed (boys and girls) public schools with different backgrounds were used to avoid bias so that the results could be generalized. The intention was to have both rural and peri-urban schools represented.

The study used questionnaires which were administered to the two selected schools at the beginning of September 2007. One school was based in a peri-urban area while the other one was situated in a rural area. The respondents were 137 learners which was a quarter ($\frac{1}{4}$) of the population. The enrolment numbers were 71 and 84 (peri-urban and rural school learners, respectively). However, 60 (85%) and 77 (92%) learners from peri-urban and rural schools, respectively, were present at the time the questionnaires were administered. The participants were almost equal in terms of gender (69 male and 68 female learners). Their age group ranged from 15 to 21 years with an average of eighteen (18) years. The two schools did not have laboratories or electrical apparatus to perform experiments. As a result, only theoretical lessons were conducted at the schools. The peri-urban school had 5 teaching periods of 45 minutes each (3.8 hours) per week for physical science whilst the rural school had 7 teaching periods of 30 minutes each (3.5 hours) per week. Theoretical lessons were taught during the third quarter of the schooling term and both schools had completed their electricity lessons at the time of testing.

3.4.4 Pilot Study

A pilot study helps in identifying possible challenges and weaknesses in the wording of questions, questionnaire length and the relevance of questions asked (Netshisaulu 1996). It provides an opportunity to develop a coding scheme for analysing written responses. It also helps in perfecting the instrument and administration procedures.

After compiling the questionnaire, a pilot study was conducted with 91 Grade 12 learners from a peri-urban school in mid-August 2007. From their responses the questionnaire was refined and some items were removed as they required mathematical competencies (application of Ohm's and Joule's laws). Piloting with the Grade 12's was intended to verify questions and to detect whether the targeted group of learners would be able to respond to the questions. There was no time specified to finish the questionnaire as a good estimate of the time to complete the questionnaire was required. Learners on average manage to complete the task in less than 45 minutes. The final version of the questionnaire used to collect data is attached as Appendix A.

3.4.5 Administration of the Questionnaire

The questionnaire was administered to the two schools on the same day but at different times at the beginning of September 2007. The researcher attended both sessions to give introductory remarks to both groups about the purpose of the study. Learners were assured that their participation would remain anonymous and results would be used for research purpose only and would not advantage or disadvantage them in any way towards their studies. The learners were given an hour to complete the task. However, on average learners took 30 minutes to complete. The researcher invigilated the writing process with the help of the educators in charge of physical science at that particular school and BSc (EDP) English and Study Skills lecturer from the University of Limpopo. All questionnaire handed out were returned.

3.4.6 Data Analysis

3.4.6.1 Analysis of the Multiple-Choice items

Altogether 137 completed questionnaires were available for analysis. Data were coded and entered into a Microsoft Excel spreadsheet. Options with similar ideas were grouped together. Frequencies and percentages of selected options were counted and tabulated. A Chi-square test was used to calculate the significance of the differences between groups. The test used two frequencies: the observed and the expected, where the observed were the actual frequencies obtained whereas the expected were the theoretical frequencies used for comparisons. The Chi-square test was performed at the 0.05 level of confidence (i.e., there was 95% chance of the observed occurring). Observed frequencies for each category were presented in tabular and or graphical form.

3.4.6.2 Analysis of Explanations

The analysis of explanations was carried out in order to get a better insight into the learners' reasons for chosen options instead of just relying on the multiple-choice responses.

Samples of 13 randomly selected completed questionnaires from 1 school were given to 3 B.Sc. (EDP) lecturers at the University of Limpopo, Turfloop Campus, in November 2007. They were asked to extract patterns and/or themes emerging from learners' written responses. The 3 lecturers were experts in the field of mathematics and science education. The lecturers worked individually in coding responses. Two of the lecturers (in the absence of the 3rd) and the researcher met to discuss the discrepancies and reached consensus. From the established categories, a coding scheme was developed, which was applied to the 13 selected scripts and were approved by the supervisor (see appendix B). The researcher then applied the coding scheme to the rest of the completed questionnaires.

Analysis, in this case, involved putting data into themes, patterns and trends using a coding scheme. Thus, statements with similar content were placed under similar categories and were linked to existing frameworks. The numbers of learners giving answers to a certain category were tallied. Each code corresponded to a particular group of responses provided by learners. The adopted coding scheme used a combination of letters and numbers.

It started with a letter then followed by three numbers, see Table 3.3 below for coding of written responses. The first letter A - E represent the selected option corresponding to i - v. The three numbers were used for the reasoning provided. The first number indicate the idea, the second the concept and the last one shows the degree/ extent (0-same, 1-less, 2-more, 3 divide/shared). For example C120 – means selected iii and the reasoning was because they are connected in series therefore current will be the same (1_ _for series,_2_ current,_ _0 same), B642 selected option ii because they are connected in parallel they will have more energy (6_ _ parallel, _4_ energy, _ _2 more), see Appendix B for a detailed coding scheme. Responses given without explanations or reasoning were referred to as A000, B000 etc. indicating the selected options followed by zero's for no reasoning. Where there was no responses given (left blank), then NR was used. Lastly, some responses could not be placed in any of the categories because they were unintelligible and they were then referred to as AUN, BUN etc.

Table 3.3: Coding scheme for written explanations

Main/Key Concept/idea/term/point		**Examples of explanations**
Type of connection (first digit)	100 = series	Because they are connected in series
Series	110= series electricity same	The two bulbs are connected in series thus have the same electricity
	120= series current same	The two bulbs are connected in series thus have the same current
	150 = series power is the same	The two bulbs are connected in series thus have the same power
Bulb of same size	200	The bulbs are equal in size/ brighter because it is big (size)
Battery is the same	300	Because they are connected to the same battery therefore have same brightness
Parallel	600	

Wrong/ incomplete infomation	700	
Uncodeable	UN	Responses not related to key issues/unclear or difficult to understand (e.g. wrong connection)
No explanation	000	Learners did not write any explanation supporting their choice or they repeated the the expression given in the alternative of multiple-choice part of the question

Main/Key Concept/idea/term/point **Second digit**	**Variables/specifics/degree** **Third digit**	**Examples of explanations**
01=Electricity related category	0 =same/conserved/not used up 1=less/decreases/lost/consumed 2=more/increases/high/gain 3=shared/divided	
02=Current related category	0 =same/conserved/not used up 1=less/decreases/lost/consumed 2=more/increases/high/gain 3=shared/divided	
03=Voltage related category	0 =same/conserved/not used up 1=less/decreases/lost/consumed 2=more/increases/high/gain 3=shared/divided	
04=Energy related category	0 =same/conserved/not used up 1=less/decreases/lost/consumed 2=more/increases/high/gain 3=shared/divided	
05=Power related category	0 =same/conserved/not used up 1=less/decreases/lost/consumed 2=more/increases/high/gain 3=shared/divided	
06=Resistance related category	0=same 1=less 2=more	
07= Light related category	0=same 1=less 2=more	

3.4.7 Interviews

Structured interviews were conducted with two focus groups of 7 rural school learners and 6 peri-urban school learners, respectively. A permission to use the audio recorder was requested from the participants and the researcher explained the need for the discussions to be recorded. The learners were asked some selected questions from the questionnaire and the questions were common for the two groups. They were provided with a range of possible answers. They had to choose an appropriate option and explain their choice. Learners were encouraged to come up with their alternative responses if they felt their responses did not fit any of the provided answers. The interviews lasted approximately 1hour each.

The researcher started by giving background information about the study, the purpose for the session and their selection for the interview. Learners were encouraged to discuss their opinions amongst each other. The researcher wanted to create an atmosphere where participants feel comfortable to express themselves. During discussions, the researcher's main role was to listen and observe when participants were influencing each other. Within the two groups emerged the dominant respondents who were always the first to answer the questions and influencing others. A collective decision was made that everybody would be afforded an opportunity to respond to all the questions asked. It was also clarified that it was not necessary for the group to reach consensus because the researcher wanted to hear everybody's own personal views.
To encourage more participation learners were encouraged to use Sepedi (Northern Sotho) in their deliberations where necessary. This was essential as it was evident that learners from the two schools were failing to express their views in English and ended up code-switching between Sepedi and English.

3.5 VALIDITY AND RELIABILITY ISSUES

Validity of the instrument is the ability of the test to measure what it is intended to measure. This is established via several measurements not with a single measurement. It can be shown through content and construct validity (Engelhardt and Beichner 2004). For example content validity for DIRECT was established by presenting the questionnaire and its objectives were given to an independent panel of experts to insure validity. A factor analysis explores the interrelationships within the data and also used to group items that appear to measure the same idea. This practice was used to ascertain the extent to which questions were being understood as intended and to better understand learners' choices (Engelhardt and Beichner 2004).

Reliability is an indication of how consistently the test measure what it supposed to measure. Engelhardt and Beichner (2004) used Kuder-Richadson formula 20 (KR-20) to evaluate the reliability of the test (DIRECT) and they found KR-20 to be above 0.70 which was desirable for the test to be reliable. The method is widely used in situations where the test is administrated once (Tarekegn 2009).

The validity of the developed questionnaire was checked by presenting it to two physics and one English and Study Skills 1st year lecturers in the B.Sc. (Extended Degree Programme) to validate the content and check language clarity respectively, before it was piloted. Content validity insures that questionnaire items cover what they are supposed to cover and are a fair representation of the issues under investigation. Language check was carried out to avoid ambiguity of instructions, questions and to ensure appropriate readability levels and accurate language usage. Interviews were also conducted with two groups of six and seven learners from the two schools to insure construct validity. Learners were asked to identify the symbols and justify their responses. Learners understood the electrical symbols in the test.

3.6 METHOD LIMITATIONS

The method used to select the sample could be over or under representing the population. This is due to a sample leaving a significant number of the population not sampled. Group interviews also resulted in some learners' ideas being influenced by dominant participants. Therefore, the results might not be a true reflection of learners' thoughts.

3.7 ETHICAL CONSIDERATIONS

Irrespective of the research design, research that requires human participation should conform to voluntary participation, confidentiality, informed consent, anonymity and no harm to the participants (Homan 1991 as cited in Lepheane 2007).

Official access to the schools was formally requested from the Limpopo Provincial Department of Basic Education, the Mankweng Circuit Manager and from the 3 Principals (including the pilot) of the schools. Learners were informed of the aims and objectives of the study beforehand. They were informed of their rights to participation. They were assured that their participation would remain anonymous and the results would be used for research purpose only and would not disadvantage them in any way towards their studies.

To insure confidentiality of the learners only the researcher and supervisor had access to the completed questionnaires. To protect anonymity during analysis of the result codes were used to identify completed questionnaires instead of learners' names. For example, acronyms D01, D02…D60 and M01, M02…M77 were used to refer to learners from peri-urban and rural school, respectively.

3.8 SUMMARY OF DATA COLLECTED IN THE STUDY

The following Table 3.4 summarises the data collection in the present study

Table 3.4: Summary of collecting data.

Question	**Answer**
Why was data collected?	To assess the Grade 12 learners from rural and peri-urban schools' knowledge and understanding of symbols representation in direct current resistive circuits. Document alternative frameworks that learners hold in electricity.
What was the strategy used?	Questionnaires and structured interviews.
Who were the participants?	Grade 12 physical science learners from two mixed high schools from rural and peri-urban areas in Mankweng circuit.
What was the size of the sample?	A total of 137 learners. Questionnaires - 137 learners Structured interviews – two focus groups of 6 and 7 learners.
What was the population?	Mankweng Circuit -Ten high schools with a total of 559 learners.
How was data collected?	Questionnaires with both closed and open-ended format were administered. Structured interviews were audio- recorded
How was data analyzed?	Statistical analysis was used for factual data and a coding scheme for qualitative data
Why the selected methods?	Interviews and questionnaires provided factual and in-depth knowledge of learners about electricity. Interviews used to confirm reliability and validity of the information.

The next chapter presents the results found and provides discussions of the findings.

CHAPTER IV: RESULTS AND DISCUSSION

4.1 INTRODUCTION

Chapter three documented the methodology followed, data collection and data analysis strategies. This chapter profiles the research sample and presents the results, and interpretation of data gathered from questionnaire and interviews per school location.

The questionnaire was divided into two sections, section A and section B. A copy of the questionnaire is attached in Appendix A. Section A sought to elicit the knowledge of rural and peri-urban learners on symbols used in direct current resistive circuits. Section B was devoted on symbols identification, role of components and applications of concepts in circuit diagrams. It was intended to understand learners reasoning patterns in analyzing direct current resistive circuits. More specifically the study aimed at investigating the following research questions:

(1) What do learners from rural and peri-urban schools know about symbols used in direct current resistive electrical circuits?
(2) What do learners from rural and peri-urban schools understand about the role of various symbols used in direct current resistive electrical circuits?
(3) How does adding or changing circuit component affect the circuit?
(4) What alternative frameworks do rural and peri-urban learners hold in electrical circuit?

Section A of the questionnaire consisted of five multiple-choice questions, assessing factual knowledge about symbols used and electrical concepts namely: current, voltage and power in electrical circuits. Frequencies of options chosen by the whole sample were presented per geographical school location. The main focus was on options with the highest percentages and not necessarily the correct ones.

The questions in section B had open and closed-ended forms. There were 7 multiple-choice questions which had 4 to 5 alternatives to choose from. Four of these questions (8 items) required learners to provide explanations for their choices. Each choice and its explanation were analyzed through a code that was developed. Each code corresponded to a particular group of responses provided by learners (see a coding framework in Appendix B). The explanation part served to assess reasoning patterns used by learners in analyzing electrical circuits. The results were summarized with some selected quotations, to support the findings. Quotations from interview quotations were used as additional supporting evidence.

Interviews responses were analyzed by grouping learners' responses into categories, where statements were analyzed for content and placed along with those of similar content.

The results are presented in percentages in tabular and/or graphical form(s). The analysis of each question starts with a presentation of the question and its purpose followed by presentation of the results for the entire sample and per geographical location. Quotes are given, where applicable. Finally an interpretation of the results with reference to existing literature is presented. The Chi-squared test at the 0.05 level of significance was used to indicate the statistical significance of the results.

4.2 BIOGRAPHICAL DETAILS

Mankweng circuit had a population of 559 learners coming from ten high schools (70% rural and 30% peri-urban) offering physical science at Grade 12 (see appendix C). The two schools which participated in the study represented 20% of the schools in the circuit. The average age group for the population was around 18 years.

The two schools in this study had neither laboratories nor apparatus to perform electricity experiments. Participants were 137 learners comprising of male and female learners from peri-urban and rural schools. The number of participants per school location are presented in Table 4.1 below:

Table 4.1 Number of learners per school location

Location	Number of learners	Percentage (%)
Rural	77	56
Peri-urban	60	44
Total	137	100

Table 4.1 shows that a larger percentage (56%) of the respondents came from the rural school whilst 44% were from the peri-urban school. Participants were requested to indicate their gender. Table 4.2 below depicts gender distribution of learners who participated in the study.

Table 4.2 Gender distribution of the learners

Gender	Number of learners	Percentage (%)
Male	69	50
Female	68	50
Total	137	100

The sample as presented in Table 4.2 had equal numbers of male and female learners.
Table 4.3 below indicates gender distribution in each school.

Table 4.3 Gender distribution per school

School	Gender	Number of learners	Percentage (%)
Peri-urban	Male	35 (58%)	26
	Female	25	18
Rural	Male	34	25
	Female	43 (56%)	31
Total		137	100

In Table 4.3, it is evident that male participation was fairly even between the two schools (26% from peri-urban and 25% from rural schools). However, the same cannot be said in respect of female participation as 18% of the sample were females from the peri-urban school whilst 31% were females from the rural school. Table 4.3 also shows that the peri-urban school was dominated by males (58%) while the rural school was dominated by female learners (56%).

4.3 KNOWLEDGE OF SYMBOLS

4.3.1 Matching schematics symbols to scientific names

Aspects of matching symbols to their names were assessed by the first two questions of section A. Question 1 required learners to match electrical components' symbols with scientific names. Learners were given 8 symbols and 8 scientific names in a table to match. The symbols were presented in the first column on the left whilst scientific names were on the right column (see appendix A). The results are presented in Figure 4.1 below as percentages of learners' choices.

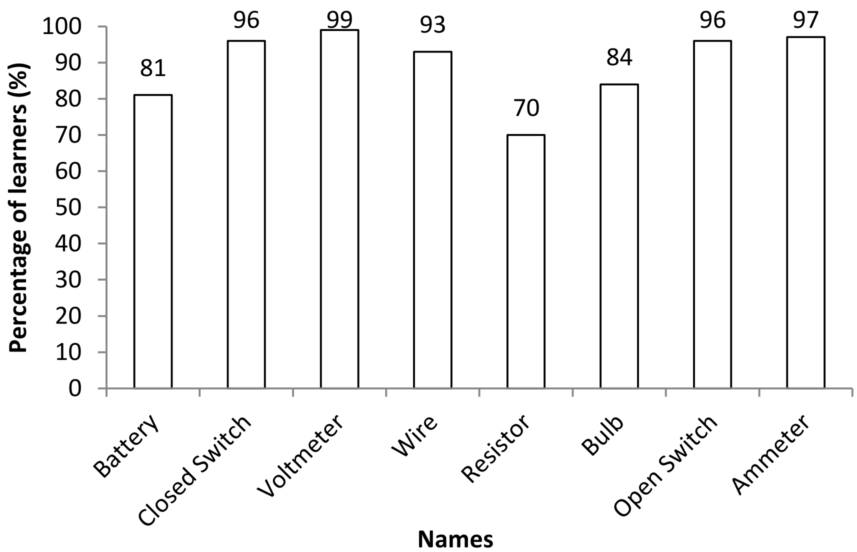


Figure 4.1: Learners' correct responses to the naming of symbols

Although the study's goal was not necessarily on identifying scientifically accepted responses, Figure 4.1 above shows that symbols were correctly matched to their scientific names (≥70%). This suggests that learners knew the symbols used. The results confirms the findings by Engelhardt and Beichner (2004) who presented that nearly all learners understood the symbols used in their test (Determining and Interpreting Resistive Electric circuit Concepts Test (DIRECT)) except for the light bulb in a socket. A similar finding was reported by Tarekegn (2009) who asked participants to identify the symbols used in DIRECT and concluded that:

"*all of the students understood the electrical symbols in the test*".

A larger percentage of learners (~97%) correctly identified symbols for both ammeter and voltmeter. This finding was anticipated as almost all schematic circuits that learners encountered during their prior electricity learning had either ammeter or voltmeter symbol.

In addition, further analysis was done to check if the findings can be associated with the geographical location of the school. Figure 4.2 below indicates the views of learners per geographical location of their school.

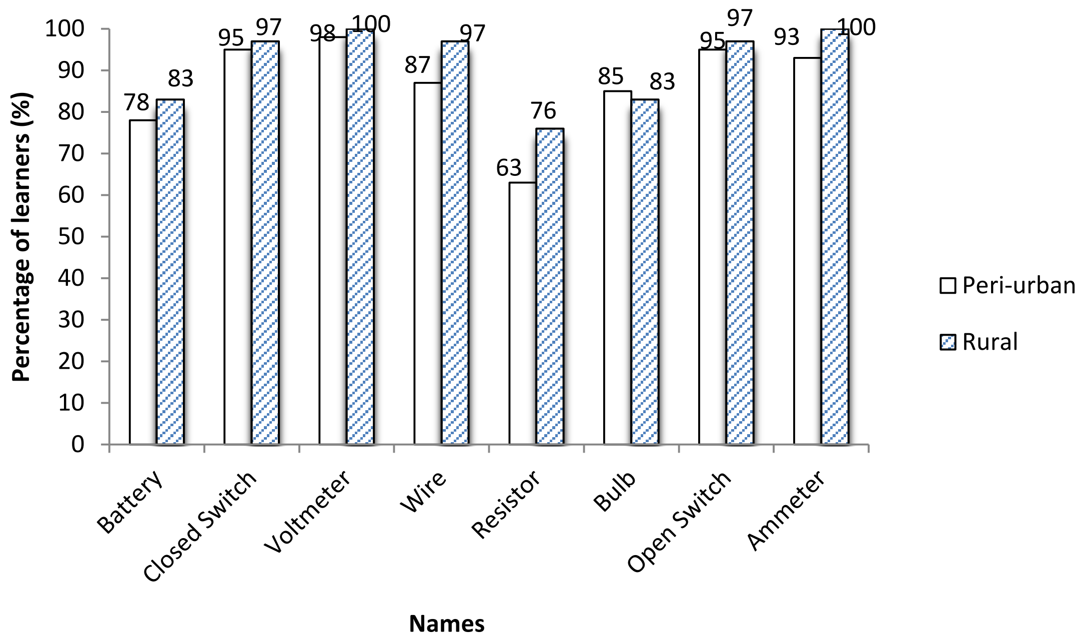


Figure 4.2: Learners' correct responses to the naming of symbols per school location

Figure 4.2 above shows that learners from the rural school were slightly getting higher percentages than those from the peri-urban school for all symbols. However, the differences were not statistically significant (X^2 = 0.76**,** p > 0.05). All learners from the rural school correctly matched the ammeter and voltmeter symbols to their scientific names. However, interviews revealed that remarkably few learners from the peri-urban school were unable to identify the correct symbols for ammeter (3) and voltmeter (1), respectively. Knowledge of symbols could therefore not be associated with school location since both rural and peri-urban learners knew the electrical symbols.

4.3.2 Matching photographs to schematic symbols

Question 2 of the questionnaire required learners to match photographs of realistic circuits' components with their respective schematic symbols. They were presented with 6 photographs and 6 schematic symbols in a tabular format. The photographs were presented in the left column while symbols were in the right column (see Appendix A). The intention was to assess learners' knowledge of real electronic components and their schematic symbols as used in direct current resistive electrical circuits. The results are shown in Figure 4.3 below as percentages of the chosen options.

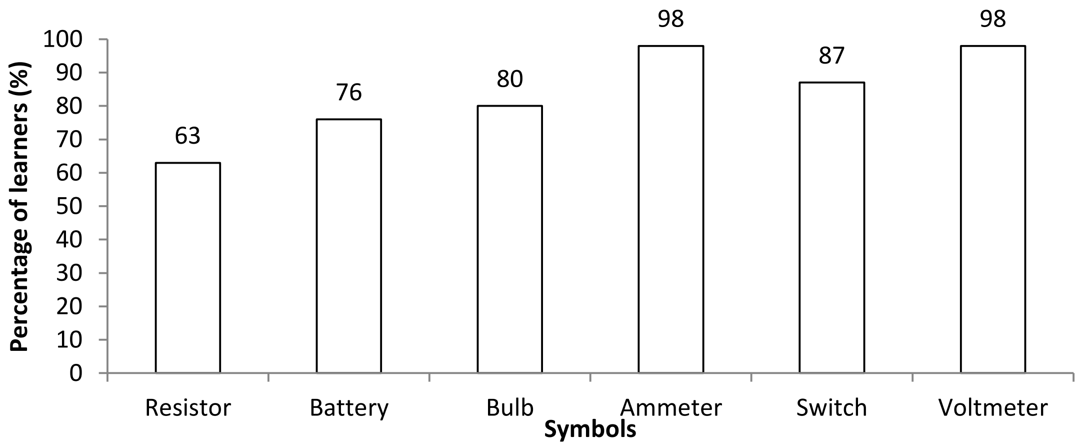


Figure 4.3: Learners' correct responses to matching photographs with their symbols

Figure 4.3 above suggests that learners knew the photographs of the real components as above 60% of them managed to correctly match the photographs against their schematic symbols. Majority of learners (98%) correctly identified and matched ammeter and voltmeter with their respective symbols. However, responses on the photograph of a resistor (carbon film) revealed the lowest number of correct percentages at 63%. This may suggest that the resistor might be uncommon and unfamiliar to some learners.

Further analysis was done to check if the findings can be associated with geographical location of the school. Responses in terms of location of the school are presented in Figure 4.4 below.

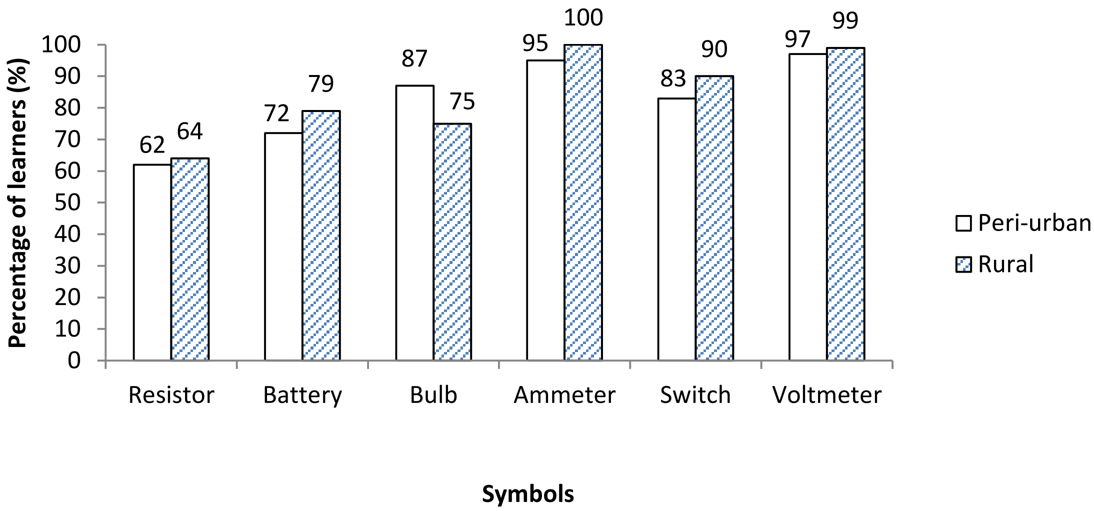


Figure 4.4: Correct responses for the matching of photographs to symbols per school location

Figure 4.4 indicates that learners from the two schools were able to match photographs to their schematic symbols. All learners in the rural school and all but 3 learners from the peri-urban school correctly matched a photograph of an ammeter with its symbols. Rural school learners seemed to know symbols and photographs more than peri-urban learners as observed from higher percentages obtained in matching symbols and photographs. However, the differences were statistically not significant ($X^2 = 0.64$, $p > 0.05$).

4.4 ROLE OF AMMETER AND VOLTMETER

Part of this section was presented orally at the 56th annual South African Institute of Physics Conference (SAIP 2011) and published in the conference Proceedings which were edited by I. Basson and A.E Botha (University of South Africa, Pretoria, 2011), pp. 602-607. ISBN: 978-1-86888-688-3 and it is also available online at http:\\www.saip.org.za. The paper is entitled: "Learners understanding of Ammeter and Voltmeter in a direct current schematic circuit". However, the effect of geographical location was not included (see paper in Appendix D).

Question 5 of section A of the questionnaire explored the roles of ammeter and voltmeter in a circuit.

4.4.1 Using an Ammeter

The first part requested learners to indicate what they thought to be the role of an ammeter in a circuit and the results are summarized in Figure 4.5 below.

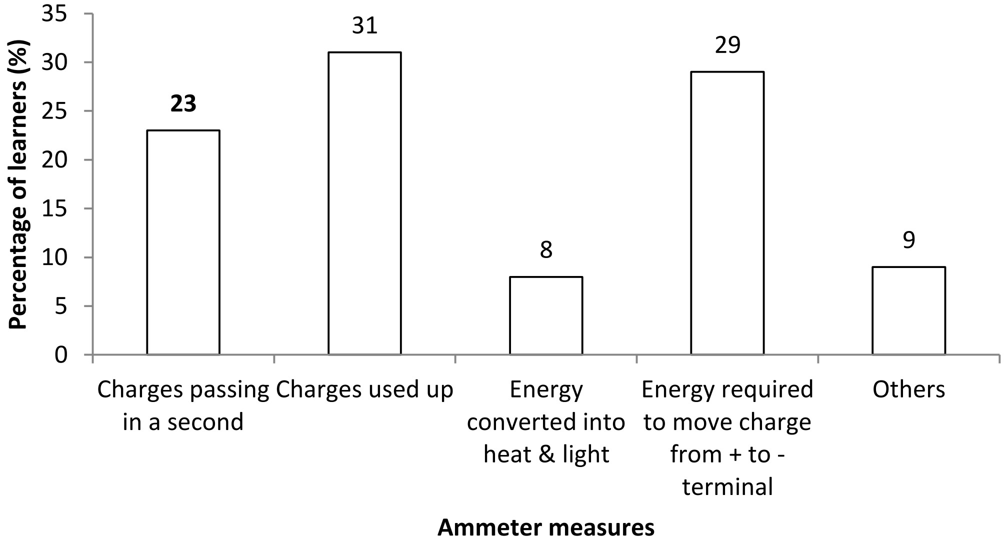


Figure 4.5: The role of an ammeter in a circuit

Figure 4.5 shows that a majority of learners' ≥ 60% held well documented alternative framework about electricity concepts. Of the given alternative frameworks 31% of the learners indicated that ammeter measured the charges which were used up by circuit components (like bulbs, resistance, etc.). Learners thought current value decreases as charges move through circuit elements. The results are consistent with Planinic and co-workers (2006) who found that learners thought current is consumed by circuit's elements, and therefore, its intensity diminishes after passing through certain elements. Current consumption has been reported by many studies and argued to be due to confusion from not relating concepts properly (Taber *et al*. 2006, Carstensen and Bernhard 2007). In addition, 29% of the learners indicated that the ammeter measured the energy required to move a charge from one point to the other. This view was evident from the interviews with most [10 out of 13, (79%)] of the learners. This alternative framework has been attributed to confusion from not relating concepts properly (namely, potential difference, current and resistance).

However, Figure 4.5 also shows that only 23% of the learners presented scientifically acceptable responses and during interviews few (3) supported the scientifically accepted view. From the results, it was apparent that learners did not understand the role played by an ammeter in an electrical circuit.

Further analysis was done in terms of school location and the results are presented below in Figure 4.6.

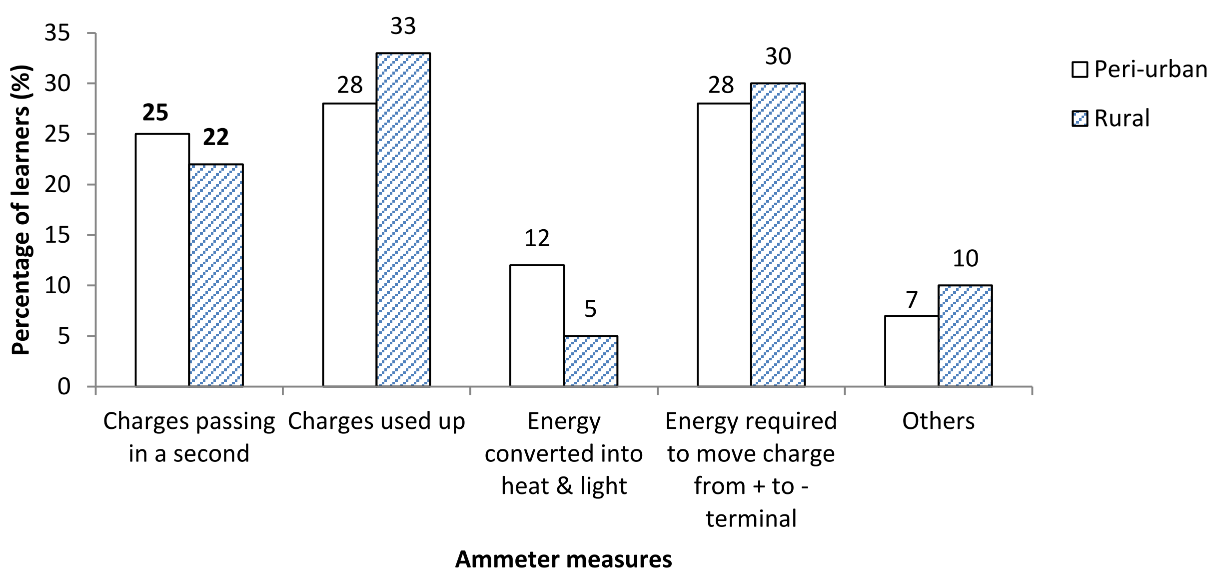


Figure 4.6: The role of an ammeter in a circuit per school location

Figure 4.6 shows that majority (28%) of the peri-urban and 33% of rural school learners were confused about the role of an ammeter. The former were of the view that charges were used up. The results seemed to follow from the thought that a battery supplied the circuit with charged particles (Planinic *et al.* 2006). If a battery is supplying the charges to the circuit, there must be components using the charges for the battery to get flat. The latter presented responses that suggested an ammeter to measure potential difference. This confirms that learners have difficulties relating current to voltage. The differences observed between the two schools in relation to knowledge of the role played by an ammeter in a circuit were not statistically significant ($X^2 = 2.39$, $p > 0.05$).

Ammeter is used to indicate current. To measure the current, one needs to break the circuit and insert the ammeter at the point where current is to be measured. An ideal ammeter has zero internal resistance, so as to drop as little voltage as possible as charged particles flow through it. However, real ammeters have as little resistance as practically possible (http://www.owlnet.rice.edu/~phys126/labs/expt07). To an educator an ammeter does not change the characteristics of the circuit; it is therefore an invisible component used to indicate current readings in a circuit (Taber *et al*. 2006). However, a learner views an ammeter differently.

4.4.2 Using a Voltmeter

The second part of the question investigated learners' understanding of a voltmeter and its role in electrical circuits. Learners were requested to indicate what they believed to be the role of a voltmeter in a circuit and the results are summarized in Figure 4.7.

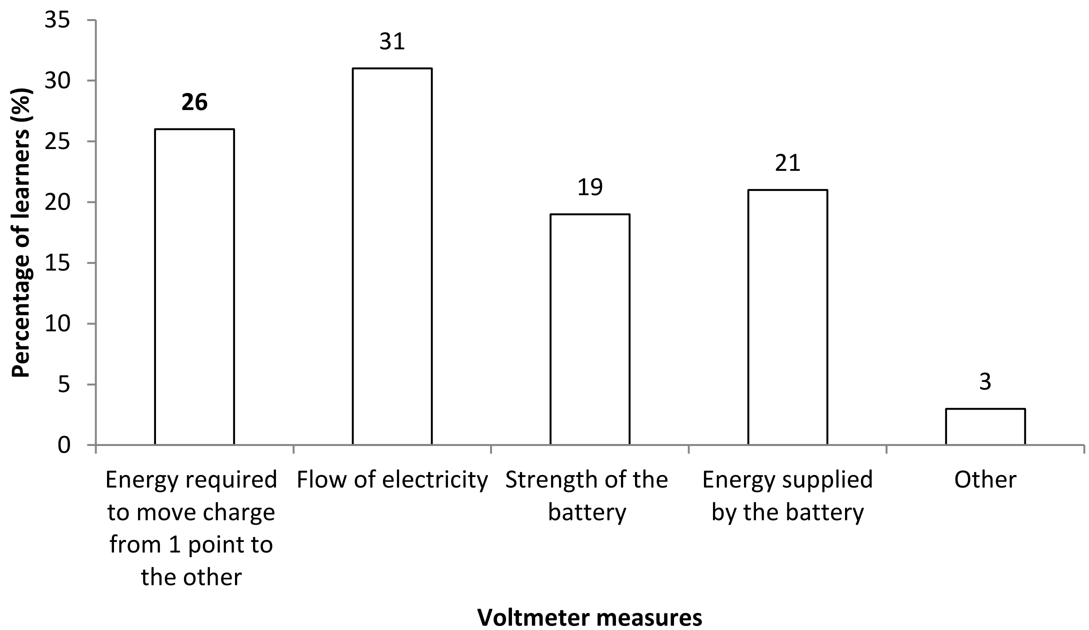


Figure 4.7: The role of a voltmeter in a circuit

Results presented in Figure 4.7 depicts that majority of learners (71%) held alternative frameworks about electricity. Of these, 31% of them thought that voltmeter measured the electricity flowing through the conductor. Learners referred the substance flowing within the wires to be electricity. This indicates learners were using electricity to refer to current (Duit and Rhonëck 1998). Difficulty with concepts differentiation is well documented in literature (Carstensen and Bernhard 2007; Dzama 1997 and Grayson 2004). The usage of the term electricity can be traced to Africans' everyday languages, where electricity, power and current are used interchangeably (Duit and Rhonëck 1998). This finding is consistent with literature. A voltmeter which is connected across components is said to measure the flow of charge. Only 26% of learners provided a correct option that voltmeter measured energy required to move a charge from one point to the other. It was apparent that learners did not know and understand why voltmeters have to be connected in parallel.

Moreover, Figure 4.7 indicates that about 1 in 5 (21%) of the learners thought that the voltmeter measured energy supplied by the battery to the circuit. Interviews with learners showed that majority of the learners (7 out of 13 learners, 54%) confirmed this finding. The other learners (3) thought voltmeter was measuring the strength of the battery. One learner in support of her choice said:

"*volts indicate the strength of the battery and it is measuring the volts*".

In addition, few (2) thought it measured the electricity through the circuit while 1 indicated that it was measuring the charges flowing through the conductors. It was apparent that learners did not understand the role played by voltmeter in a circuit. Figure 4.8 below was used to evaluate if responses could be associated with the geographical location of the school.

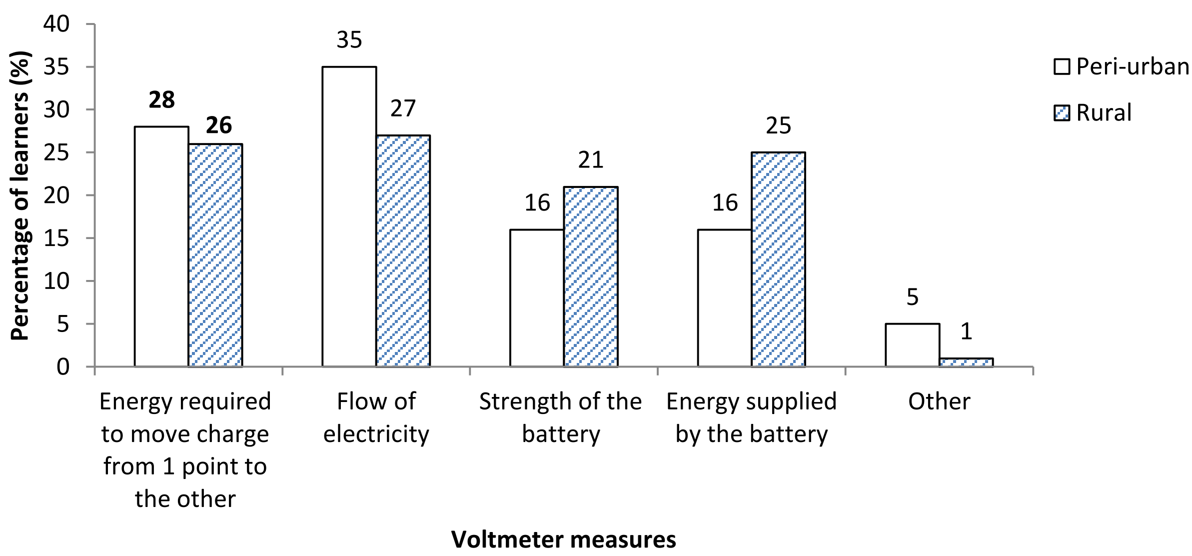


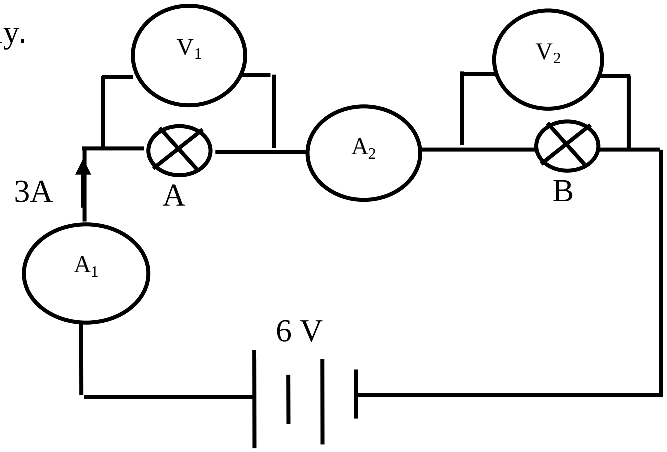
Figure 4.8: The role of a Voltmeter in a circuit per school location

Figure 4.8 indicates that 35% of peri-urban learners and 27% of the rural school learners thought voltmeter measured electricity flowing through the circuit. More peri-urban learners were referring to the substance moving within the wires as electricity. However, 26% from the rural school and 28% from the peri-urban school presented acceptable responses that voltmeter measured energy required to move a charge from one point to the other, while 25% of the rural school learners thought it measured the energy supplied by the battery. It seemed for the rural school learners their responses were evenly spread across 3 options while the peri-urban school learners chose predominantly 2 options (the correct option and flow of electricity). The differences between the two schools in relation to knowledge of the role played by voltmeter in a circuit were not statistically significant ($X^2 = 0.80$, $p > 0.05$) and therefore, cannot be associated with geographical location.

Voltmeter is used to measure voltage in an electrical circuit; voltage is defined to be the difference in electrical potential between two points in a circuit. It is, therefore, connected between two points. An ideal voltmeter would have an infinite resistance to avoid disturbing the flow of charge (http://www.owlnet.rice.edu/~phys126/labs/expt07). A real voltmeter has the highest resistance possible to minimize drawing of current from the circuit.

4.4.3 Voltmeter and Ammeter in a series circuit

Question 6 of section B of the questionnaire had three parts [(a) to (c)] on meter readings with multiple-choice questions followed by a part where learners had to give explanations for their choices. Learners were presented with a schematic circuit diagram (see circuit 12). The circuit consisted of 2 batteries, 2 light bulbs and 2 ammeters all in series and 2 voltmeters across the bulbs. The ammeters and voltmeters were labeled A_1, A_2, V_1 and V_2, respectively, while light bulbs werelabeled A and B. Voltmeter V_1 was connected across bulb A and V_2 connected across bulb B, ammeter A_2 was connected between the two bulbs. The total current and voltage of the circuit were presented as 3A and 6V, respectively.



Circuit 12

Learners had to use their knowledge of symbols and how meters have to be connected to identify the voltmeters and ammeters. They were also required to indicate readings the meters would have shown. For example, question 6[(a) and (b)] required learners to indicate the potential differences that would be displayed by voltmeters V_1 and V_2, respectively. Learners had to first identify V_1 and V_2 to be voltmeters and to apply the knowledge that potential difference divides in series. They were to give reasons for their chosen responses. The results for parts (a) and (b) without considering their explanation for choices are presented below in Figure 4.9.

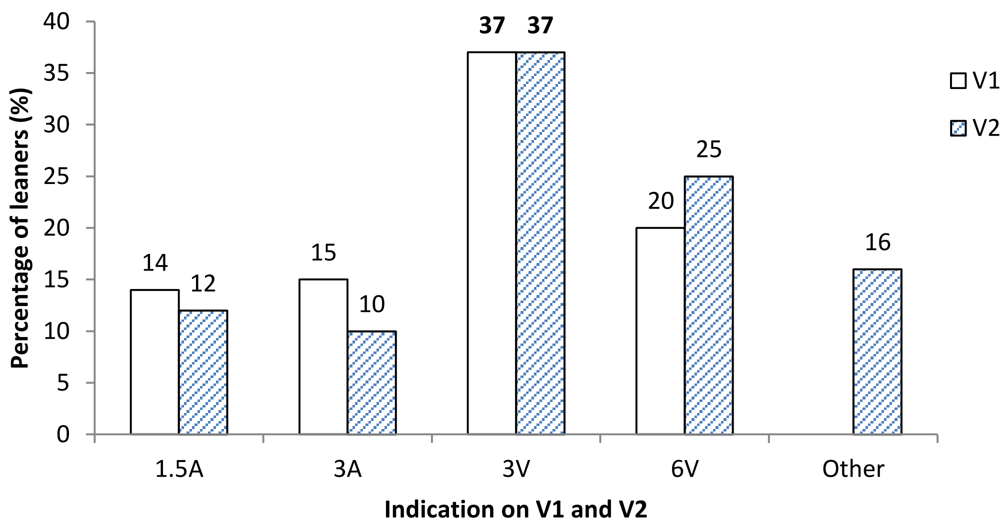


Figure 4.9: Learners' responses to readings on voltmeters V_1 and V_2

Figure 4.9 depicts that majority (57% and 62% of the responses) of learners correctly identified V_1 and V_2 to be voltmeters (as shown by their choice of responses with correct units-3V and 6V). This suggests that the majority knew that voltmeter had to be connected in parallel in electrical circuits. The first two questions of section A of the questionnaire (Figs 4.1 and 4.3) on identifying symbols showed that learners (~ 97%) knew the symbol for voltmeter. However, Figure 4.9 suggests when a symbol is connected to other components in a schematic circuit, learners experience difficulties in identifying it. The results show a dramatic decrease from 97% to 57% and to 62% in identifying V_1 and V_2, respectively. The findings suggest that more components connected together in a circuit complicate the circuit such that some learners fail to recognize the individual components.

On the other hand, 29% and 22% learners thought V_1 and V_2 were ammeters (as shown by their choice of responses with correct units-1.5A and 3A), respectively. Thus, these learners had difficulties with how measuring devices should be connected in an electrical circuit; they thought an ammeter should be connected in parallel. They might also have had difficulties with concept differentiation. Only 37% presented correct indications for both V_1 and V_2. There were no significant differences ($X^2 = 3.13$, $p > 0.05$) in learners' responses to indications on the two voltmeters. This result shows that majority of learners did not understand that potential difference across each element in series sums to equal the total voltage from the battery. This finding confirms literature that learners who fail to apply the basic rules had difficulty in understanding the concept (Carstensen and Bernhard 2007, Gilbert 2009, Küçüközer and Kocakülah 2007).

Interviews revealed that learners experienced difficulties with circuit 12 where learners were required to indicate the reading on the two voltmeters. The main difficulty was that learners were not told that V_1 and V_2 were voltmeters. Two learners said:

"*….meter reading I don't know whether it should be Volts or Amperes"* and *"….not sure what the meter is",*

Other learners agreed to the statements. I highlighted the need for learners to identify the measuring instruments. Although, they were not happy with the idea to identify the meters, four learners said that the question would require some calculations. However, resistance of the bulbs was not provided. Thus the readings on the two meters could not be determined. Two learners said that the question was not clear. Thus, there were not sure what is expected of them. The other learners (4) thought the 2 meters were measuring current and said they would indicate half (1.5A) readings of the total current. For example 1 learner said:

"*the two bulbs are equal therefore they should share current equal".*

Only three learners were able to select and provide proper explanations for the two voltmeters to have the same voltage.

Below in Figures 4.10 and 4.11 are the learners' responses on the reading of voltmeters V_1 and V_2 in terms of school geographical location without considering explanation for their choices.

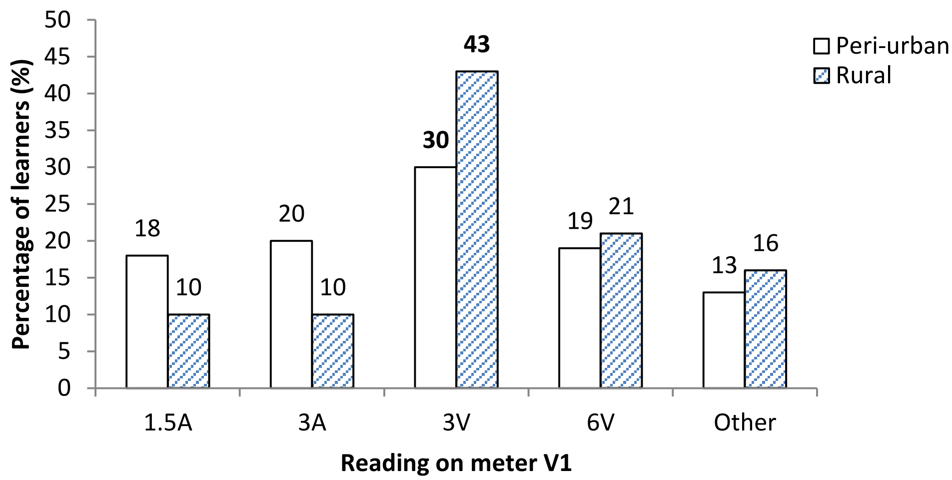


Figure 4.10: Learners' responses to reading on meter V_1 per school location

Figure 4.10 shows that majority of the peri-urban and rural school (49% and 64%, respectively) correctly identified the meter V_1 to be voltmeter (3V and 6V). Moreover, 43% of rural school and 30% of peri-urban school learners presented the correct option of reading 3V on V_1. Majority of learners in both schools experienced difficulties with the reading on V_1. However, the differences between the responses from rural and peri-urban schools in demonstrating the reading on V_1 were not statistically significant ($X^2 = 0.41$, $p > 0.05$).

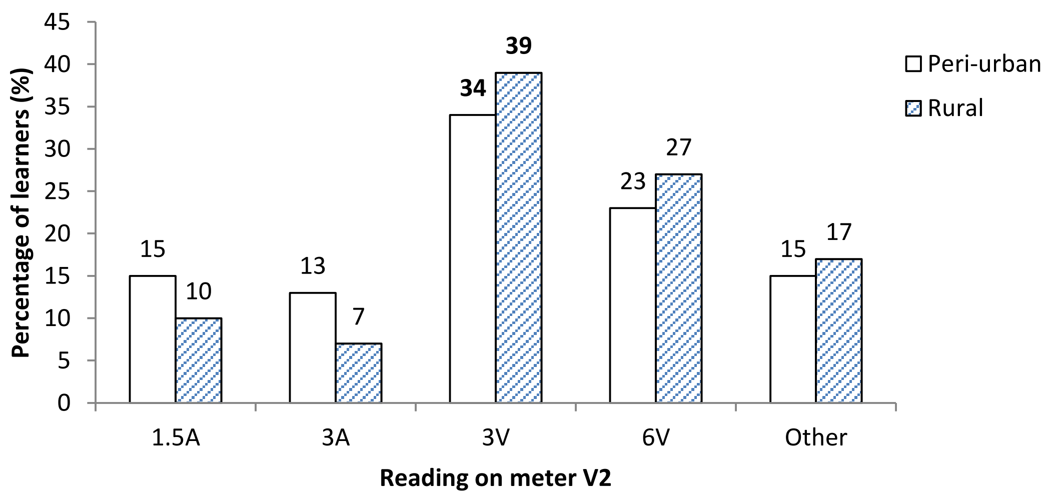


Figure 4.11: Learners' responses to indication on meter V_2 per school location

Figure 4.11 shows that majority, 57% of peri-urban and 66% of rural school learners, correctly identified V_2 to be a voltmeter (3V and 6V). The figure shows an improvement of 8% and 2% for the peri-urban and rural school, respectively, in identifying the second voltmeter. Once more, peri-urban school learners performed slightly lower than the rural school in identifying voltmeter symbols in the circuit. Moreover, few (34%) of the peri-urban and 39% of the rural school learners provided the correct meter reading. There seems to be a slight increase of 4% in the number of learners who provided correct responses from the peri-urban school while a slight decrease of the same percentage (4%) from the rural school learners observed. These changes could be attributed to lack of firm conception using different concepts for a presented situation (Engelhardt and Beichner 2004). The differences between the rural and peri-urban schools with regard to application of voltage in a series circuit were not statistically significant ($X^2 = 1.78$, $p > 0.05$).

Table 4.4 below presents a summary of the explanations provided by learners for supporting their choices on meters V_1 and V_2.

Table 4.4 Explanations for indications on meters V_1 and V_2 (Chi-square, $p < 0.05$)

Explanation N=137	**Actual number of responses**	**Frequency (%)** V_1 (N=137)	**Actual number of responses**	**Frequency (%)** V_2 (N=137)
No response	43	31	37	27
Uncodeable (not clear)	27	20	27	20
Energy/power related	5	4	6	4
Current related	21	15	22	16
Voltage divide	**19**	**14**	**27**	**20**
More/less voltage	5	4	2	1
Arrangement	7	5	11	8
Others	10	7	5	4
Total	**137**	**100**	**137**	**100**

Table 4.4 above indicates that majority of learners (51% V_1 and 47% V_2, respectively) experienced difficulties with the written language, because their explanations could not be comprehended as they were unintelligible or nothing was written to support their choices. The difficulty is best presented in Howie (2001) as cited in Probyn (2003) that:

> *The majority of South African pupils cannot communicate their scientific conclusions in the languages used for the test (i.e., English which was the medium of instruction and the language currently used for matriculation examination). In particular, pupils who study*

mathematics and science in their second language tend to have difficulty articulating their answers to open-ended questions and apparently had trouble comprehending several of the questions (p 1857).

Only 14% and 20% of the learners provided acceptable reasoning that potential difference divides in series. Excerpts give testimony to this assertion:

'Because we divide the potential difference by two' M67.

'Their potential difference is 6V so $V_1 + V_2 = 6V$ which is 3V + 3V' M56.

'Because the bulbs are identical they will share equal voltages, as they are connected in series' M57.

There were statistically significant differences in explanations provided for the readings shown by the two voltmeters ($X^2 = 4.81$, $p < 0.05$).

Part (c) required learners to identify ammeter A_2 and to indicate the current through it. They had to apply their knowledge of conservation of current in a series circuit and were also required to provide explanations for their choices. The results for identifying and showing a reading on A_2 are presented in Figure 4.12 below.

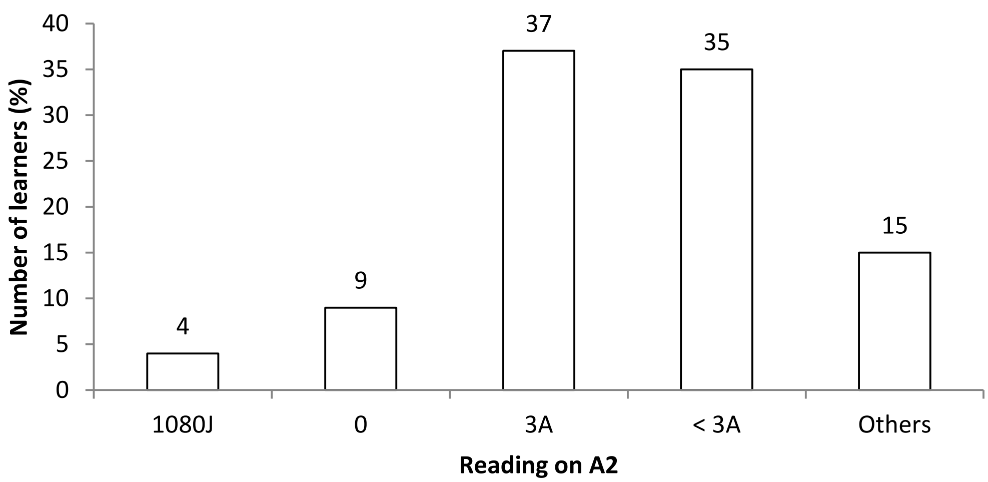


Figure 4.12: Learners' responses to a reading on Ammeter A_2

Figure 4.12 indicates that majority of learners (72%) correctly identified A_2 to be an ammeter (indications 3A and < 3A options). This suggests majority of learners knew how ammeter should be connected in a circuit. Figure 4.1 showed that almost all learners (~ 97%) knew the symbol for the ammeter. A decrease of 25% could be attributed to difficulties with identifying ammeter in a circuit. It seemed when individual components were connected together in a circuit, the circuit became complex such that learners experienced difficulties in identifying symbols for individual components. Only 37% of them provided the correct reading meter A_2 would have shown, while the other 35% thought ammeter A_2 would read less current. The latter indicates that learners were using current consumption model therefore, did not understand the conservation of current in a series circuit. This result confirms the observations made earlier where 31% of learners preferred the current consumption model. Some studies indicated that learners believed that an ammeter consume current for it to function (Planinic *et al.* 2006). Although majority of learners seemed to know how ammeter is connected in a circuit, results suggest that learners do not understand the device's role in the circuit and why it had to be connected the way it is connected.

Interviews revealed that all learners identified ammeter and 6 out of 13 presented that it would show 3A while the other (3) thought the current should be half (1.5A). In addition (4) thought current displayed by the meter should be less than 3A. This result shows that majority (7 of 13) were using current consumption model. One learner in support of the current consumption said:

"*I don't know how much current would reach bulb B because it is between A & B but A will use some and less left for B…*"

Figure 4.13 below shows the responses to the reading on ammeter A_2 presented in terms of geographical location of the schools.

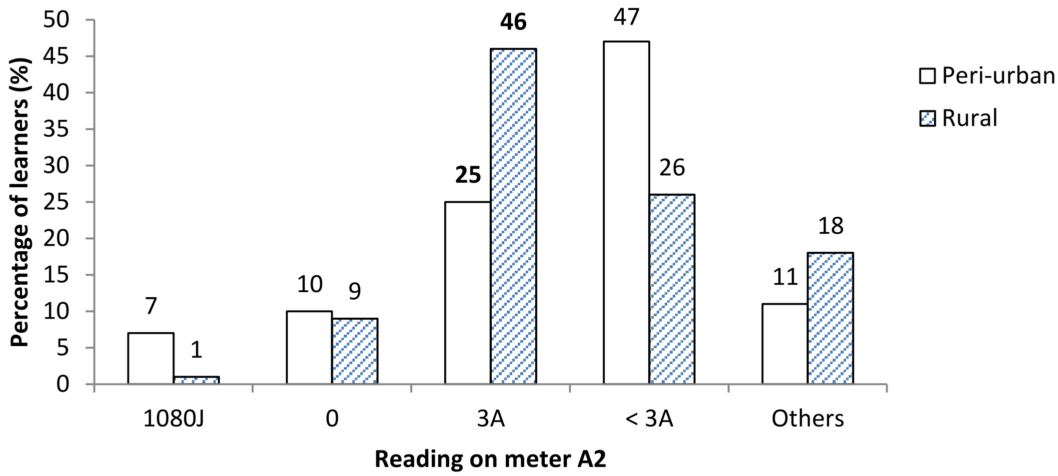


Figure 4.13: Learners' responses to reading on Ammeter A_2 per school location

Figure 4.13 shows that majority of the peri-urban learners (47%) were using current consumption model where they showed that current through the second ammeter would be less than 3A. They were of the view that current gets used up along the way; hence the need for a battery to supply the circuit with charged particles. On the other hand majority of the rural school learners (46%) provided the correct option that A_2 would have read 3A (the total current of the circuit). About half of the rural school learners seemed to have appreciated the fact that current remains constant in a series circuit. The differences between rural and peri-urban school learners with regard to knowledge of current in a series circuit were statistically significant (X^2 = 10.65, p < 0.05). Thus current conservation could be associated with geographical area. Summary of the explanations provided to support the reading on ammeter A_2 are presented in Table 4.5 below.

Table 4.5 Explanations for the reading on Ammeter A_2

Explanation	**Number of responses**	**Frequency (%)** N=137
No response	46	34
Uncodeable (not clear)	22	16
Energy/power related	9	7
Same current	**25**	**18**
Less current	14	10
More current	3	2
Others	18	13
Total	**137**	**100**

According to Table 4.5 majority of learners (34%) did not provide reasons for their choices, while the other 16% of the responses could not be comprehended because they were unintelligible. Half of the learners either seemed to have had difficulties with providing written explanations, or they lacked knowledge to support their choices.

Only few learners (18%) provided correct explanations that current in a series circuit remains constant. There were also some few learners (10%) who explained that current gets reduced as it moves along the circuit therefore less would reach bulb B. The latter confirms the current consumption model which literature says is easy and logical to learners (Planinic *et al.* 2006).

The results have shown that learners were able to identify ammeter and voltmeter symbols in the circuit. However, a majority were unable to indicate the correct reading the meters would have shown. Moreover, majority failed to offer explanations in terms of scientific principles but resorted to observable phenomena to support their answers such as ammeter connection to indicate more or less current. Clearly the role played by ammeter was not understood. Hence, recognizing the symbols involved in schematics circuit diagrams without knowing and understanding their functions does not suffice.

4.5 UNDERSTANDING OF BASIC ELECTRICAL CONCEPTS

4.5.1 Knowledge of a Conductor

Question 3 of section A, part (b), dealt with knowledge of a conductor. It required learners to indicate what they understood to be a conductor. The results are presented in Figure 4.14 below indicating the responses in terms of percentages.

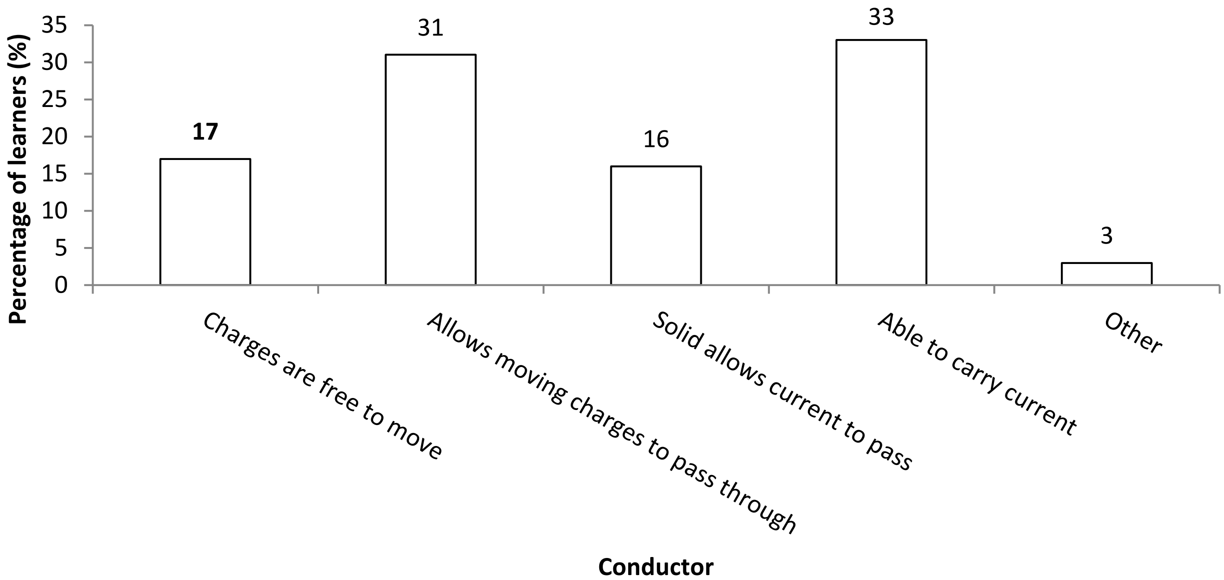


Figure 4.14: Responses to knowledge of a conductor

Figure 4.14 shows that 33% of the learners presented a conductor to be a material which was able to carry electrical current and 31% thought it was a material which allowed moving charges to pass through easily. Only 17% answered correctly in accordance with the appropriate scientific knowledge. Eighty percent (31%+16%+33%) of the learners chose options with alternative conceptions. The ability to carry electrical current and allowing moving charges to pass through suggest that learners thought of a conductor to be a hollow pipe like material which allowed moving charges or electric current to pass through.

Follow up interviews with smaller numbers of learners (N = 13, two groups of 7 and 6 from each school) showed that most learners (6) thought that a conductor should allow moving charges to pass through easily while others (3) thought a conductor should be any material that is capable of carrying electric current. One learner said:

"*it should be something that conducts electricity*".

However, 3 learners responded that the material should be a solid for it to be able to carry electric current. The latter could be attributed to lack of practical experience.

Several learners' text books use simplified water-in-pipes analogy to explain current as the flow of water and voltage as the force (pressure) responsible for moving the water and relate pipes to conductors (Sefton 2002). The analogy introduced inadequate understanding of the crucial basic concepts, as learners thought of conductors as solid hollow materials rather than materials with charges which are free to move. A hollow material and ability to carry would suggest that charges moving within the wires would have to come from elsewhere. Hence, there has to be a component that supplies conductors with charges and there should be components which use the charges.

Figure 4.15 below indicates responses in terms of geographical school location.

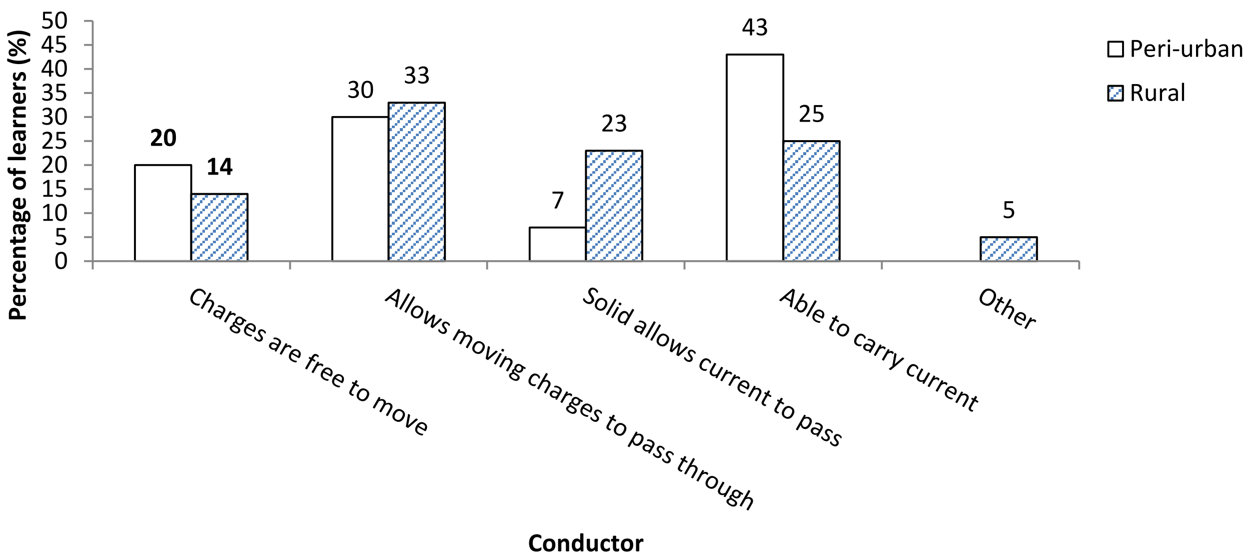


Figure 4.15: Responses to knowledge of a conductor per school location

Figure 4.15 indicates that majority (43%) of the peri-urban learners thought a conductor should be a material which is capable to carry electric current. Only 20% of the learners from this school presented scientifically acceptable option. On the other hand, a majority (33%) of rural school learners thought a conductor to be a material which allowed moving charges to pass through easily, while only 14% presented scientifically acceptable responses. There was a statistically significant difference (X^2 =10.64, $p < 0.05$) between the responses presented by the two schools. It, therefore, suggests that results could be associated with the location of the school. It was apparent from the responses that the concept 'conductor' was not well understood by learners from the two schools (80%). The results are in agreement with observations made by Bilal and Mustafa (2009) who specified that the roles of the conductor need to be given more attention during instruction.

4.5.2 Learners' knowledge about Current, Voltage and Power measurements

Question 4 of section A dealt with the meaning/interpretations of readings for current, voltage and power. It had three parts (a) - (c) where learners were requested to choose the correct option. The questions were intended to explore if learners understood and appreciated the meaning of measurements (reading of current, voltage and power) taken using measuring instruments. The questions explored learners' mental models of what happens in electrical circuits to enable them to understand key concepts like current, voltage, etc.. Frederiksen *et al.* (2000) reported that learning electricity is centred on solving numeric problems. Therefore, the reasoning involved is on how to manipulate the equations. Learners are not shown how the circuit theory is related to what is happening in the physical circuit.

4.5.2.1 Electric Current Measurements

In part (a), learners were presented with a reading of 2 Amperes to interpret. They were to use their understanding of the concept of current to interpret the reading. The results are presented below in Figure 4.16 indicating the responses as presented by learners.

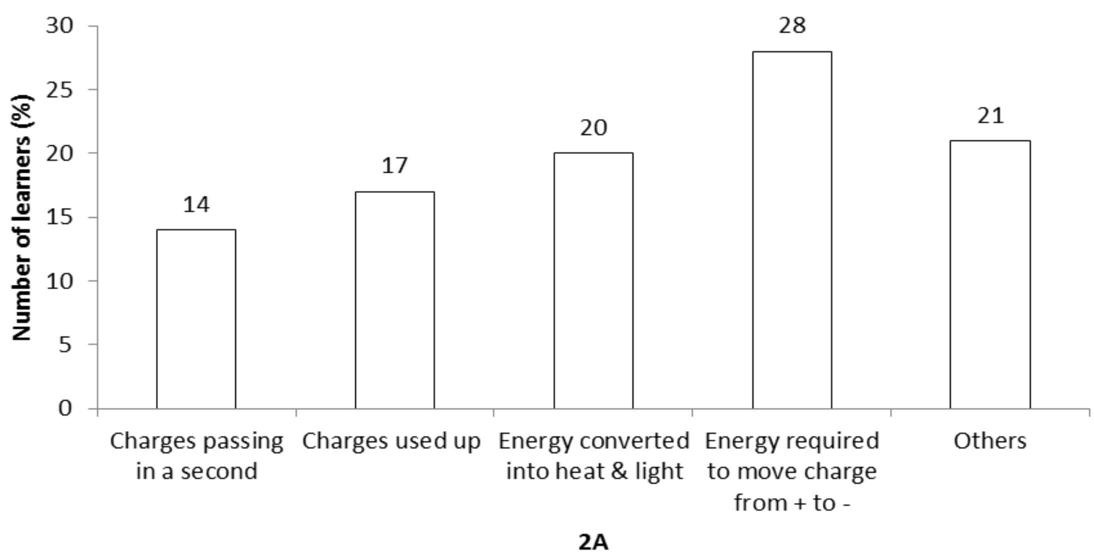


Figure 4.16: Learners' responses to interpretation of 2A

It is apparent from Figure 4.16 above that majority (28%) of learners thought 2A to be the amount of energy required to move 2 Coulomb of charge from the positive terminal to the negative terminal. Subsequent interviews showed that five (5 of 13) learners supported this view. This finding indicates that learners associated current with potential difference. It shows that learners did not distinguish between current and voltage. Cartensen and Bernhard (2007) presented that learners have a problem with concept differentiation because current and voltage are interdependent.

Few learners (14%) correctly interpreted 2A as the amounts of charge that flows through a given area or point in a second while the other responses were spread. Interviews further showed that 3 learners thought 2A indicated the energy converted into light while the other 3 thought it showed the consumed charges. There were also 2 learners during interviews, who could not provide a meaning for 2A and responded by saying:

"*not sure*".

Further analysis was done in terms of geographical location of the school and the responses are presented in Figure 4.17 below.

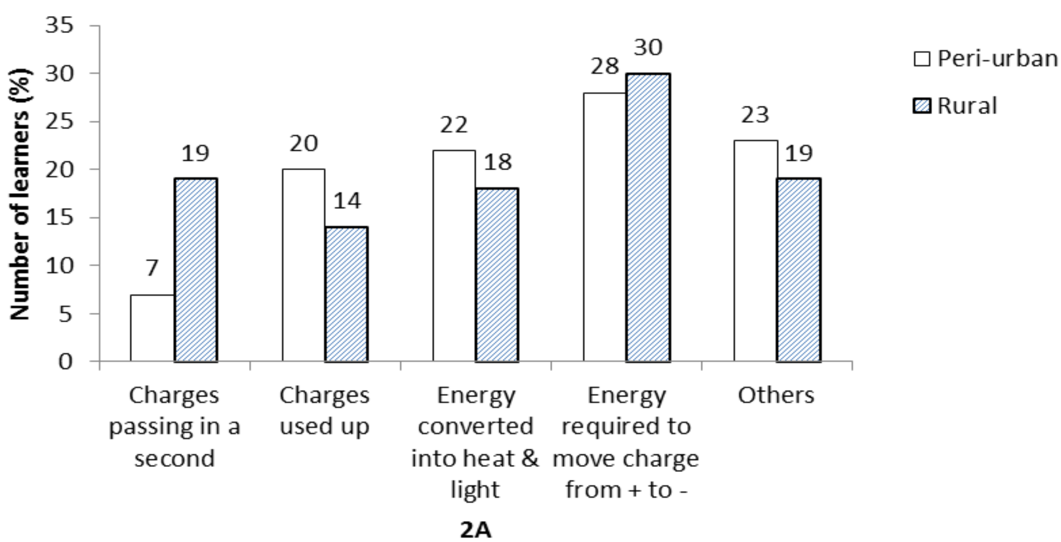


Figure 4.17: Learners' responses to interpretation of 2A per school location (Chi-square, $p < 0.05$)

Figure 4.17 above shows that only 7% from the peri-urban school and 19% from the rural school provided acceptable responses. A statistically significant difference ($X^2 = 4.48$, $p < 0.05$) between the responses presented by the two schools, suggests that the geographical location of the school could be a factor. Figure 4.17 also indicates that majority (30%) of the peri-urban learners and 28%

of the rural school learners chose the option that 2A was the energy required to move a charge from one terminal of the battery to the other, this indicate lack of concept differentiation.

4.5.2.2 Voltage measurements

Part (b) asked learners to interpret a reading of 220 volts. The question explored learners' understanding of numerical values found written on batteries and readings they get from voltmeters during measurements. They had to apply their knowledge of potential difference- a conception found by many authors difficult to understand because it is unobservable (Duit and Rhӧneck 2002, Planinic *et al.* 2005, Taber *et al*. 2006).

Responses to the interpretation of the reading of 220 volts are shown in Figure 4.18 below.

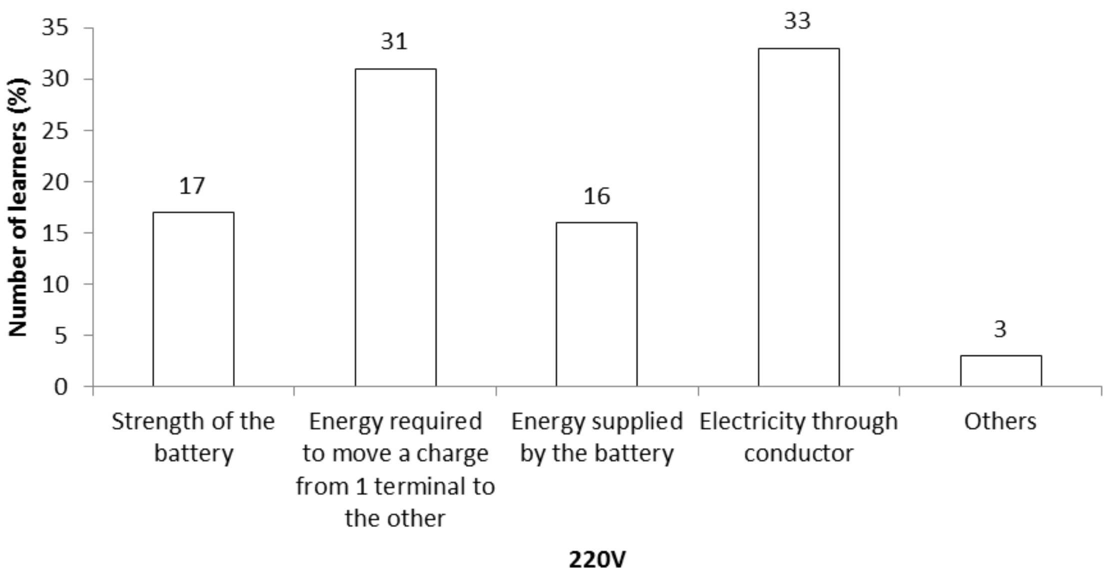


Figure 4.18: Responses to interpretation of 220V

Inspection of Figure 4.18 above depicts that most (33%) learners thought of 220V to be the electricity through the circuit. The use of the term 'electricity' flowing through a conductor seemed to suggest that learners were using 'electricity' to refer to the substances moving within the conductors. Current is said to be the amount of electrically charged particles flowing through a particular point in a conductor per second. Therefore, flowing 'electricity' may be equated to current. Learners could be using electricity and current interchangeably. Similar results were observed by Duit and Rhӧneck (2002) who found that even after instruction learners used voltage as if it had the same properties as current. In addition, Psillos (1998) found that several learners thought the number of volts indicates the quantity of current stored in a battery. Thus, they considered voltage to indicate the current instead of the electrical energy required to move a charge from one point to the other.

However, a similar percentage of learners (31%) thought 220V was the energy required to move a charge from one terminal of the battery to the other terminal. Few learners (17%) thought it was indicating the strength of the battery.

The interviews showed that majority of learners (7 of 13) thought 220V indicated the amount of energy the battery would supply to the circuit, while the other (6) learners thought it specified the strength of the battery. One of the 6 learners said:

"*it is the strength of the battery because it indicates how much current the battery will give to the circuit*".

It was apparent from this explanation that the learner thought voltage indicates how much current the battery had and how much it will give to the circuit as soon as it is connected.

Figure 4.19 below indicates learners' responses in terms of geographical location of their school.

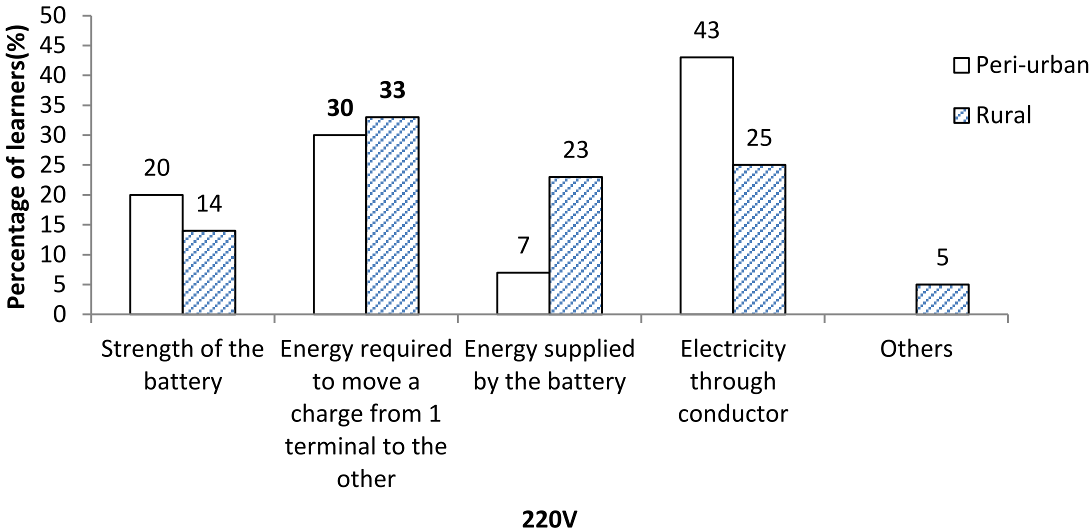


Figure 4.19: Responses to interpretation of 220V per school location

Figure 4.19 shows that the prevalent view among peri-urban school learners **(**43%) was 220V indicated the electricity through the conductor while the prevalent view among the rural school learners (33%) was the energy required to move a charge from one terminal to the other. Most of the peri-urban school learners seemed to be the ones confusing voltage and current while few rural (33%) and peri-urban school learners (30%) presented scientifically acceptable responses. There was a statistically significant difference (X^2 = 10.01, p < 0.05) between the responses to interpretation of 220V. Thus, the results can be associated with geographical location of the school.

4.5.2.3 Electric Power measurements

Part (c) presented learners with a reading of 440 watts to interpret. They had to use their understanding of the electrical power in electrical circuits to interpret the reading. The results for interpretation of 440W are presented in Figure 4.20 below.

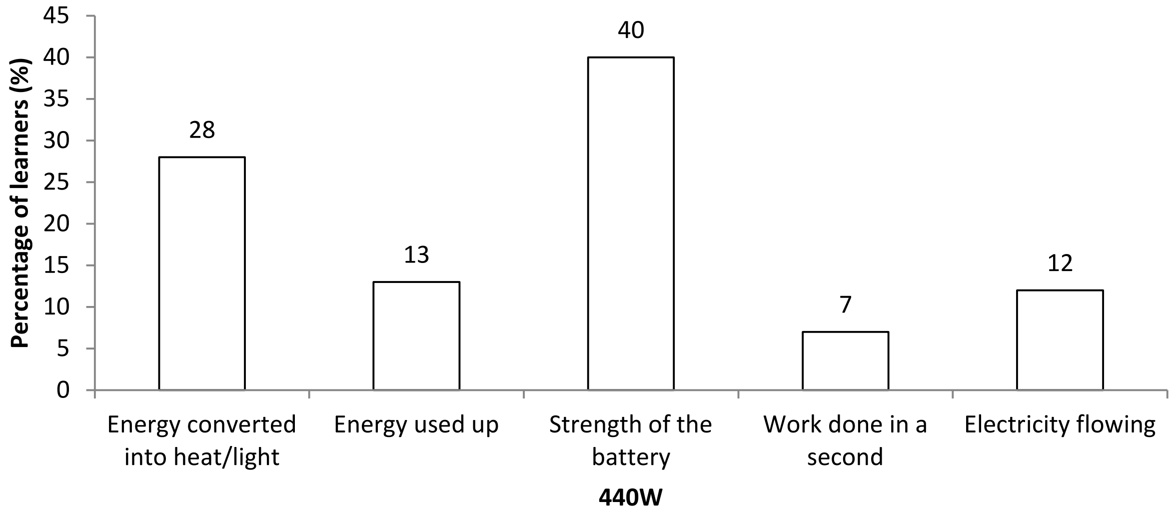


Figure 4.20: Summary of the responses to interpretation of 440W

Figure 4.20 above shows that most learners (40%) thought 440 W to be the 'strength' of the battery. Strength of the battery suggests power is an indication of how much the battery is giving to the circuit, irrespective of the arrangements of the components. This indicates learners took power to have the same properties as current. Hence, 440W is the amount of current the battery supplied to the circuit. According to Bryan and Stuessy (2006) the terms current, potential difference, power, resistance and energy cause confusion in learners' minds as a result they are often used interchangeably.

Further analysis was done in terms of location of the school and the responses are presented in Figure 4.21 below.

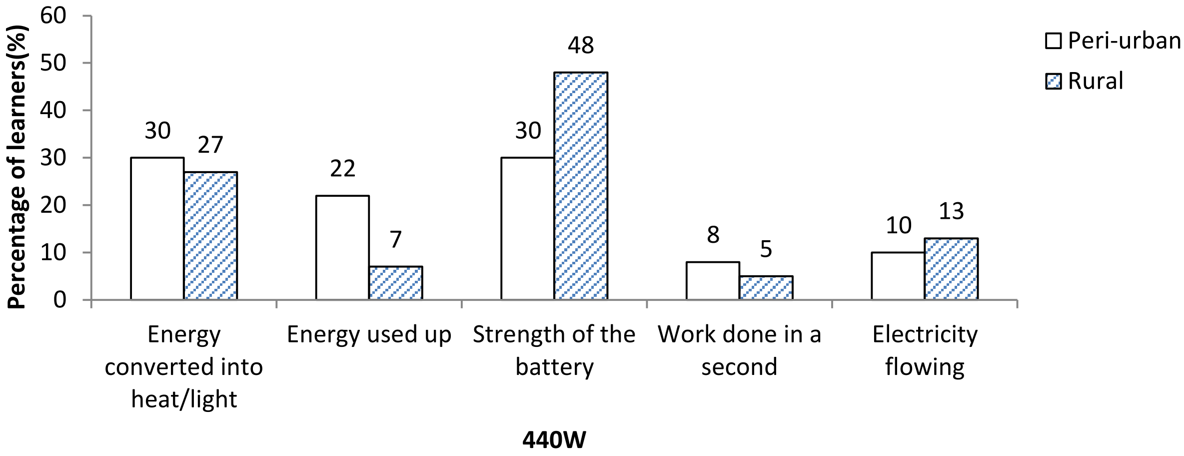


Figure 4.21: Summary of the responses to interpretation of 440W per school location

Figure 4.21 shows that a majority (48%) of the rural school and 30% of the peri-urban school learners thought 440W was the strength of the battery. There was a statistically significant difference between the responses presented by the two schools ($X^2 = 6.88$, $p < 0.05$). The results can be attributed to a location of the school due to a pattern of responses presented.

4.5.3 Basic direct current electrical circuit

4.5.3.1 Conceptualization of a physical layout of a realistic circuit

Question 2 of section B of the questionnaire focused on a translation of realistic circuit to a schematic representation. The learners were presented with a pictorial representation of a realistic circuit, which they had to analyze to identify the measuring devices used. The circuit consisted of 2 batteries connected in series, 1 light bulb, an ammeter and a switch (see Figure 4.22 below).

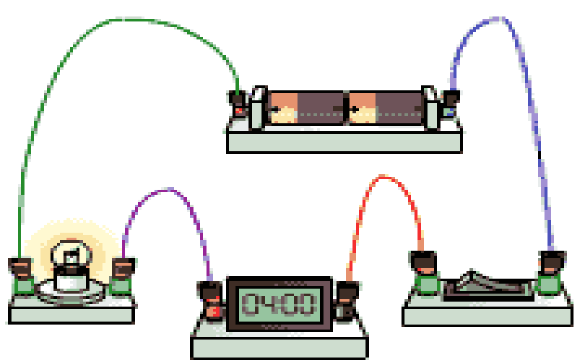


Figure 4.22 Representation of a realistic circuit showing how variuos elements in the circuit are connected.

Figure 4.22 depicts light bulb lit with an ammeter indicating current readings. However, learners had to identify what the measuring instrument was (i.e., ammeter). They had to look at configurations of the circuit to make an informed decision. The question required learners to use their knowledge of real components, circuit symbols and knowledge of how measuring instruments have to be connected in a circuit. The responses to translation from realistic circuit to a schematic representation of a circuit are presented in Figure 4.23 below.

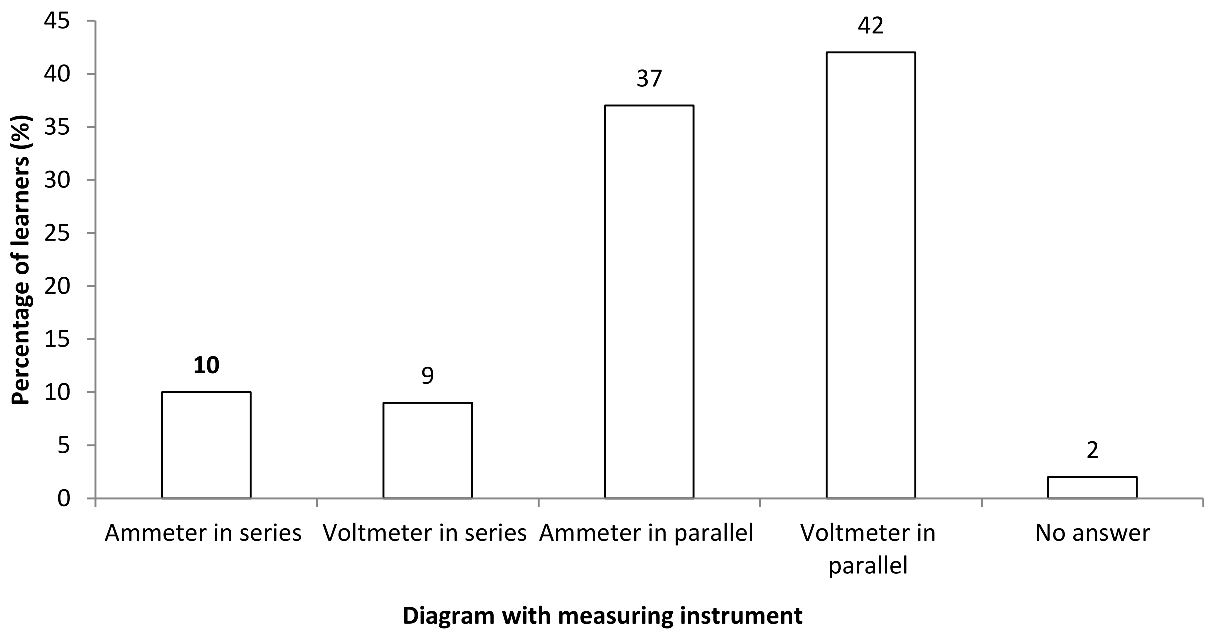


Figure 4.23: Learners' responses to matching realistic circuit to a schematic diagram

Figure 4.23 shows that the majority of learners (42%) were of the view that voltmeter was connected across the circuit, whilst 37% thought that ammeter was connected in parallel. Hence, altogether 88% (42%+37%+9%) of the learners had difficulties configuring how meters should be connected. Bernhard and Cartensen (2002) indicated that learners who cannot differentiate between voltage and current tend to struggle in connecting their measuring instruments.

In addition, Figure 4.23 indicates that about half of the learners (51%) were unable to recognise the measuring device in question to be an ammeter, as they chose circuits with voltmeters. During the interview, learners were requested to identify and label the components involved. Almost all positively identified battery, bulb, and switch however, almost all failed to identify ammeter. One learner said

“...*not sure whether there is voltmeter or not*”.

After some deliberations among themselves, the majority (8) decided on a circuit diagram which had an open switch and voltmeter while the other learners (5) opted for a circuit which had its ammeter in parallel. When they were asked to provide explanations for their choices they wanted to change their responses, and there was no proper reasons given. It was apparent that learners had difficulties with the presented schematic circuit diagrams.

Learners could not analyse the arrangement of the circuit components to decide on what the meter was measuring. About 80% of the learners chose diagrams which had their meters connected in parallel (37% & 42% for ammeter and voltmeter, respectively). Interviews revealed that some learners were using orientation to support their responses. They argued that the switch was open because it was in the same orientation as the open switch on the schematic circuits.

Due to difficulties in both concept differentiation and component identification, confusion between parallel and series, it was, therefore, difficult for learners to move from a realistic circuit to a schematic circuit representation. Only a few learners (10%) provided scientifically accepted schematic circuit diagram. This finding contradicts the findings of Engelhardt and Beichner (2004). Learners lacked the understanding of the role played by ammeter and voltmeter in electricas circuit (why they are essential in electrical circuits). Not knowing how these meters should be connected in electrical circuits, could be related to a lack of actual practical experience with electrical circuits and not seeking to understand the circuits, but using them to manipulate equations to get correct answers. Dzama (1997) in their investigation in London and Malawi found that learners were unlikely to make mistakes of how measuring devices are connected if they had practical experience with electrical circuits. Research also indicates that learners have difficulties in translating between the ‘real’ world (electrical circuits) and mathematical representation (Bernhard and Carstensen 2002).

Responses are further presented below through Figure 4.24 in terms of learners’ school location.

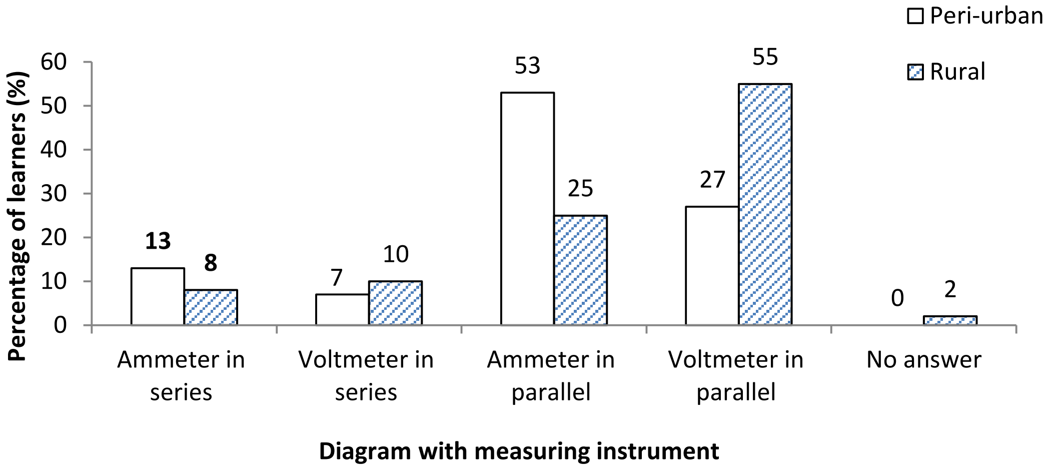


Figure 4.24: Responses to matching realistic circuit per school location

Figure 4.24 above indicates that the majority of peri-urban school learners (53%) opted for circuit diagrams with ammeter in parallel, while majority of the rural school learners (55%) chose circuit diagrams with voltmeter in parallel. It seemed that more than half of the rural school learners knew that voltmeter is connected in parallel, although they could not differentiate between parallel and series in a realistic circuit. The differences of rural and peri-urban school in transforming from a realistic circuit to a schematic one were statistically significant (X^2 =14.43, $p < 0.05$).

It was apparent that without experience learners could not translate from realistic circuit into a schematic diagram. They lacked the essential process skills. As a result, they did not associate the realistic circuit with its schematic representation. The results are in contrast to Engelhardt and Beichner (2004) who found that learners had difficulties in translating from schematic circuits to real circuits not vice versa. In addition, Bernhard and Cartesen (2002) found that learners who have not conceptualised the difference between current and voltage struggle to connect meters. For example, they would connect ammeter in parallel and voltmeter in series. The latter seemed to be the reason learners were confusing ammeter with voltmeter.

4.5.3.2 Flow of electric charge between a battery and a bulb in a schematic circuit diagram

Question 7 of section B dealt with the understanding of a flow of charge in a direct current resistive circuit. Learners were presented with a layout of circuit diagram showing a lit bulb connected to a battery with two wires. They were required to select the best model which represented the direction of current through the wires. They were presented with four (models) schematic diagrams to choose from which were as follows:

- Model (a) indicated charges in one wire moving towards the bulb (uni-polar model).
- Model (b) showed charges in both wires, however, with unequal amounts of charges in the wires, one wire had more charges flowing from the battery to the bulb and less charges moving towards the battery after the bulb (attenuation model).
- Model (c) showed the same amount of charges in both wires in a continuous loop (scientific model).
- Model (d) indicated equal amount of charges in the two wires moving from the battery to the bulb (clashing current model).

The results presented by learners are depicted in Figure 4.25 below as percentages of chosen model.

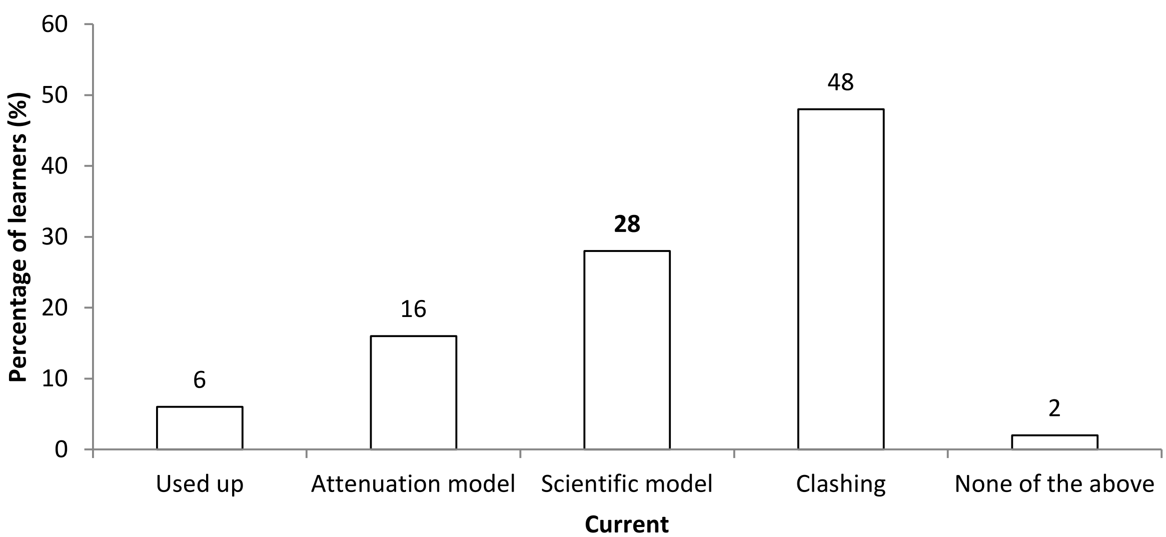


Figure 4.25: Learners' responses about path of the current in a circuit

The majority of learners (48%) were in support of the clashing current model as shown in Figure 4.25 above. The results are in agreement with observations made by Jaakkola and Nurmi (2004) who investigated learners conceptual change process in understanding the current in direct current resistive electrical circuits. Figure 4.25 further indicates that only 28% opted for the scientifically accepted model. However, interview results were inconsistent. Seven of the 13 (54%) learners presented the scientific acceptable responses although they could not support their choices. In addition, there were others 3 who selected the clashing current model, lastly (3) learners selected the attenuation model. A high number of learners (54%) opting for the scientific acceptable model during the interview could have been due to influence by dominant participants. During discussions it emerged that in a rural school a similar circuit was discussed during their class sessions and one learner reminded the other learners about it and the conclusions made thereof.

Results are further presented below in Figure 4.26 in terms of the geographical location of the school.

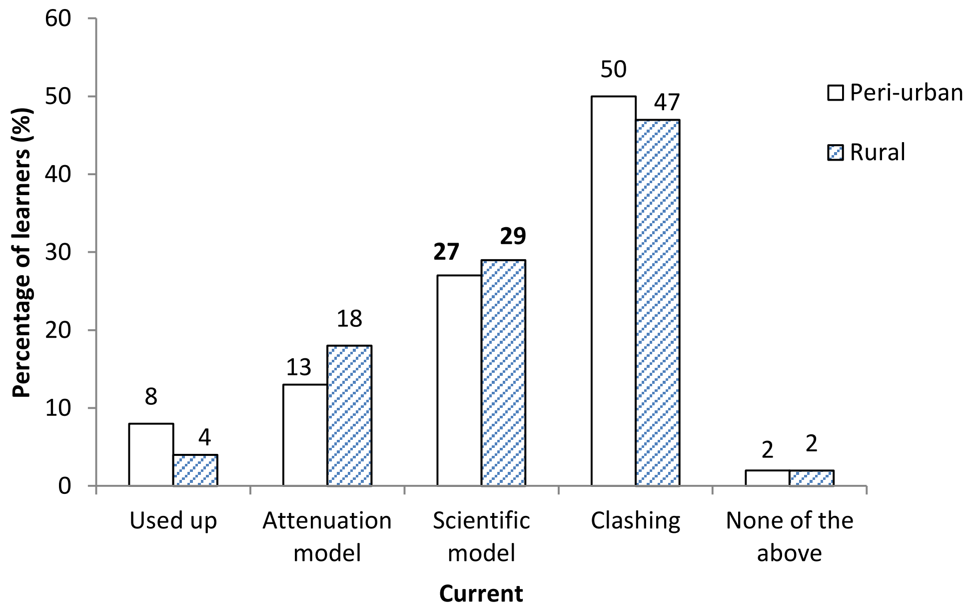


Figure 4.26: Learners' responses about path of the current in a circuit per school location

Figure 4.26 indicates that majority of the learners (50% peri-urban school and 47% rural school) chose a clashing current model. However, the scientific acceptable model received 27% and 29% from the peri-urban school and rural school learners, respectively. The difference between the two schools with regard to knowledge of the flow of charge in a circuit was not statistically significant (X^2 =1.59, $p > 0.05$).

The findings are inconsistent with responses presented in Figures 4.5 and Figure 4.12 above, which presented that 31% and 35% of learners respectively, where using current consumption models.

Planinic *et al*. (2005) reported that simple direct current resistive circuits to be an area that learners' lacked understanding of any nature (scientifically correct or alternative). Researchers presented that many learners failed to develop conceptual model regarding the flow of electric charge in circuits and those who did, embraced alternative models rather than the scientifically acceptable one.

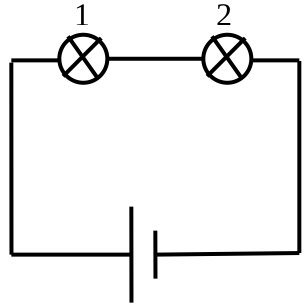
The direct current resistive circuits presents a confusion of concepts due to concept abstraction, concept interdependent and therefore results in lack of solid conception of any kind. The results are likely an indication of the learners' experiences through their schooling years and also an indication of the manner they were taught electricity. Research indicates that learners who were exposed to traditional way of teaching cannot apply concepts to new situations not specifically memorized and cannot give the necessary qualitative reasons (Heron *et al*. 2005).

4.6 SERIES-PARALLEL DIRECT CURRENT RESISTIVE CIRCUITS

Question 1 of section B of the questionnaire had two parts [(a) and (b)] with both closed and open-ended formats. Closed-ended questions consisted of a multiple-choice with four options to choose from. However, there was only one correct answer. The open-ended questions required learners to give reasons for their selected options.

4.6.1 Current in series and parallel circuits

In part (a) learners were presented with a simple series circuit with two light bulbs (see circuit 1). Learners had to indicate the bulb(s) which would glow brighter and give reasons for their choices. They were to apply their knowledge that current in a series circuit is constant, because there is only one path for the charged particles to flow through.



Circuit 1

The results are presented below in Figure 4.27 as percentages of their responses.

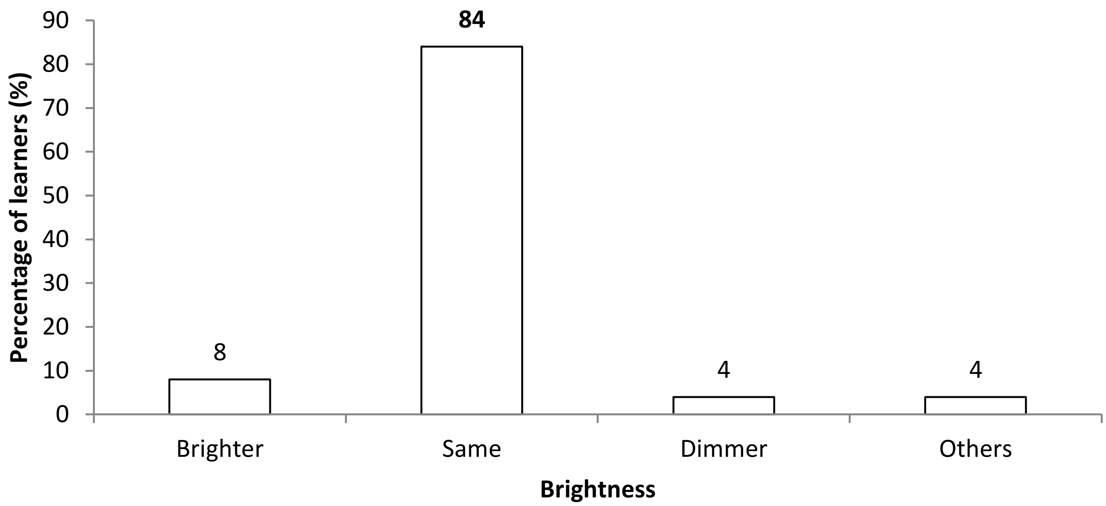
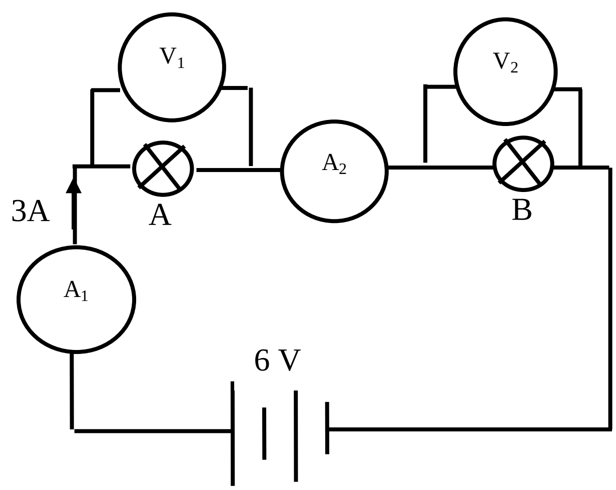


Figure 4.27: Learners' responses to brightness in series

As depicted in Figure 4.27 majority of learners (84%) correctly provided that two bulbs in circuit 1 would have the same brightness. Learners seemed to have known that current is conserved in a series circuit. However, in contradiction, Figure 4.12 of section 4.4.3 showed that only 37% of learners presented the correct current through ammeter A_2 in circuit 12.



Circuit 12

Since the results are contradictory, it could be suggested that perhaps circuit 12 was too populated and therefore made it difficult for learners to look at it as a simple series circuit. According to Taber *et al* (2006) addition of ammeters in a circuit complicates the circuit. This confirms the thought that learners lacked firm conceptions as they presented different solutions to different situations. Moreover, the results are further presented in Figure 4.28 below in terms of the location of the school.

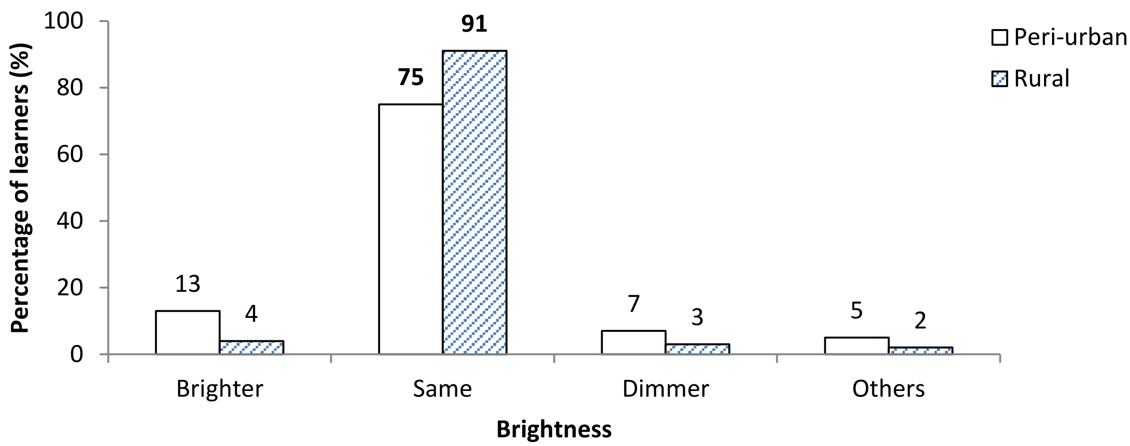


Figure 4.28: Learners' responses to brightness in series per school location

The results presented through Figure 4.28 shows that 91% of the rural and 75% of the peri-urban school learners expressed a view that the brightness of the two bulbs in series would be the same. Although, both schools presented the scientifically accepted responses there was a statistically significant difference in the number of learners choosing the correct option (X^2 = 4.34, p < 0.05). Table 4.6 below presents the summary of the explanations provided by learners.

Table 4.6 Learners explanations to brightness of two bulbs in series (circuit 1)

Explanation	**Number of respondents (**N=137)	**Frequency (%)**
Electricity related	14	10
Energy related	20	15
Power related	4	3
Connected in series	36	26
Series, current same	**25**	**18**
Bulb size	4	3
Battery related	5	4
Others	7	5
No response	5	4

Uncodeable (not clear)	17	12
Total	**137**	**100**

The dominant reasoning across the given situations was phenomena-based; learners were looking at the arrangements of the components. Table 4.6 indicates that the most common reasoning given by learners (26%) was two bulbs display same brightness because they are in series. For example:

> ‘Because they are connected in series’ D46, M64, M72
> ‘Because both of them are connected in series’ D04
> ‘They are connected in series’ D56, D12, D32, M08, and M54
> ‘They are all in series’ M02

Bryan and Stuessy (2006) found that learners who used this kind of reasoning thought when two bulbs were connected in series, they would share the amount of brightness that one bulb would have. Although a majority of learners (84%) in Figure 4.27 presented the correct option for the multiple-choice question, Table 4.6 shows that only 18% gave partially acceptable reasoning because the usage of terminology was scientifically inadequate in most instances. For example some learners said:

> ‘Because they are connected in series so they have the same current flow’ D54.
> ‘They share the same current flowing in the circuit’ M46

The use of ‘current flow’ by learner D54 seems to suggest what was flowing within the wires was current, therefore when the flow stops one would have a stationary current.

Table 4.6 also indicates that a number of learners 25% (10%+15%) used explanations that what was flowing through the circuit to be electricity or energy. Below are some of the extracts:

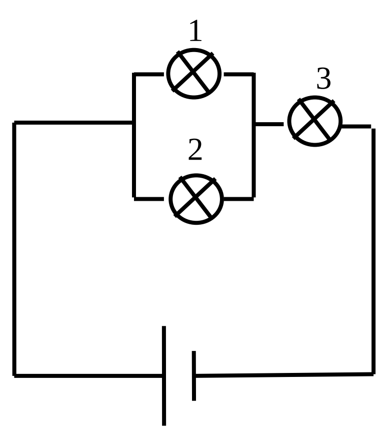
> ‘They have the same electricity flowing through them…….’ M22, M09.
> ‘They share the electricity that flow in the circuit’ M35.
> ‘They receive equal amount of electricity flow…’ D36, D52.
> ‘They receive the same amount of energy from the cell’ D08
> ‘They are connected in the same circuit, and energy flow is the same’ D 16

‘They all get the same energy in the circuit’ M56

The use of electricity could be traced to the everyday talk where one buys ‘electricity’ from the utility company. It was clear that learners did not differentiate between the scientific concepts and their everyday usage. Since everyday concepts do not have the same meaning as scientific ones, this could have a negative effect on learners’ understanding of the concepts in a scientific context. This result is consistent with previous observations where voltage (220V) was said to indicate the electricity flowing within the wires.

Moreover, Table 4.6 shows that 16% (4%+12%) of the learners presented explanations that could not be comprehended or did not provide any reasoning for their selected option. Because of the responses which could not be comprehended it could be suggested that some learners had difficulties with the language used.

Part (b) presented learners with a series-parallel direct current resistive electrical circuit (combination circuit) (see circuit 2 below) consisting of a battery and three identical bulbs (1, 2 and 3). Two of the light bulbs (1 and 2) were connected in parallel to each other and in series to the third (3) one. Learners had to compare brightness of bulb 1 to bulb 3.



Circuit 2

The results are presented through Figure 4.29 below indicating learners’ responses to comparing the brightness of bulb 1 to bulb 3.

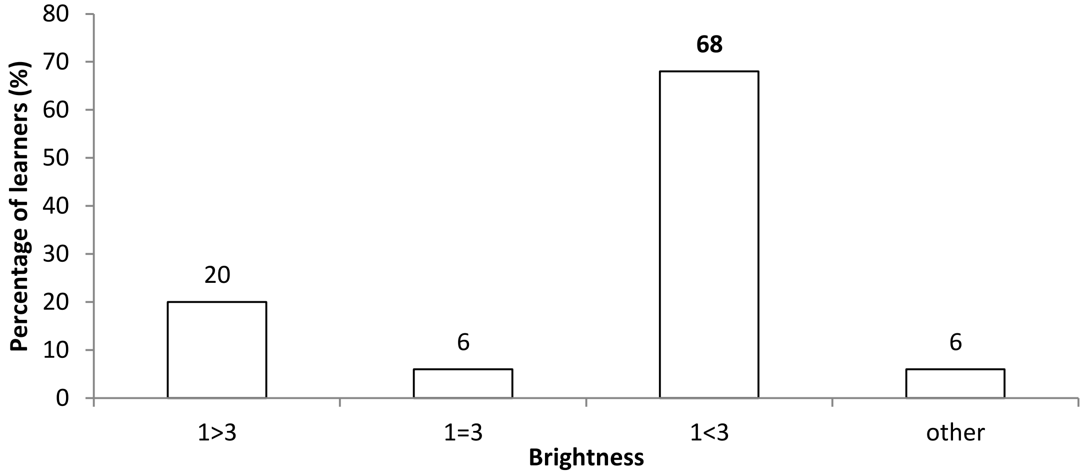


Figure 4.29: Learners' responses to brightness in series-parallel combination circuit

Figure 4.29 indicates that most learners (68%) correctly presented that bulb 3 would be brighter than bulb 1. They seemed to know that current divides in parallel branches and (combine) whole in series. Küçüközer and Kocakülah (2007) used a similar circuit diagram to probe learners understanding of current in series and in parallel, however, their circuit had four light bulbs instead of three and they also had a closed switch in one of the parallel loops. The fourth bulb was connected after the parallel branch, and thus their circuit had one bulb before the branch, two in parallel and the other one after the branch. Learners were required to choose the correct order of bulbs in terms of brightness and to explain their choices. Their findings showed that only 8% provided acceptable responses while majority (33%) thought there would not be current in the circuit since the switch was closed. Their results contradict our findings since majority of their learners got confused by the presence of a closed switch.

Results are further presented below in Figure 4.30 in terms of the location of the school.

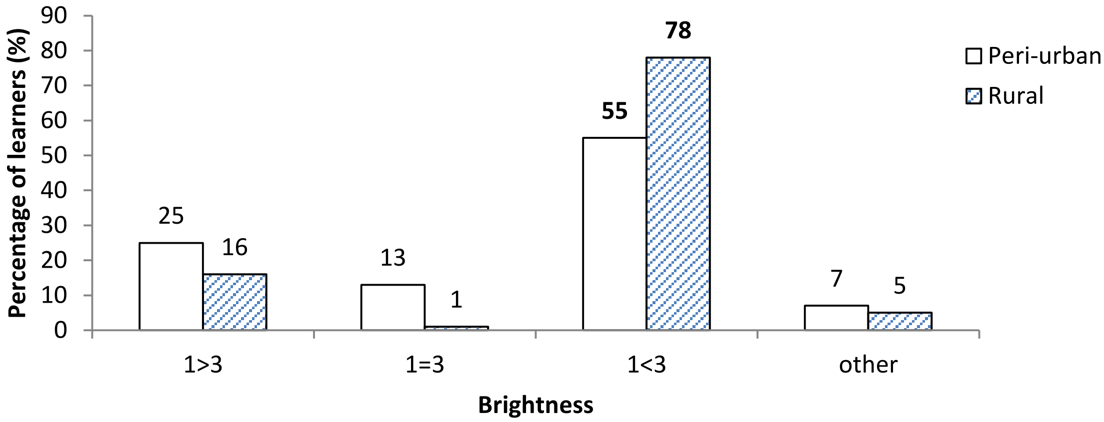


Figure 4.30: Learners' responses to brightness in combination circuits per school location

Figure 4.30 depicts that a majority of learners (78%) from the rural school and 55% of the peri-urban school held the same view that current divides/splits in parallel circuits. The estimated significance of rural and peri-urban responses regarding the brightness of bulbs in series-parallel circuits is statistically significant (X^2 = 4.56, p < 0.05). This indicates that knowledge of current splitting in parallel and combining in series could be associated with the location of the school.

Table 4.7 below presents a summary of the explanations given by learners and followed by some selected quotations.

Table 4.7 Explanations about brightness of one bulb in series compared to two in parallel

Explanation	Number of responses N=137	Frequency (%)
Current related	7	5
Voltage related	1	1
Energy/Electricity & Brightness	36	26
Power related	4	3
Resistance related	1	1
Bulb size/Battery	4	3
Parallel, current divide	30	**22**
Arrangement	29	21
No response	10	7
Uncodeable (not clear)	15	11
Total	137	100

It is apparent from Table 4.7 that few learners (22%) gave acceptable reasoning where they presented that since bulb 1 is connected in parallel to bulb 2 current will divide between the two and will be whole in 3. It is worth noting that from 68% of learners who selected acceptable options, only 22% where able to write scientifically acceptable explanations. Below are some of the examples of explanations:

> 'Bulb 1 and 2 share the same current which passes through bulb 3 because they are connected in parallel (current which passes through 3 divides into 2 when it reaches bulb 1 and 2)' M08.
>
> 'Because bulb 3 uses all the current in the circuit and bulb 1 share the current with bulb 2 because they are connected in parallel' M70.
>
> 'Bulb 3 requires more current than 1, because 1 shares current with 2. They connected in parallel' D03.

It is evident from Table 4.7 that some of the learners (21%) who responded correctly to the multiple-choice question were using phenomena-based reasoning like bulb displays a certain degree of brightness because they are in a particular arrangement. These learners used observable features in their reasoning rather than conceptual models. This kind of reasoning is said to be due to lack of distinction between a description and an explanation (Bryan and Stuessy 2006).

Table 4.7 also depicts that 26% of the learners who responded correctly to the multiple-choice question were using alternative conceptions to refer to current within the conductors. For example they were using electricity, brightness and energy in their explanations:

> 'Because this two bulbs 1, 2 are sharing the electricity from the battery and bulb 3 is not sharing with any bulb' D11.
>
> 'Because 1 is connected in parallel to 2 and uses ½ the electricity is used by 3' D27.
>
> 'Because it does not share its energy with any bulb unlike bulb 1 which is sharing energy with bulb 2' D26.
>
> 'Bulb 1 shares its brightness with bulb 2, while bulb 3 does not share its brightness' M37.
>
> 'Bulb 3 is in series and 1 parallel to bulb 2 so bulb 3 gain more electricity than 1 and 2.

This kind of reasoning indicates that some learners had difficulties with differentiating electrical concepts. Learners who were using brightness in their explanation support Bryan and Stuessy (2006) brightness rule, where they indicated that brightness of the circuit is shared evenly amongst the bulbs.

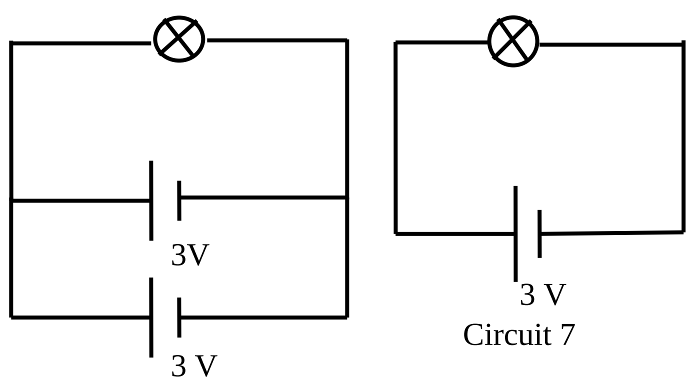
In addition, Table 4.7 illustrates that 18% (7%+11%) of the learners presented explanations that could not be comprehended or they just did not provide any reasoning to their chosen options. This indicates that a number of learners had difficulties with the language used or were not willing to write their thinking.

4.6.2 Batteries in series and in parallel configurations

4.6.2.1 Basic and parallel connected cells

Learners understanding of the battery/cells potential difference was dealt with in section B [question 4 (a - d)]. Parts (a) and (c) required learners to give reasons for the choices while (b) and (d) were multiple-choice questions which did not require learners explanations.

In part (a) learners were presented with two schematic circuit diagrams (see circuits 6 and 7 below), where circuit 6 (parallel circuit) had a single light bulb connected to two 3V parallel batteries. However, circuit 7 (basic circuit) had one bulb connected to a single 3V battery.



Circuit 6 Circuit 7

All bulbs were identical and potential differences of individual cells were shown to be equal. Learners were required to indicate the circuit which would glow brighter, and give reasons for their choices. The results are presented in Figure 4.31 below.

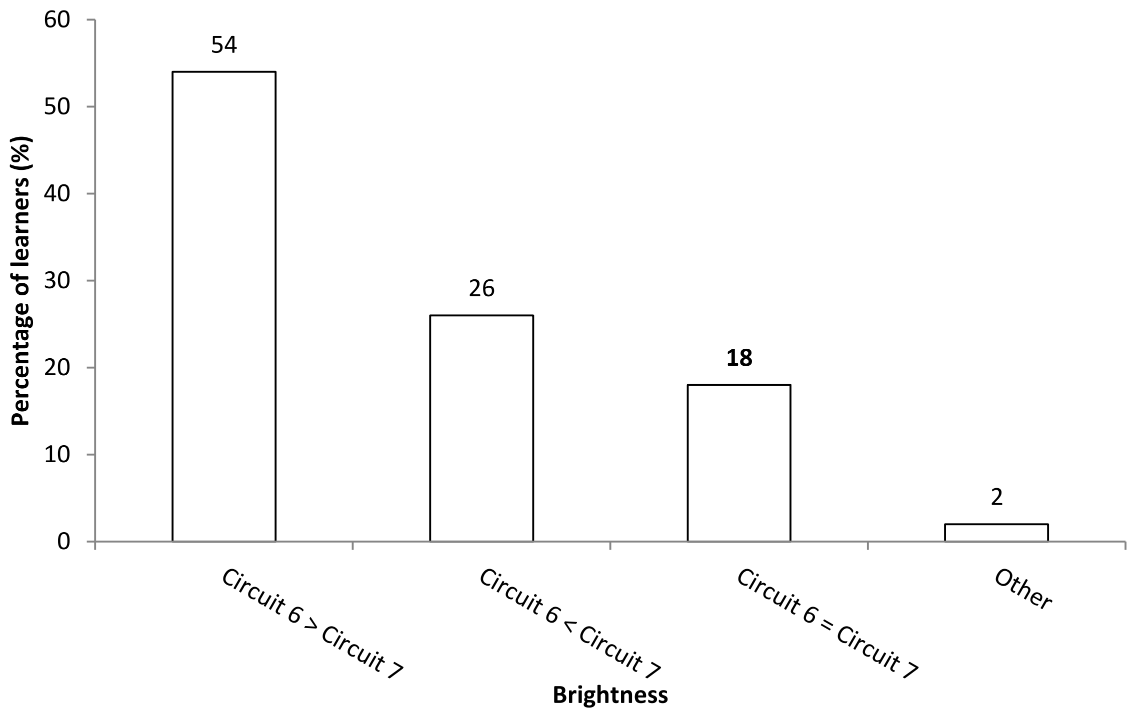


Figure 4.31: Learners' responses to circuits 6 and 7 about voltage

Figure 4.31 indicates that most learners (54%) thought circuit 6 was brighter than circuit 7. The learners thought the two cells connected in parallel would make circuit 6 to be brighter. A similar observation was noted by Psillos (1998) prior to performing an experiment where learners were asked to make predictions. Figure 4.31 also show that only few (18%) correctly presented the scientifically acceptable response because of lack of practical experience. Interviews results show that about 4 of 13 learners thought circuit 7 was brighter and one learner explained that:

'*when the batteries are connected in parallel we going to divide them by 2 and they will give us a low ratio of a voltmeter*'.

The other 3 thought circuit 6 would be brighter and the reason given was:

'*the current flowing from two batteries is going to be added'*.

However, there were 3 learners who presented scientifically acceptable responses and reasoning. These learners used their knowledge that the amount of current in a circuit depends on the potential difference of the battery and the resistance in the circuit. Moreover, they applied their knowledge that adding batteries/cells in series increases the potential difference whilst in parallel potential difference remains the same. The last 3 learners could not support their choices and two of the three tried to make some calculations.

Further analysis was done to check if responses could be related to the geographical location of the school. Figure 4.32 below present the learners' responses in terms of their school location.

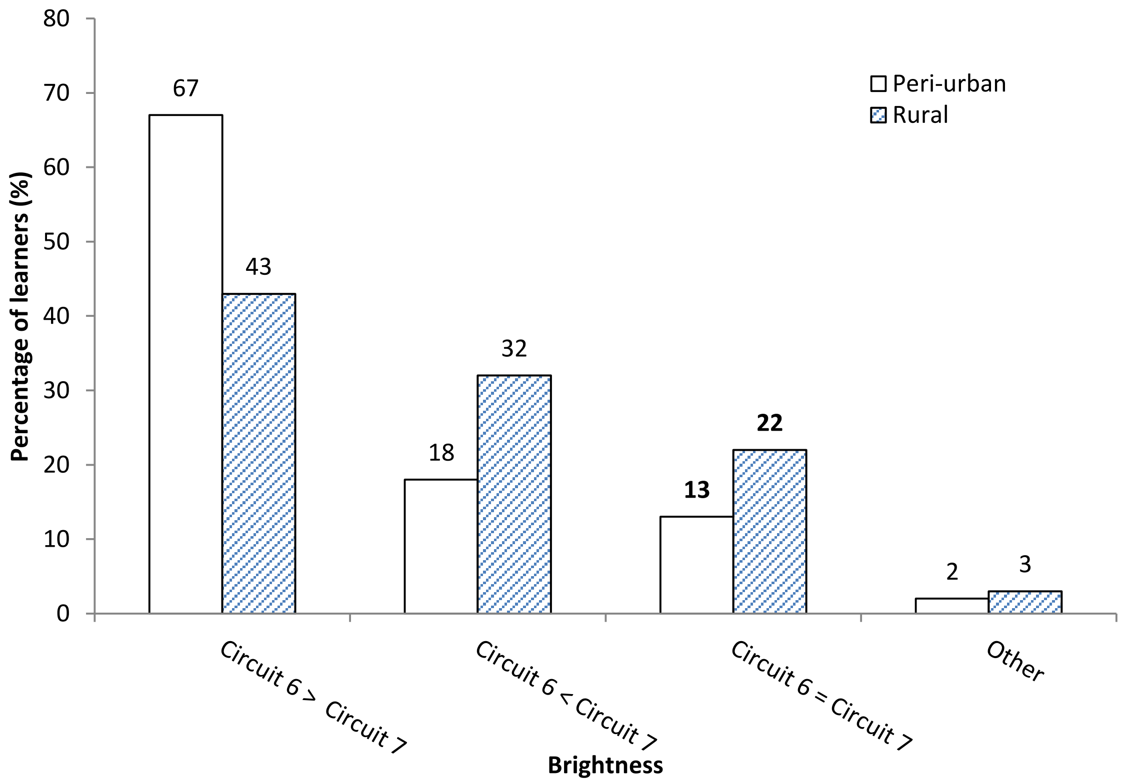


Figure 4.32: Learners' responses to circuits 6 and 7 per location of the school

A majority of learners (67%) from the peri-urban thought circuit 6 was brighter than circuit 7. This view was also expressed by 43% of the rural school learners. Few learners from peri-urban and rural schools (13% and 22%, respectively) presented the correct option. In addition, there were also 32% of the rural and 18% of peri-urban school learners who thought connecting two batteries in parallel would result in less voltage as compared to one battery. There was a statistically significant difference between rural and peri-urban school learners' responses regarding the brightness of bulbs in a basic circuit and in parallel-connected cells ($X^2 = 5.70$, $p < 0.05$).

Learners' explanations about brightness of one bulb connected to two parallel batteries compared to one bulb in a basic circuit are summarized in Table 4.8 below.

Table 4.8 Explanations about brightness of one bulb in parallel with two batteries compared to one bulb in a basic circuit.

Explanation	**Number of responses** N=137	**Frequency (%)**
Current related	15	11
Same voltage	**15**	**11**
Voltage less	3	2
Resistance related	8	6
Others	3	2
Arrangement	9	7
2 cells, more voltage, more power, more energy	52	38
No response	10	7
Uncodeable (not clear)	22	16
Total	137	100

According to Table 4.8, the most common reasoning presented by learners (38%) was based on the number of cells/batteries (circuit 6) leading to more voltage, more energy, and more power as illustrated by the examples below:

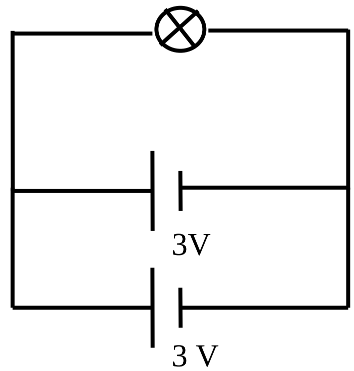
> 'The volts in circuit 6 are greater than in circuit 7' D32.
>
> 'Circuit 6 has two battery of 3V but circuit 7 has one battery of 3V. 6 has greater voltage than 7' D09
>
> 'Potential difference is higher than circuit 7' D04.
>
> 'Because bulb in circuit 6 will be experiencing a voltage of 6V when bulb in circuit 7 get 3V' M67.
>
> 'Circuit 6 has 6V while circuit 7 has 3V' M37
>
> 'The volts in circuit 6 are greater than the volts in circuit 7' M75

It seems learners conceptualized the quantity stored in the battery to determine how much current is given to the bulb and hence the brightness increases. The results support Psillos' (1998) findings, where it was reported that for learners the number of volts indicates the quantity of current stored in a battery. It is clear from Figure 4.31 and Table 4.8 that 54% of the learners chose circuit with two batteries to be the brightest, while only 38% used the argument that two batteries results in more voltage in their explanations. Moreover, Figure 4.31 above presented that 18% of the learners thought the two circuits would have the same brightness. However, only 11% of the learners in Table 4.8 provided this in their reasoning. Some of the learners could have had difficulties with writing down their thoughts due to the language used. According to Probyn (2003) South African English second language learners cannot communicate their scientific conclusions in English, as a result they have difficulty in responding to open-ended questions.

Few learners (11%) gave a scientifically acceptable explanation, (e.g. the two batteries in parallel would have the same potential difference as one battery but their life span would increase). Very few learners knew that the two batteries/cells in parallel would have the same effect as one battery/cell. This is due to a lack of practical experience on the part of learners (Planinic *et al.* 2005). Planinic *et al* investigated learners' views about batteries getting flat. They presented learners with two circuits of two identical batteries, one circuit had one light bulb while the other was connected to two light bulbs in series to each other. Learners were asked to indicate the battery which would become flat first. Their findings showed that majority of learners were choosing the circuit with two bulbs in series. Thus, they rejected the statement that the circuit with one bulb will become flat first. The researchers suggested that the main reason for rejecting the correct statement was because learners lacked experience.

Table 4.8 also display that 23% (7%+16%) of the learners presented explanations that could not be comprehended or they did not provide an explanations for their chosen options. These learners experienced difficulties with the written language or they were not willing to write what they were thinking.

Part (b) of section B, required learners to indicate the total voltage of circuit 6.



Circuit 6

The results are presented in Figure 4.33 below.

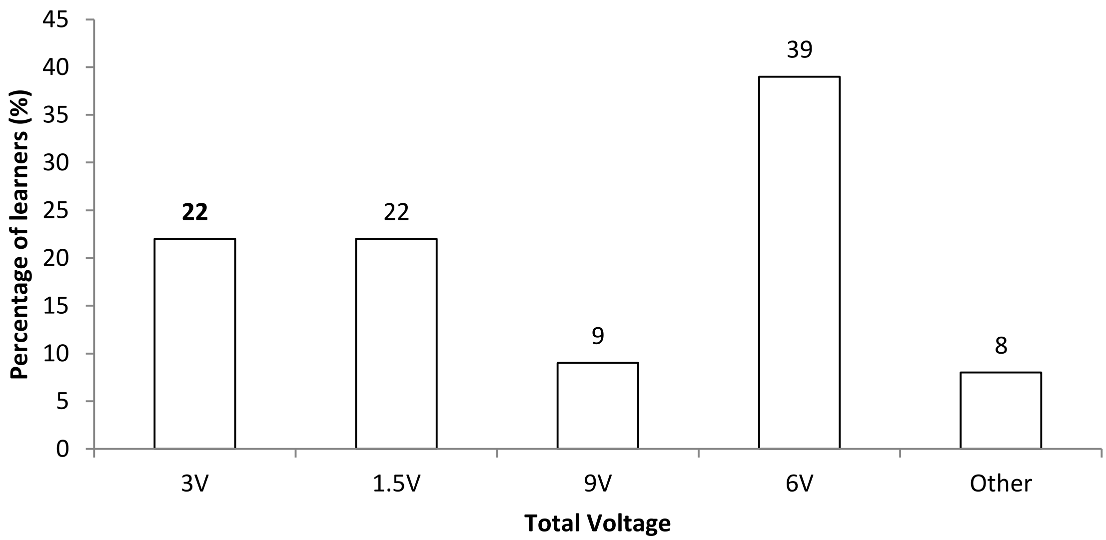


Figure 4.33: Learners' responses to total voltage of circuit 6

A Majority (39%) of the learners shown by Figure 4.33 shows that circuit 6 would have a potential difference of 6 volts (3V+3V). The results show that these learners added individual voltages as they would do for a series connected cells. Hence, the arrangement of batteries/cells in parallel or series with each other seemed not to matter to learners. The correct option was that the potential difference of circuit 6 would be the same as for circuit 7(3V). However circuit 6's batteries/cells would last longer than those in circuit 7.

Figure 4.33 also show that 22% of the respondents presented the correct option. However, a further 22% of learners thought the total voltage of circuit 6 would be less than (half) the potential difference of one battery. The later shows that learners were applying the principle for equivalent resistors in parallel to solve batteries/cells. It seems like some learners knew the formulae but did not appreciate its limitations.

Further analysis was done in terms of school location. The results are presented below in Figure 4.34.

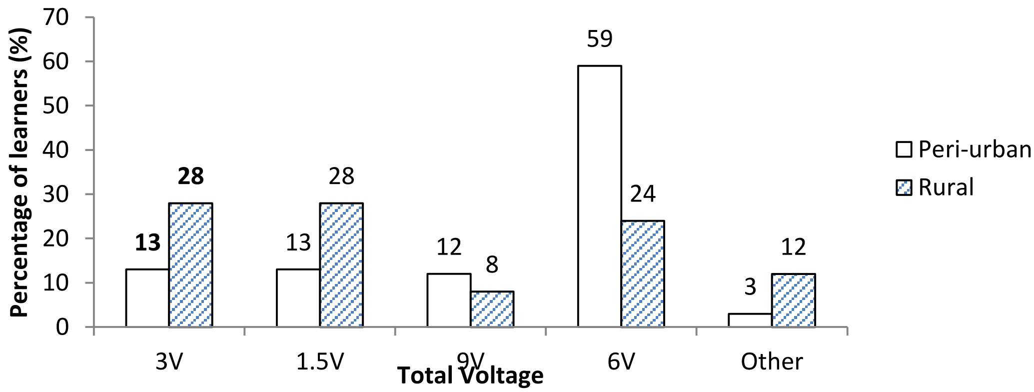
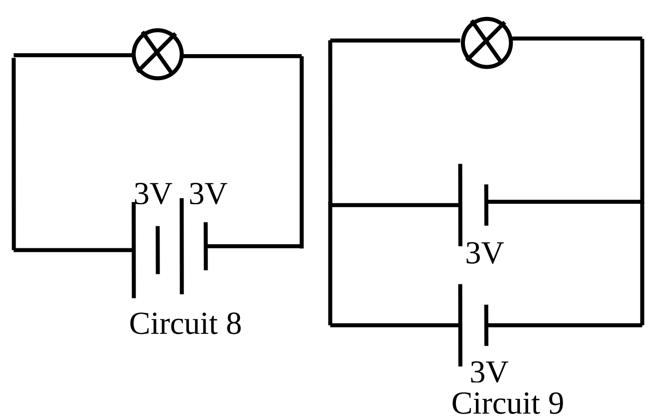


Figure 4.34: Learners' responses to total voltage of circuit 6 per location of school

On the one hand, it is apparent from Figure 4.34 that most of the peri-urban learners (59%) thought that the total voltage of circuit 6 was 6V (i.e. 3V+3V). They thought that the two batteries would have the same effect as if they were connected in series. On the other hand, 28% of the rural respondents and 13% of the peri-urban respondents chose the correct option (3V). Similarly another 28% of the rural respondents chose 1.5V (half) [i.e. learners applied the principle for equivalent resistors in parallel (where $\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2}$) to solve the potential difference]. The difference between rural and peri-urban learners' responses regarding the total voltage of circuit 6 was non-significant ($X^2 = 1.61$, $p > 0.05$).

Part (c) of section B presented learners with two schematic circuit diagrams (circuits 8 and 9), with two batteries and one bulb each.



The potential differences of individual batteries were equal and light bulbs were identical. However, the batteries were connected in series in circuit 8 and in parallel in circuit 9. Learners were to compare the two circuits and indicate the one which would glow brighter and give reasons for their choice. The results are presented in Figure 4.35 below.

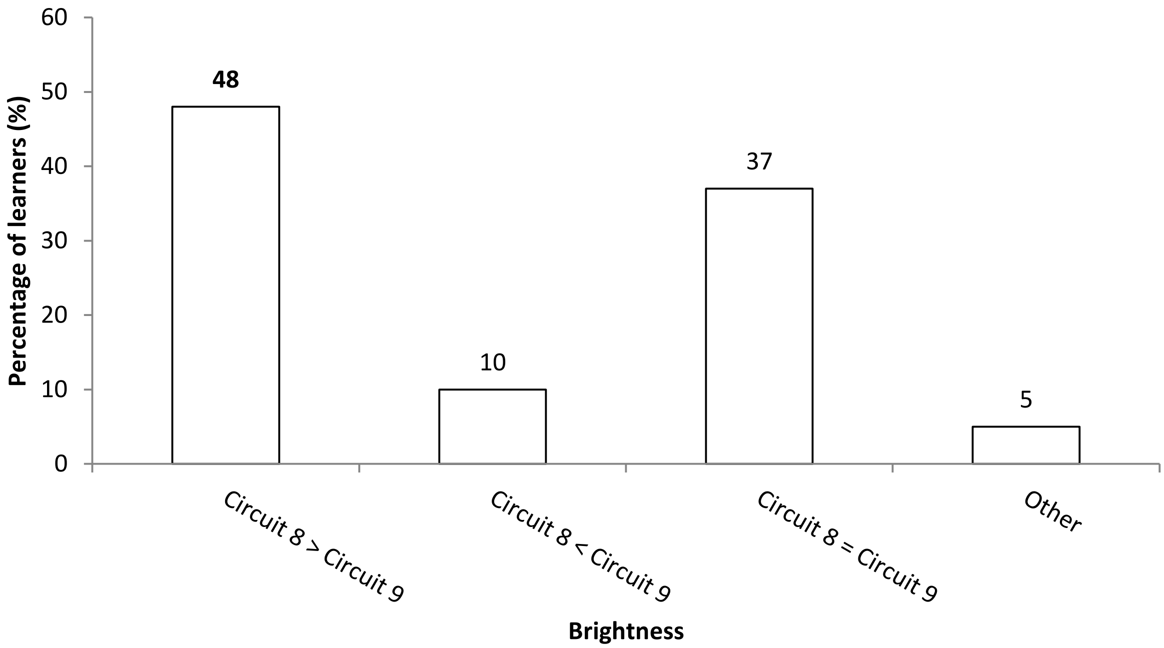


Figure 4.35: Learners' responses to circuits 8 and 9 on brightness

Figure 4.35 depicts that a majority of the learners (48%) correctly showed that circuit 8's bulb would be brighter than circuit 9's. A number of learners (37%) were of the view that the two circuits would have the same brightness. From the interviews all learners (13) presented the correct option. However, they were not using scientific principles in their explanations. For example, one learner said:

'*I am seeing this kind of connection with batteries for the first time*'.

The learner was referring to circuit 9 which had its batteries connected in parallel. This confirms that lack of practical exposure with real circuits has deprived learners some good personal experiences.

Further analysis is presented in Figure 4.36 below indicating the responses in terms of geographical location of the school.

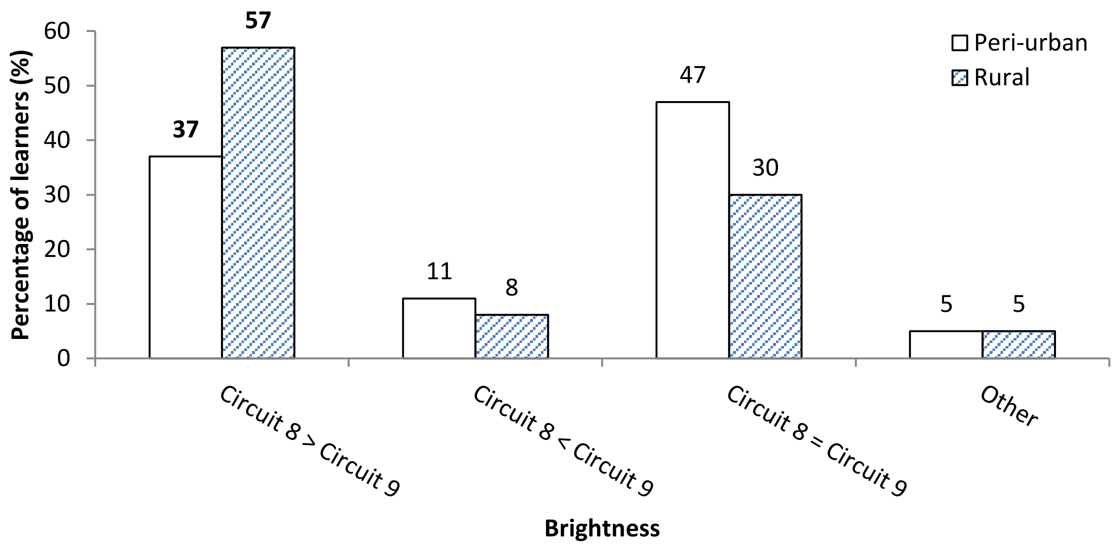


Figure 4.36: Learners' responses to circuits 8 and 9 on brightness per school location

As can be seen in Figure 4.36 above, 47% of the peri-urban school learners thought the brightness of the two circuits was the same. Thirty seven percent of the learners presented the correct option (i.e., circuit with batteries arranged in series is brighter than the one with batteries in parallel setting). The results seem to suggest that for the peri-urban learners, arrangement of batteries in a circuit does not matter but the number of individual batteries involved. Thus, when the number of batteries increases (independent from the type of connection) the bulb gives more light. However, 57% of the rural school learners provided the correct option, while only 30% indicated the two circuits to be of the same brightness. Thus, more than half of the learners from the rural school seemed to have realized the importance of the battery arrangement in circuits. However, the difference in rural and peri-urban learners regarding brightness of bulbs connected to two batteries in parallel and in series was not statistically significant ($X^2 = 1.82$, $p > 0.05$).

The reasons provided to support their explanations are presented below in Table 4.9.

Table 4.9 Explanations about brightness of one bulb with two batteries in parallel and two in series

Explanation	**Number of learners** N=137	**Frequency (%)**
Series, more V, I & E	**18**	**13**
Same I, E, P, V and number of cells	49	36
Parallel, more I,R,V	3	2
Arrangements	29	21
Others	7	5

No response	12	9
Uncodeable (not clear)	19	14
Total	137	100

The common reasoning (36%) presented in Table 4.9 was that the two circuits have the same voltage because they have the same number of batteries. Almost all learners who thought the two circuits would be of the same brightness presented this reasoning: For example,

> 'There are the same volts and cells' D58
>
> 'They all have the same number of cells in the circuit' D07.
>
> 'They have the same batteries and the equal voltage' D38
>
> 'Because the combination of 3V & 3V makes the same voltage hance the same brightness' D02.
>
> 'They both have the same voltage, even though one is in series and other in parallel' M26
>
> 'The both have same potential difference. ……' M53
>
> 'They all have same voltage it's just that 1 is in series the other in parallel' M25.
>
> 'Even if circuit 9 is connected in parallel they are equal because each contains two cells' M47.

The above indicate learners were using observable features rather than conceptual reasoning.

Table 4.9 also shows that a number of learners (21%) were using phenomena based reasoning where they were using the arrangements of the batteries to support their choices.

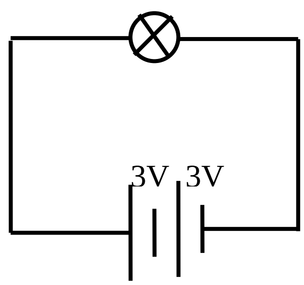
Although, a number of learners 48% thought that circuit 8 would be brighter than circuit 9, Table 4.9 indicates that only 13% correctly supported their choices. They indicated that because the batteries in circuit 8 are connected in series their individual voltages should be added together. This leads to more voltage in circuit 8. For example:

> 'Voltage in circuit 8 greater than voltage in circuit 9. I = V/R, ……….' M13.
>
> 'Circuit 8 is in series so we add the results is more V and I. …….' M57.
>
> 'More voltage in series more current and …….' M55.

Some learners (13%) indicated that two batteries in series have more voltage therefore they will give more current to the circuit. Although, it was correct for learners to add the voltages of the two batteries in series, it seems that learners were using voltage to determine how much current the battery gives to the circuit. The results suggest that the brightness of the bulb depend solely on the battery, which determines how much is given to the circuit.

There were also a number of learners (23%) whose explanations could not be comprehended because they were unintelligible and those who did not bother to write anything to support their choices. These learners either experienced difficulties with the written language or were not willing to write what they were thinking.

Part (d) required learners to indicate the total battery's potential difference of circuit 8.



Circuit 8

The results are presented in Figure 4.37 below.

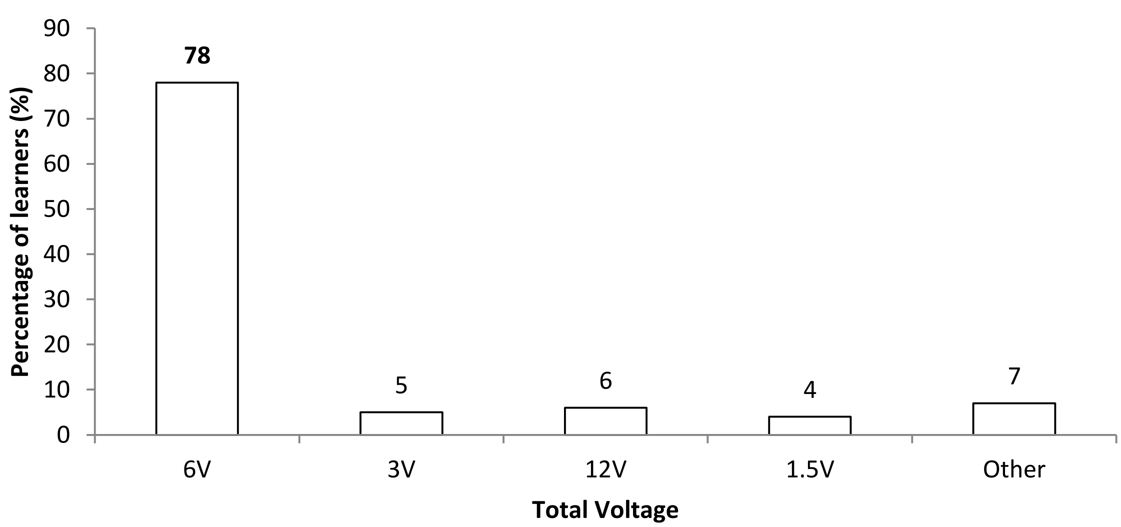


Figure 4.37: Learners' responses to the total voltage of circuit 8.

Figure 4.37 depicts that a majority of the learners (78%) provided the correct total voltage (6V) of circuit 8. It seemed learners did not have difficulties in determining the total voltage for batteries connected in series.

Figure 4.38 below presents the results for the total voltage of circuit 8 to evaluate if they could be associated with the location of the school.

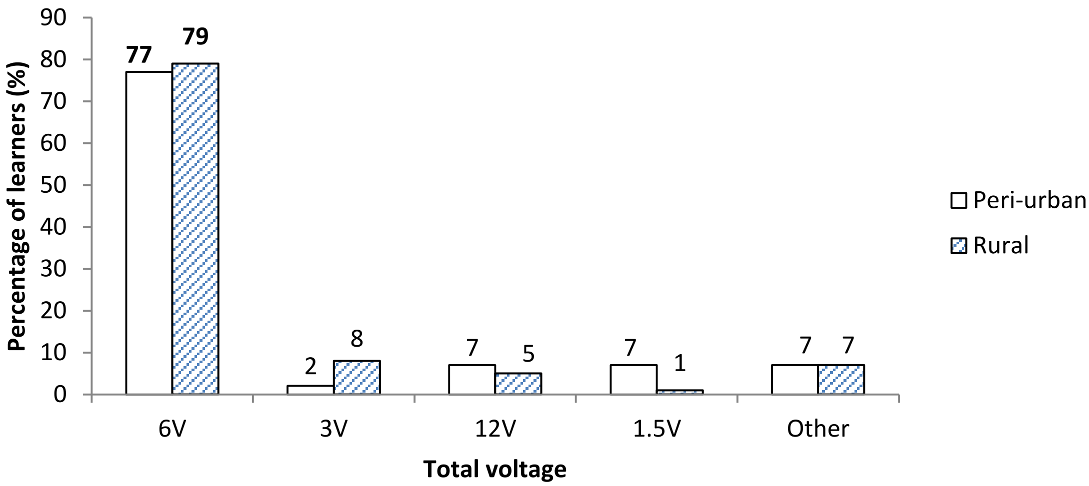


Figure 4.38: Learners' responses to the total voltage of circuit 8 per school location

Figure 4.38 above shows that more than 75% of both peri-urban and rural respondents provided the correct potential difference of circuit 8. There were no statistically significant differences between the responses from the two schools (X^2 = 3.48, $p > 0.05$), with a probability of higher than 0.05. Thus, the results could not be associated with the school location.

4.6.3 Role of a battery

Part (a) of question 3A focused on the role played by a battery in a circuit. Learners where required to choose the best option from the given five. Learners were to use their understanding of what a battery does in an electrical circuit. The scientifically accepted option was: the battery supplied the circuit with energy to move charges. The results are presented in Figure 4.39 below.

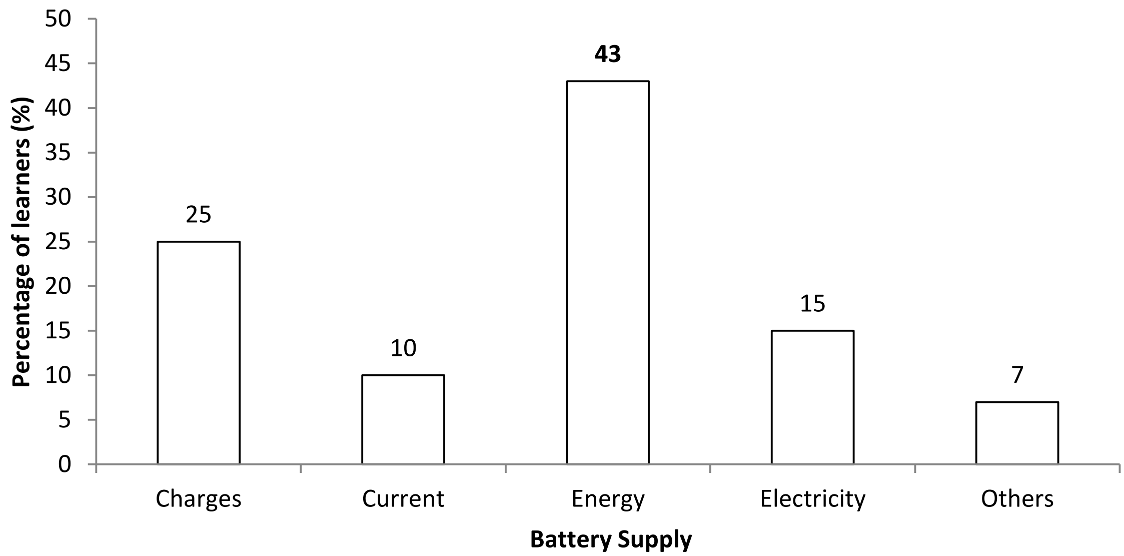


Figure 4.39: The role of a battery in a circuit

Figure 4.39 above indicates that majority of learners (43%) provided the correct option. More than half of the learners presented alternative views, ranging from supplying the conductor with charges to supplying the circuit with electricity. The results suggest that the majority of the learners did not understand the role played by the battery in a circuit. This was evident from the lower percentage of learners choosing the scientifically accepted option. From the interviews, majority (7 out of 13) of learners indicated that a battery's role was to supply the circuit with electricity, while few (3) thought it was to supply the energy to the circuit. Others (3) thought it was supplying the charges to the circuit. It also emerged from interviews that learners did not have firm understanding of 'what the role of the battery was', because they changed their choices when asked to support their responses. The findings are in agreement with Engelhardt and Beichner (2004) who indicated that learners fail to understand what the battery supplies to the circuit because they did not understand the properties of a battery. Moreover, Bilal and Mustafa (2009) pointed out that the roles played by the battery be given more attention during instruction.

The results are further presented in Figure 4.40 below in terms of school location.

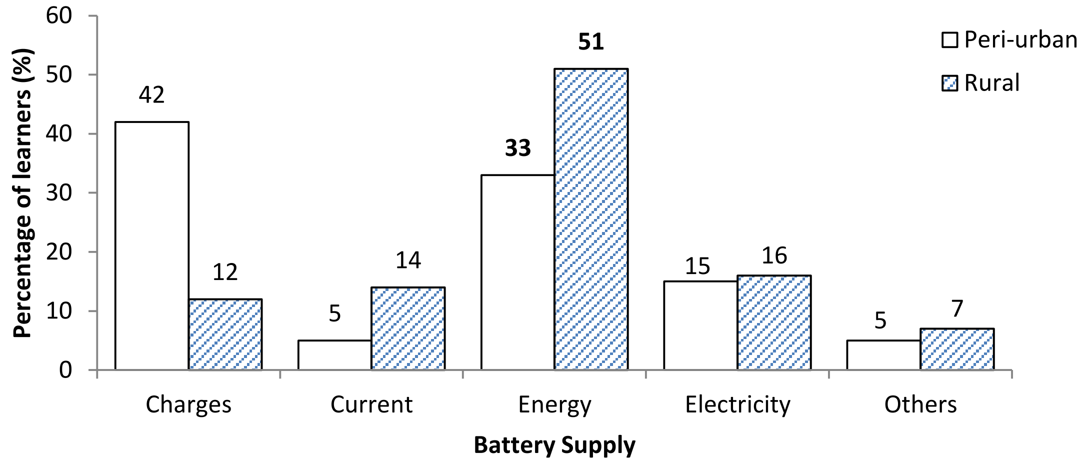


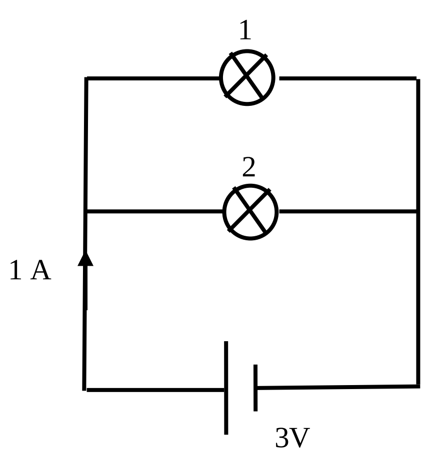
Figure 4.40: The role of a battery in a circuit per location of the school

Figure 4.40 displays that the prevalent view (51%) from the rural school learners was the scientifically accepted option. About half of the rural school learners seemed to realize the role played by a battery in a circuit. The other half was spread between incorrect options, which may be associated with guess work due to lack of firm understanding of the role played by the battery in a circuit. However, majority of peri-urban school learners (42%) thought battery supplied the conductor with charges. The latter suggested a battery to be the source of charges and which may imply when a battery is flat, it is out of charges (www.Physicsclassroom.com/class/circuits/u912e.cfm). This might be as a result of everyday usage of the so-called 'rechargeable' batteries, which imply they had to be 'recharged' or be refilled with charges to work again. If one believes the battery to be a source of charge then it implies that the charge must move very fast from the battery through wires to the bulbs such that when the switch is closed, there would not be a noticeable delay in lighting the bulb. The above explanation is logical for one who believes batteries to be the source of charge in a circuit because they must be recharged when they no longer work. This logical reasoning is formulated on an incorrect basis (i.e. batteries are rechargeable). This leads to incorrect conclusions that charges are used up and travel in very high speed within the wires. The differences in rural and peri-urban responses with regard to knowledge of the role played by a battery in the circuit were statistically significant (X^2 =11.36, p < 0.05).

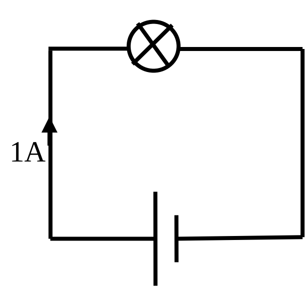
It is important to realize that the presented logical explanations by the peri-urban school learners are inconsistent with the scientific knowledge. The scientific model as presented by the rural school learners specifies that the battery supplies the energy needed to move a charge from a low potential to a high potential. The charge is the medium through which energy moves from location to location. The charge at a high potential spontaneously begin to move slowly towards the low potential. Charges anywhere within the wire moves together, as they move through light bulbs their energy is transformed to light and heat (thermal energy). As they move past the bulb their energy is less energized and at a low electric potential. As the low potential charges reach the battery, work is done (energies) to put them back to high electric potential (www.Physicsclassroom.com/class/circuits/u912e.cfm).

4.7 ANALYSIS OF DIRECT CURRENT RESISTIVE CIRCUIT WITH BASIC AND TWO PARALLEL CONNECTED BULBS

Question 5 of section B dealt with the concepts of current, potential difference and power. It was divided into three parts: (a), (b) and (c). Two schematic circuit diagrams (circuits 10 and 11) were given. Circuit 10 consisted of two parallel identical light bulbs connected to a battery, while circuit 11 had one light bulb connected to a battery. Only the potential difference of circuits 10 was provided. However, the total current for both circuits was given as 1 Amperè.



Circuit 10



Circuit 11

4.7.1 Current

Part (a) required learners to compare the brightness of the two circuits and give reasons for their choices. They were expected to use the given total current in their reasoning to indicate that circuit 11 bulb was brighter than circuit 10. The question required learners to use their knowledge that current splits in parallel and whole in series.

Learners' responses to circuits 10 and 11 on the effect of current on brightness are presented in Figure 4.41 below.

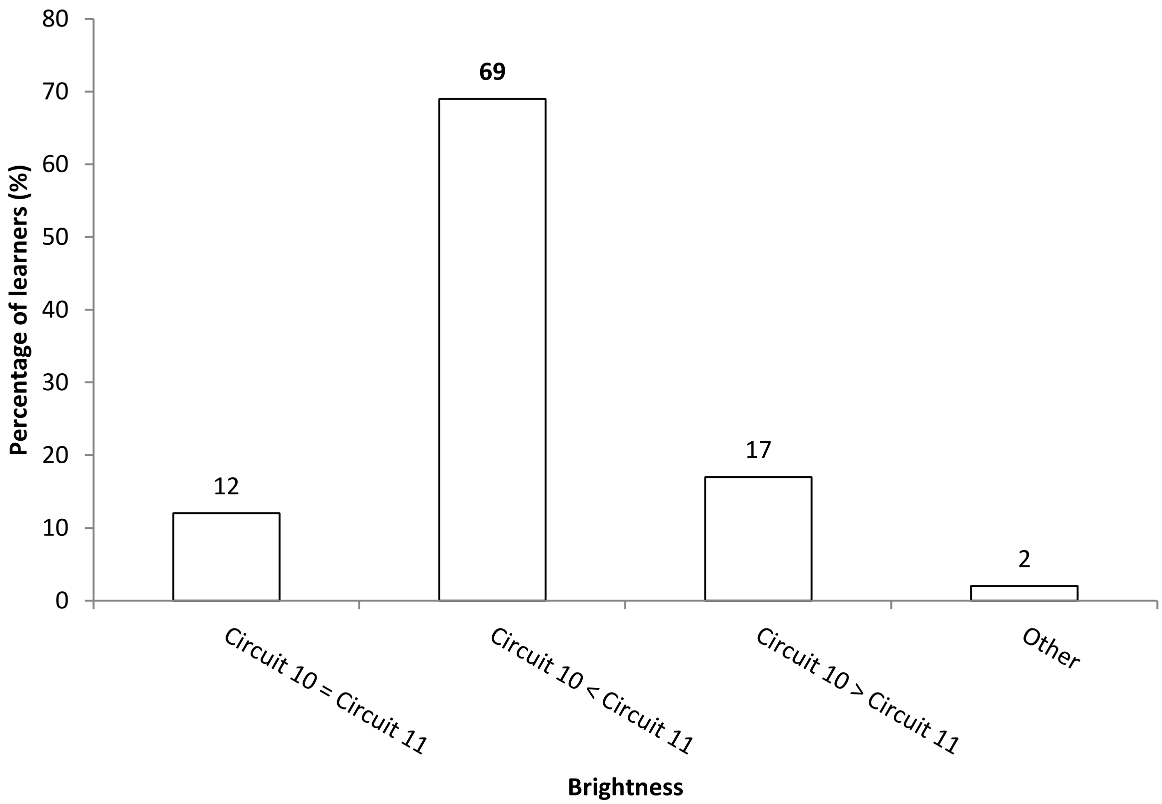


Figure 4.41: Learners' response to circuits 10 & 11 on the effect of current on brightness.

Figure 4.41 above indicates that a majority of learners (69%) correctly provided that circuit 11 was brighter than circuit 10. Almost the same results were observed in Figure 4.29 where learners were comparing brightness of bulbs 1 and 3 of circuit 2.

The results on further analysis in terms of geographical location of the school are presented in Figure 4.42 below.

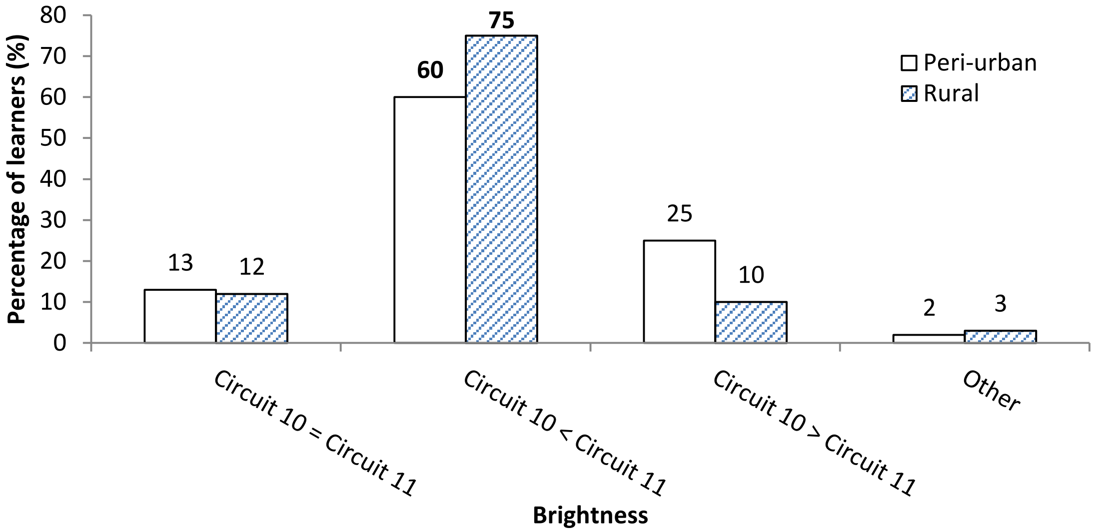


Figure 4.42: Learners' responses to circuits 10 and 11 per location of school

Figure 4.42 above shows that a majority of the peri-urban (60%) learners and 75% of the rural school learners gave a correct option. Both schools' learners seemed to know that current splits at a branch. The differences were not statistically significant (X^2 = 1.64, p > 0.05). The explanations to support the choices are summarized in Table 4.10 below.

Table 4.10 Learners' explanations on brightness of bulbs in parallel compared to basic circuits

Explanation	**Number of learners** N=137	**Frequency (%)**
Electricity	4	3
Same current	12	9
Current divide	**23**	**17**
Voltage related	21	15
Same energy/power	7	5
Arrangement	21	15
Parallel, less resistance	3	2
Two bulbs	16	12
No response	16	12
Uncodeable (not clear)	14	10
Total	137	100

Table 4.10 indicates that only few learners (17%) presented a correct reasoning that the current divides between the two bulbs in circuit 10 as they are in parallel and is whole in series circuit. Below are some examples of the responses in support of the choice above:

> 'Bulb 1 & 2 are connected in parallel they share current and bulb of circuit 11 is connected in series it does not share its current' M03.
>
> 'Bulb in circuit 10 will share the current while one in circuit 11 will have the whole current' M57.
>
> 'Bulbs in circuit 10 are connected in parallel so they are going to share the current' M64
>
> 'Bulb in circuit 10 share the current while in 11 there is one bulb which does not share' D30.

In addition, other learners (15%) used phenomena-based reasoning like 'bulbs are in parallel' or in series. They were using the arrangement of components to decide on the brightness of the bulbs as presented below:

> 'They are connected in parallel' D46, M16
>
> 'Because these two bulbs are connected into parallel lines' D31
>
> 'Because of parallel bulbs in circuit 10' M75
>
> 'They are parallel to each other' M32

Similar results were presented by Bryan and Stuessy (2006) who reported that this kind of reasoning is due to learners making no distinction between the description and the explanation of the phenomena.

There were also learners (15%) who used potential difference of the two circuits to support their choices. They ignored the total current that was given as a hint.

Moreover, there were few learners (12%) who used the number of bulbs to claim circuit 10 to be the brightest. Learners seemed to have used the 'brightness rule' (as observed by Bryan and Stuessy 2006) in stating that brightness of a single bulb was a property that could be shared evenly among other bulbs. Learners were not using conceptual reasoning to decide on the brightness of the bulbs but the number of bulbs in the circuit. For example:

> 'The battery is supporting two bulbs' M49.
> 'Because of one bulb in circuit 11' M71.
> 'Light of two bulbs…..'M05
> 'Because there are two bulbs in circuit 10 and …..'D44
> '….Circuit 10 has two bulbs' D50

In addition, some learners (22%) experienced difficulty with the written language, because their explanations could not be comprehended as they were unintelligible and others did not write anything to support their choices.

4.7.2 Potential difference

Part (b) required learners to indicate the potential difference across bulb 1 of circuit 10 which had its two bulbs connected in parallel. The results are presented in Figure 4.43 below.

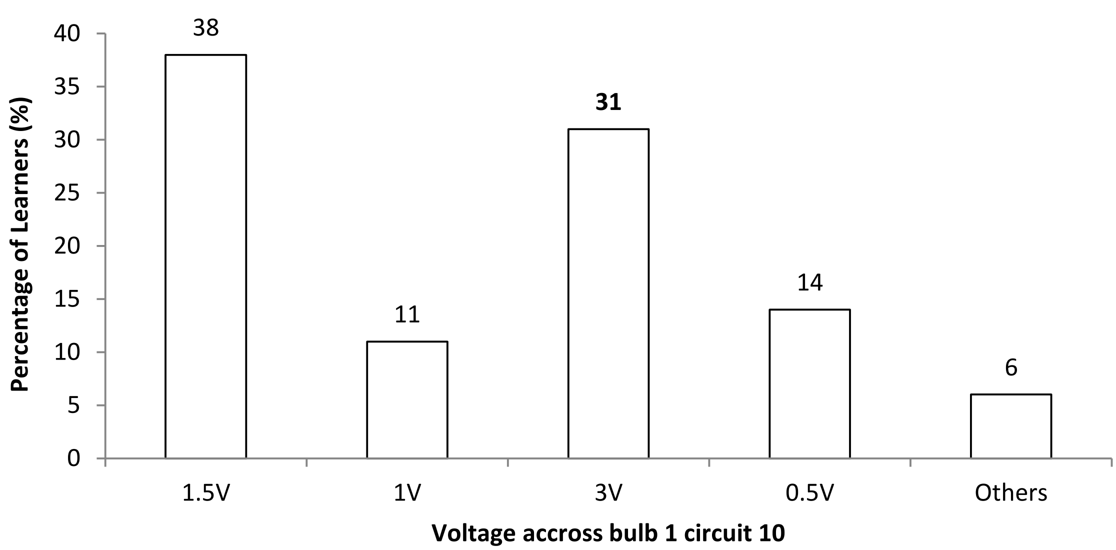


Figure 4.43: Learners' responses to voltage across bulb 1 in circuit 10

From Figure 4.43, it is clear that most learners (38%) thought that potential difference of bulb 1 was half potential difference of circuit 10. It was apparent that most learners applied the basic principle for current in parallel (current divide) to solve potential difference. The mistake could have arisen from lack of differentiation between the two concepts. Hence, same principles could be applied to both. However, 31% gave scientifically acceptable option that potential difference across bulb 1 was the same as the potential difference of the battery.

The results are considered further in terms of location of the school and are presented in Figure 4.44 below.

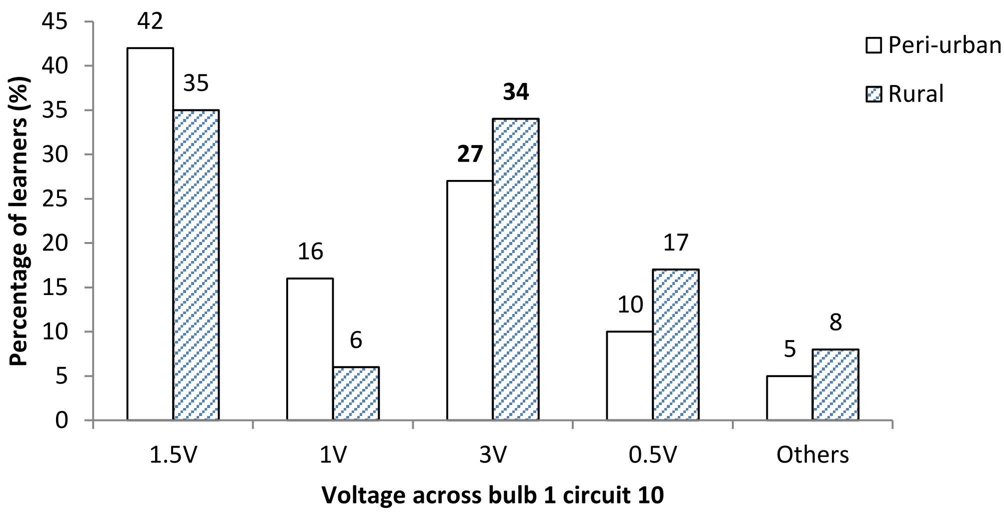


Figure 4.44: Learners' responses to voltage across bulb 1 in circuit 10 per location of school

According to Figure 4.44 above most learners (42% of peri-urban and 35% of rural school learners) chose 1.5V (half) to be the voltage across bulb 1. However, the scientifically acceptable option received 27% and 34% from peri-urban and rural schools learners, respectively. Almost the same number of learners from the rural school was shared between potential difference dividing and remaining the same. Once more the results indicate that the rural school presented more scientifically acceptable responses than the rural school learners although the differences were not statistically significance ($X^2 = 2.13$, $p > 0.05$).

4.7.3 Electric Power

Part (c) required learners to determine the power dissipated at bulb 1 of circuit 10. They had to apply their knowledge of power (energy transferred in 1 second) using the power relationship P =

$VI = I^2R$, (where P, V, I & R represent electric power, potential difference, electric current and resistance, respectively). Learners were also expected to use conservation of electric power to indicate the power dissipated in bulb 1. They were expected to first determine the current through bulb 1, voltage across it and to use the combination to determine power dissipated.

Figure 4.45 below shows the responses presented by learners about power dissipated at bulb 1 in circuit 10.

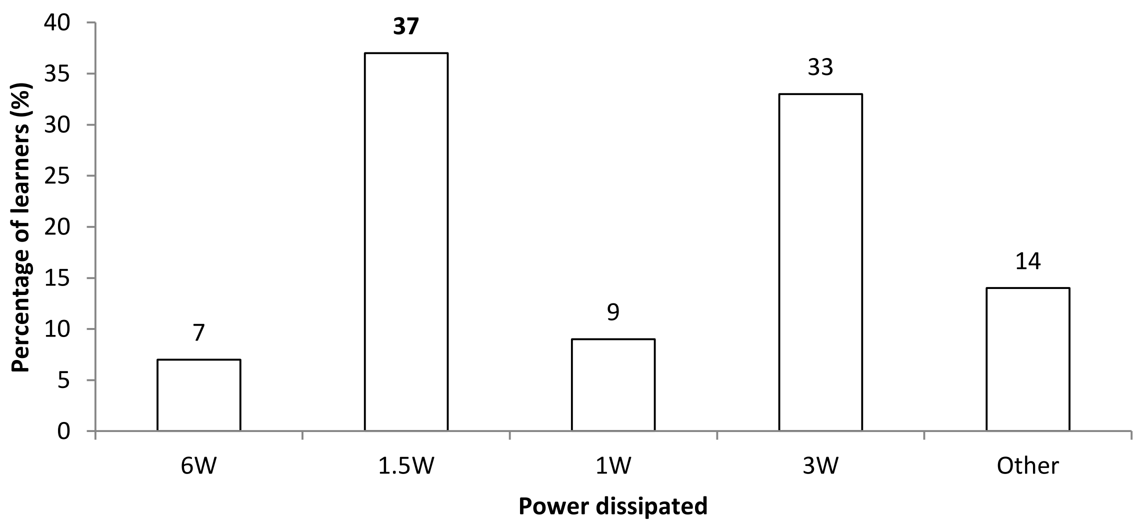


Figure 4.45: Learners' responses to power dissipated in bulb 1 of circuit 10

According to Figure 4.45, 37% of learners presented the correct power dissipated in bulb 1. From part (b), it was noted that 31% of the learners thought that the potential difference across bulb 1 remained the same while the other (38%) thought it was less by half. It was therefore, expected that nearly 38% should indicate a power of less than 1W since a majority (69%) indicated that current would be less in part (a). However, more than 31% of the learners provided the correct power dissipated in bulb 1. These learners seemed to have used the wrong approach to get correct results. The results seemed to came from dividing the potential difference and leaving current as 1A. It could therefore, be concluded that these results were due to guess-work as they are inconsistent. Literature shows that learners are less confident with electricity irrespective of giving correct responses (Planinic *et al.* 2005). It also emerged from interviews that due to lack of firm understanding, learners tend to change their responses when asked to provide reasons for their responses.

Moreover, Figure 4.45 indicates that 33% of learners thought power would be the same as potential difference of the circuit. It is interesting to note that the learners ignored the current through the circuit when making their choices. This result indicates that learners equated potential difference to power. This could have resulted from lack of sound knowledge about power. Hence, the learners could not relate potential difference and current to power.

Results for responses in terms of school location are presented in Figure 4.46 below.

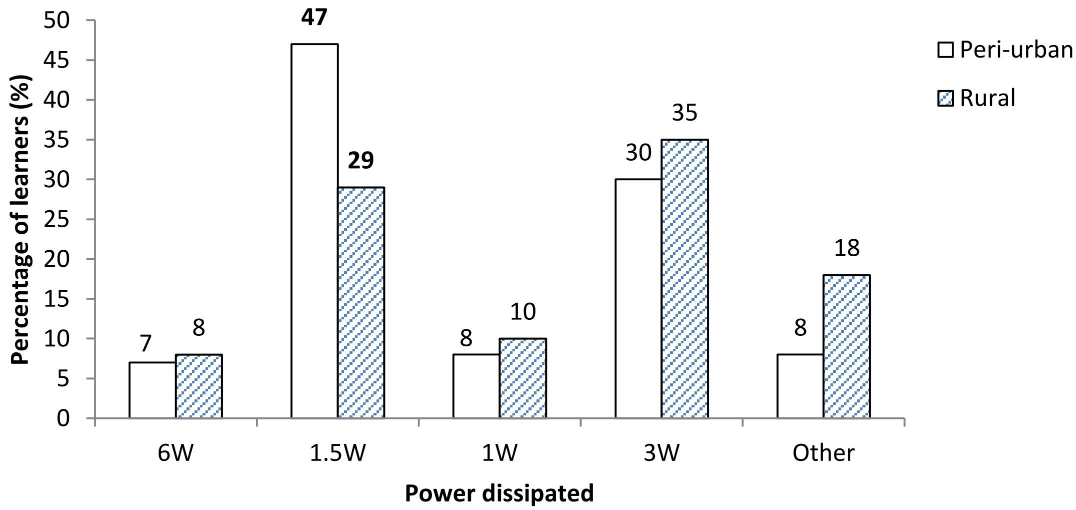


Figure 4.46: Learners' responses to power dissipated in bulb 1 of circuit 10 per school location

Figure 4.46 above shows that 47% of peri-urban school learners and 29% of rural school learners presented the correct option. It is worth noting that a majority (42%) of the peri-urban school and 35% of rural school learners thought that potential difference across bulb 1 was 1.5V earlier in part (b), while only 27% of learners from peri-urban and 34% of rural school learners presented scientifically acceptable responses. A similar percentage of learners seemed to use the wrong base by relating power to voltage to get acceptable results. Moreover, there were 30% peri-urban and 35% rural school learners who presented that power dissipated in bulb 1 would be 3 watts which is the same as potential difference of the circuit. These results show that learners were unable to differentiate between power and potential difference. The difference between rural and peri-urban school learners' responses in relation to power dissipated were not statistically significant (X^2 = 1.03, $p > 0.05$).

4.8 THE EFFECTS OF ELECTRICAL RESISTANCE ON CURRENT

Part (c) of section A dealt with the concepts of resistance. It required learners to use their logical skills to relate current with resistance. The ability to relate the two concepts is the base of circuit theory. Learners were requested to use their understanding of the concepts to decide on the correct statement about resistance. They were given statements which were giving relationships between current and resistance. The results are presented below in Figure 4.47.

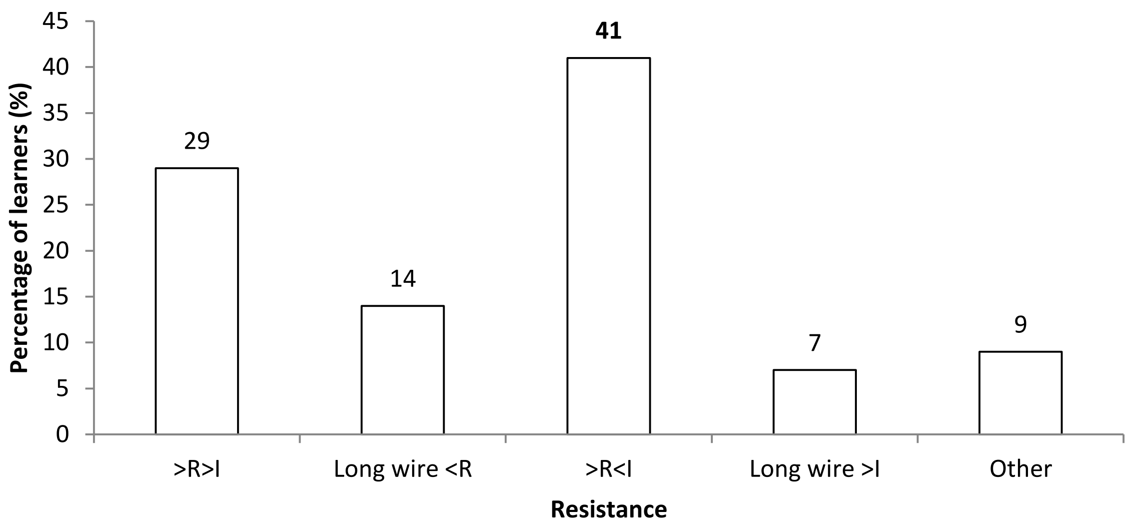


Figure 4.47: Learners' options to relationship between resistance and current

Figure 4.47 indicates that a majority (41%) of learners correctly provided that current was inversely proportional to the resistance in a circuit for a constant voltage. Thus, for a greater resistance current would be less. However, the Figure also depicts that some learners (29%) thought increase in resistance results in increase in current. These results confirm the findings of Dzama (1997) who observed a similar pattern of responses with rural Malawian learners and none with the urban London learners and concluded that the observation was due to lack of experience. The researcher argued that if learners were exposed to practical experiments they would unlikely make mistakes such as increase in resistance lead to an increase in current because experience would have taught them the opposite.

Results are further presented in Figure 4.48 below in terms of geographical location of the school.

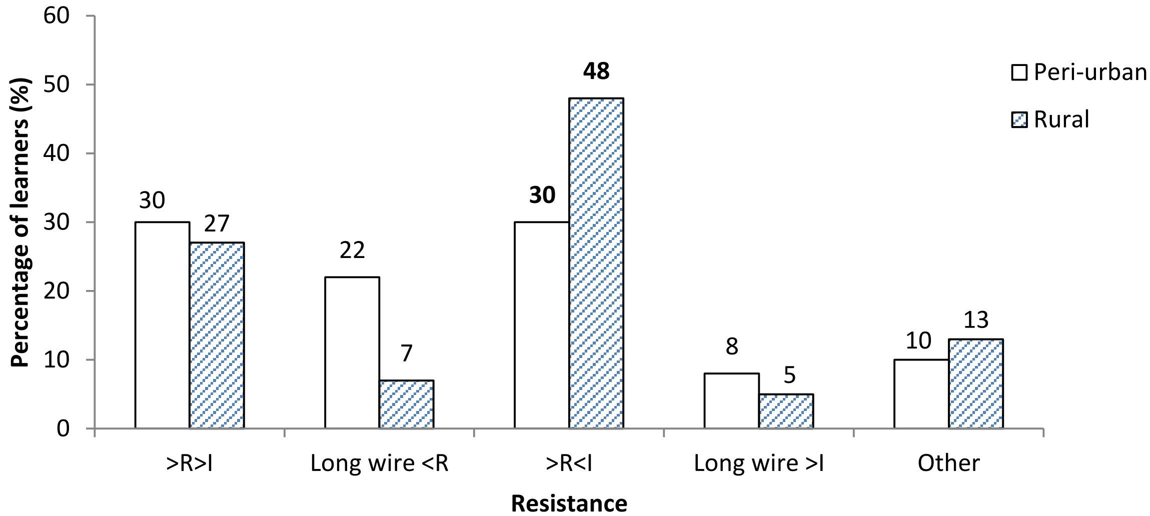


Figure 4.48: Learners' responses to resistance in terms of school location

Figure 4.48 indicates 30% of the peri-urban learners thought an increase in resistance led to an increase in current while the other 30% thought the opposite. The results indicate that due to lack of practical experience, a number of learners from the peri-urban school could not relate current and resistance properly (Dzama 1997). However, a majority of rural school learners (48%) correctly presented that an increase in resistance would lead to a decrease in current for a constant potential difference and only few (27%) thought the opposite. Although, the number of learners who presented the scientifically acceptable responses was less than 50%, rural school learners seemed to have a fair notion about current and resistance. The difference between the two schools in relation to knowledge of the relationship between current and resistance was statistically significant (X^2 = 6.43, $p < 0.05$).

4.9 RESISTORS IN SERIES AND SERIES-PARALLEL CIRCUITS

4.9.1 Comparison of resistors in series and in combination circuits

Question 3 of section B had two parts [(a) and (b)], which were about total resistance in a circuit. The question required learners to apply the concept of resistance and use the knowledge that resistance in series increases while in parallel decreases.

Part (a) of question 3, presented learners with two circuit diagrams (Circuits 3 & 4) with identical light bulbs of 2 Ohms each. Learners were asked to indicate the circuit with greater total resistance. Circuit 3 consisted of a battery and 2 light bulbs in series, while circuit 4 had 3 bulbs, 2 of which were connected in parallel and in series to the 3rd. The two circuits are presented below.

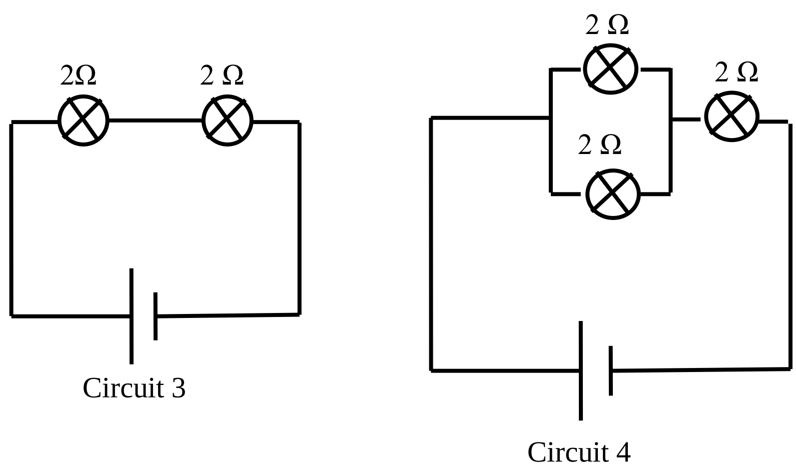


Figure 4.49 below shows the responses presented by learners comparing the total resistance of circuits 3 and 4.

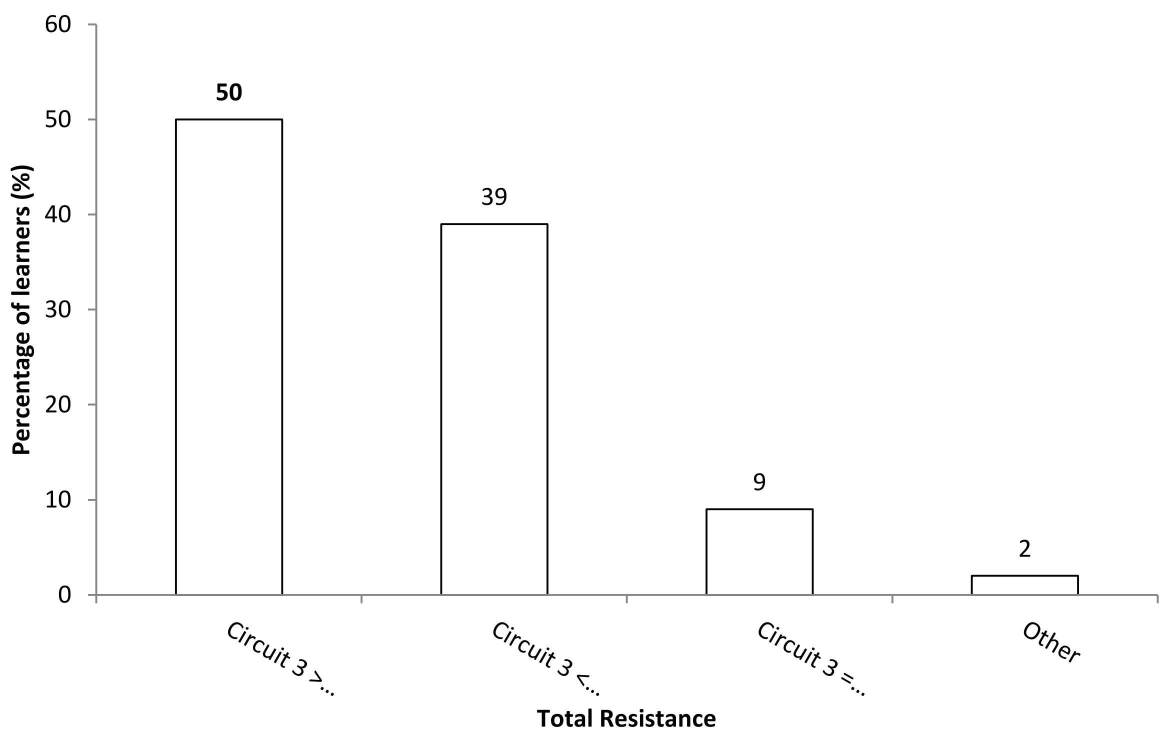


Figure 4.49: Learners' responses to total resistance of circuits 3 and 4

Figure 4.49 depicts that half of the learners (50%) thought that the total resistance of circuit 3 was greater than that of circuit 4. They applied the basic principle that resistance in series sums ($R_t = R_1 + R_2$) while in parallel equivalent resistance is given by ($\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2}$). It seems half of the learners knew how to manipulate/determine the resistance in circuits. However, some learners (39%) thought that the total resistance of circuit 4 was greater than that of circuit 3. There were few (9%) learners who thought the two circuits had the same resistance.

Figure 4.50 below further present the responses given by learners in terms of geographical location of their school.

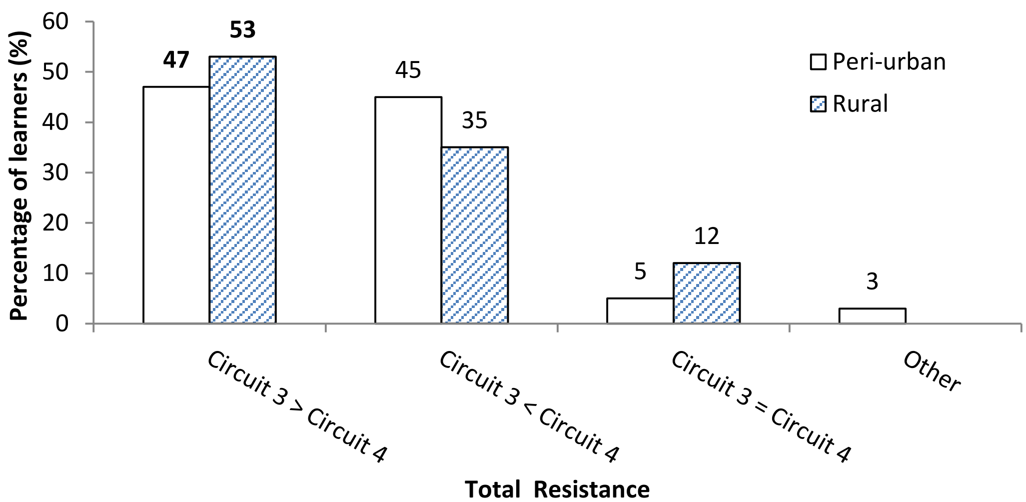
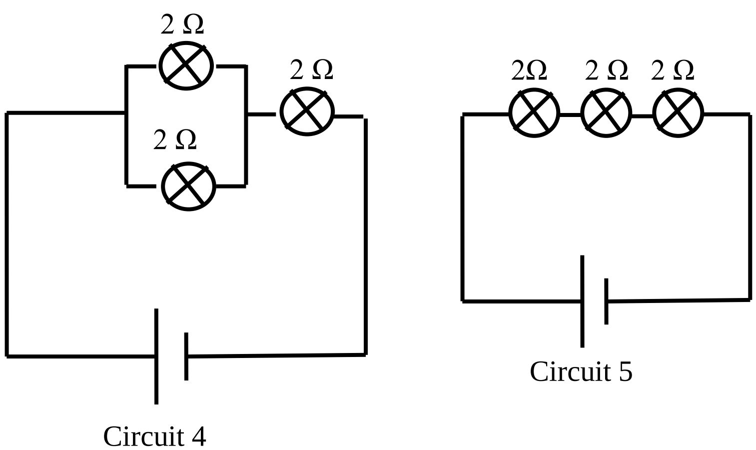


Figure 4.50: Responses about total resistance of circuits 3 and 4 per school location

Figure 4.50 shows that 53% and 47% of the rural school and of the peri-urban school learners, respectively, indicated that circuit 3's total resistance was greater than that of circuit 4. However, almost the same percentage (45%) of the peri-urban learners and few (35%) of the rural school learners presented the opposite. The peri-urban school learners seemed to have lacked the necessary skills and knowledge to manipulate resistors in series and parallel combinations. However, the difference between the two schools was not statistically significant ($X^2 = 2.69$, $p > 0.05$).

4.9.2 Comparison of resistors in parallel and in combination circuits

Part (b) of question 3 presented learners with two circuits (4 and 5) with 1 battery and 3 identical light bulbs of 2 Ohms each. Circuit 4 was the same circuit as in part (a) above while circuit 5 had its 3 bulbs connected in series (see Circuits 4 and 5 below). Learners were to compare the total resistance of the two circuits.



The results are presented in Figure 4.51 below.

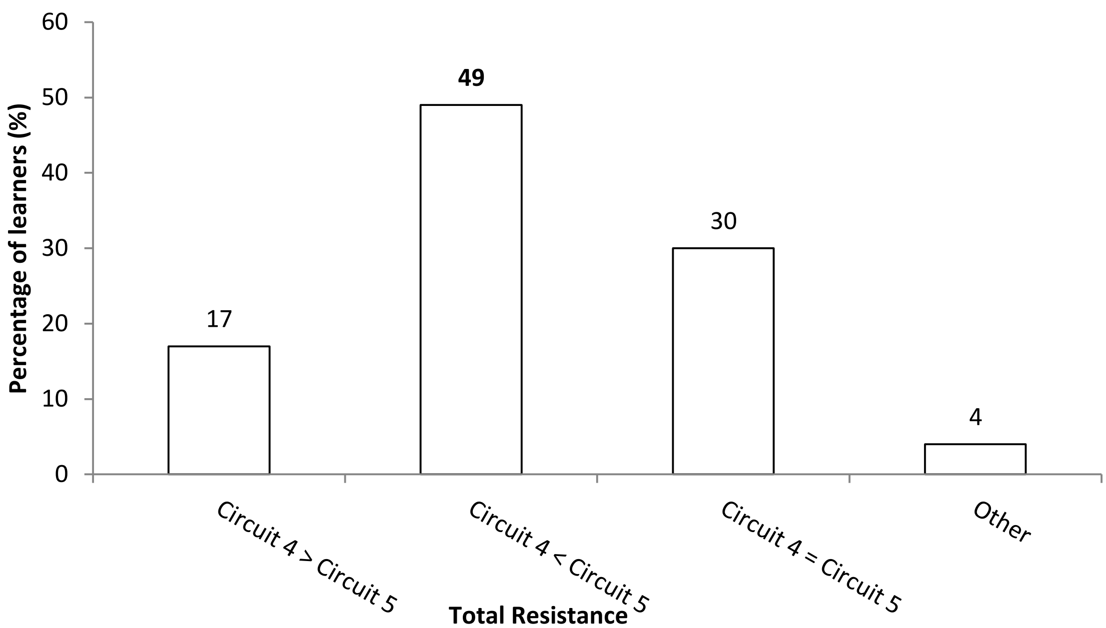


Figure 4.51: Learners' responses to total resistance in circuits 4 and 5

It is clear from Figure 4.51 that about 50% of learners correctly provided that the total resistance of circuit 4 was less than that of circuit 5. Similar results were observed in Figure 4.49 above where half of the learners presented scientifically acceptable responses that circuit 3's total resistance was greater than that of circuit 4. This is a confirmation that half of the learners knew how to manipulate resistance in a circuit.

Figure 4.51 also depicts that some (30%) learners thought, since the two circuits had the same number of bulbs, they would have the same total resistance irrespective of their arrangement. These learners were using phenomena-based reasoning than conceptual reasoning.

Figure 4.52 below shows learners' responses in terms of their school location.

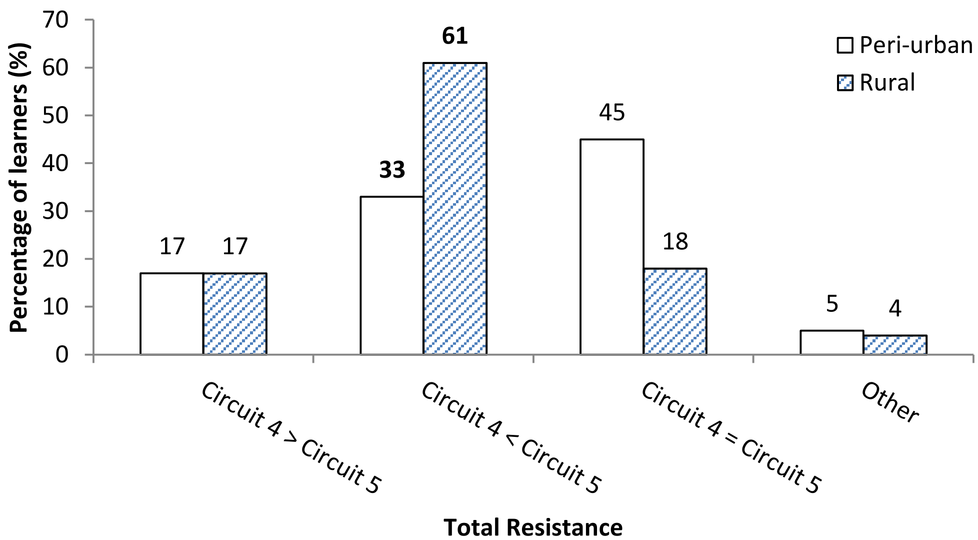


Figure 4.52: Learners' responses to total resistance of circuits 4 and 5 per school location

Majority of the rural school learners (61%) presented the scientifically acceptable option that circuit 5 had greater resistance than circuit 4 because resistance sums up in a series circuit. Figure 4.52 above shows that a majority (45%) of the peri-urban learners thought that the two circuits had the same total resistance. It is apparent from the figure that more than half of the rural school learners knew how to manipulate the resistance in a circuit. They have been consistent in giving scientifically acceptable responses to the three questions about resistance. On the other hand, 45% of the peri-urban school learners were using number of bulbs in the circuit to determine the total resistance of the circuits. It should be noted that circuit 3 had 2 bulbs while circuit 4 and circuit 5 had 3 bulbs each. Peri-urban learners who provided that circuit 3's total resistance to be less than that of circuit 4 had once more presented that circuit 4 and circuit 5 had the same total resistance.

The results could not be associated with the geographical location of the school because the differences were not statistically significant ($X^2 = 2.20$, $p > 0.05$).

4.10 SUMMARY OF THE FINDINGS

The results from this study could be summarized as follows:

- Learners knew isolated symbols and photographs for electrical components. However, they had difficulties when components were put together in a circuit.
- The role played by voltmeter and ammeter was not understood.
- More batteries meant more voltage, which leads to more current.
- Conductor was thought to be a solid hollow pipe like material, capable to carry electrical current.
- Concept differentiation (i.e., electricity, current, energy, voltage, power were used interchangeably) was cause for concern.
- Learners used equivalence equation for resistors to solve potential difference
- Some learners applied the ‘Brightness rule’.
- Bulbs showed certain brightness because of their arrangement.
- Current consumption - learners thought current was used along the circuit.
- They had difficulties in translation from realistic circuit to a schematic one.
- Inconsistent results where learners used different conceptions for a given situation.

The above summary is a snapshot of findings which the researcher deemed critical in this study however, there were more which are not necessarily listed but can be deduced from the document. The next chapter presents the conclusions made, limitations of the study and recommendation for further studies. It also reflects on the research questions asked in chapter one.

CHAPTER V: CONCLUSIONS, LIMITATIONS AND RECOMENDATIONS FOR FURTHER WORK

5.1 INTRODUCTION

This chapter presents a summary of the findings in chapter IV, study limitations and recommendations for future work.

The main goal of the study was to investigate the extent to which Grade 12 learners from rural and peri-urban areas understand what the symbols represent and what the roles of symbols used were in simple direct current resistive electrical circuits and to document related alternative frameworks. The participants were comprised of 56% and 44% rural and peri-urban learners, respectively.

The study addressed four research questions. The first question assessed learners' knowledge of schematic symbols. The second question probed learners' understanding of the role played by each symbol in a circuit, whilst the third one sought to establish the effect of adding more symbols in direct current resistive circuits. The last question assessed if learners had any alternative frameworks in schematic circuits. All research questions were used to determine the extent to which geographical location affect learners' knowledge of concepts and understanding of direct current resistive circuits.

Literature indicates that learners have difficulties in understanding electric concepts and schematic circuits. This study investigated if the difficulties experienced by learners were due to learners having challenges with symbols used or the role played by symbols in the circuits. The study also investigated if knowledge and understanding of direct current resistive electrical circuits is influenced by learners' geographical area.

5.2 CONCLUSIONS FROM THE STUDY

5.2.1 Knowledge of electrical symbols

The learner's responses to the first two research questions about knowledge of symbols showed that learners knew the basic symbols used in direct current resistive electrical circuits. This was evident as learners' managed to identify symbols, photographs and their associated names. However, there was a significant decrease in the number of learners who correctly identified symbols when connected together in direct current resistive electrical circuits. Learners struggled to identify some components which they knew, when they were put in a circuit.

The differences in terms of school location were not statistically significant. The findings were in agreement with literature. In situations where learners were exposed to similar experiences they were unlikely to have different alternative frameworks. In addition, the results showed that learners lacked the understanding of the roles played by each symbol in the circuit. Similarly, when more symbols were connected together in a circuit, the circuit became very complex for the learners to understand. Identifying individual symbols for each component also became a challenge. Therefore, addition of symbols in a circuit complicates the schematic circuit.

5.2.1.1 Role of measuring instruments (ammeter and voltmeter) in a schematic circuit diagram

Although learners knew the symbols for ammeter and voltmeter, results showed that learners had difficulties in understanding the role played by the two electrical devices in a direct current resistive electrical circuit. Learners thought the current value (displayed on the ammeter) decreases as charges move through circuit elements – current consumption model. There was no concept differentiation between the voltmeter and the ammeter. It was also evident that both peri-urban and rural learners experienced challenges on how ammeters and voltmeters should be connected in circuits. The differences observed between the two schools (in relation to their knowledge about the role played by both ammeter and voltmeter in a circuit) were not statistically significant.

Although this might be due to lack of practical experience, it is important for learners to understand why electrical meters must be connected in a particular manner. It is not sufficient to provide learners with rules on how instruments should be connected without providing them with explanations why they had to be connected that way.

5.2.1.2 Role of a battery in a schematic circuit diagram

Learners' responses to the role of a battery in a direct current resistive circuit revealed that 43% of the learners presented the scientifically acceptable view while majority thought it supplied charges, current or electricity to the circuit. It was clear that most learners were applying current consumption model which viewed the battery as a source of current or charge, in a circuit for bulbs. These learners' responses did not come as a shock because they were consistent with literature.

This current consumption model could be linked to everyday usage of the 'rechargeable battery'. The presented thought indicates that electrical circuits are all about charge whereas the scientific view is electrical circuits are about energy. When a battery does not work it is out of energy, therefore it had to be re-energized for it to work again. The battery's role in a circuit is to provide energy required to move a charge from low potential to high potential.

The differences in rural and peri-urban responses with regard to knowledge of the role played by a battery in the circuit were statistically significant. Explanations presented by the peri-urban school learners were inconsistent with the scientific knowledge whereas rural school learners were correct in their explanations. They indicated that the battery supplies the energy needed to move a charge from a low potential to a high potential.

5.2.2 Knowledge of conductor, resistance and the use of analogies

This study looked at learners' knowledge of a conductor. The results indicated that learners (80%) thought of a conductor to be a hollow pipe-like material which is able to carry or allow an electric current to pass through it easily. The results could be associated with the location of the school, with the peri-urban school learners performing better.

The responses could be linked to the strategy used (in most text-books) to introduce the concept. It was evident that the use of analogies introduced inadequate understanding. This hollow pipe-like material could be traced to water in a pipe analogy that most textbooks use to explain electric concepts. The learners related the pipes to the conductors and as a result thought conductors should be hollow for the electric current to pass through easily. This water-in-pipes analogy promotes current consumption model which suggests current is supplied to the circuit for it to be used by other components. Educators need to observe the limitations of each analogy used; its implications and to critically select analogies to avoid introducing alternative frameworks

The study also investigated the learners' knowledge and understanding of the relationship between resistance and current. The results showed that 45% of the learners had difficulties in relating resistance to current. Literature shows that the difficulties could have been due to lack of practical experience with electrical circuits.

The results from the current study also show that a majority of rural school learners (48%) correctly indicated that an increase in resistance would lead to a decrease in current for a constant potential difference whilst only few (30 %) of their rural counterparts thought so. The difference between the two schools in relation to knowledge of the relationship between current and resistance was statistically significant.

5.2.3 Series and series-parallel combination circuits

Learners' responses to questions on bulbs (resistors) in parallel and in series circuits revealed that half of their responses were scientifically acceptable for the two circuits. These results suggest that learners had a fair ability to manipulate resistors in both parallel and series circuits. The latter seemed to confirm the claim that learners could manipulate equations but lack the understanding behind the equations and the results thereof. The difference between the two schools in respect of their understanding of resistances in parallel and in series was not statistically significant. However, the peri-urban learners seemed to have lacked the necessary skills and knowledge to manipulate resistors in series and in series parallel combinations. Similar patterns were noted for resistors in parallel and in combination circuits.

There were also questions on learners' understanding of current in series and in parallel circuits. The majority of learners (84%) expressed that the brightness of two bulbs in series will be the same. Despite good performances by the two groups of learners (91 % of the rural and 75 % of the peri-urban school learners), there was a statistically significant difference in the number of learners choosing the correct option. In addition, when the same circuit was populated with two ammeters for measuring currents through bulbs 1 and 2, respectively, the picture changed for the worse. In a similar vein, knowledge of current splitting in parallel and combining in series could be associated with the location of the school (78% rural and 55% peri-urban).

Results from learners' conceptualization of basic and parallel connected (identical) cells showed leaners thought that a circuit with two parallel cells would be brighter that the one with a single cell. Only 18 % opted for the correct option (same voltage) due to lack of practical experience. The performance by learners from the peri-urban school was comparatively poor. The difference in performances between the two groups of learners was statistically significant.

When two cells connected to one bulb were arranged in series and in parallel, respectively, their voltages were compared. A majority of the learners (48%) correctly showed that a bulb in the series circuit would be brighter than the one in in the parallel circuit. In addition, the results seemed to suggest that for the peri-urban learners, arrangement of batteries in a circuit does not matter but the number of individual batteries involved. More than half of the learners from the rural school seemed to have realized the importance of the battery arrangement in circuits. However, the difference in rural and peri-urban learners regarding brightness of bulbs connected to two batteries in parallel and in series was not statistically significant

5.2.4 Interpretation of values for current, voltage and power

Insights on the understanding of abstract concepts such as current (2 A), voltage (220 V) and power (440 W) were gained through a set of questions that required learners' interpretations of values for each concept. The results confirmed the findings presented by numerous researchers that learners had difficulties in differentiating among the concepts. It was evident that learners did not have mental models of the working of electrical circuits, in agreement with literature. Literature indicates that the ability to interpret the readings is related to understanding the phenomena implied. Although the number of learners who presented the correct interpretations of the three concepts was small, resulting in a statistically significant difference between the responses given by the two schools suggests that the geographical location of the school could be a factor. Learners from the rural school performed well in all conceptual questions.

Learners could not interpret the data because interpretation should be based on interaction of existing knowledge and experience (Bryan and Stuessy 2006). These findings suggest that even if learners were to produce required results after manipulation of an equation, they are unlikely to understand them. It is therefore important for learners to be helped to relate electric circuit to the mathematical representation and to make sense of the results they get after manipulation of equations.

A similar observation was made by Thacker *et al.* (1999) that important scientific concepts such as potential difference, current, power were not understood and their meanings were unclear to learners. They concluded that:

"*It was very clear that the macroscopic parameters usually used in analyzing electric circuits were not well internalized and their meanings were rather vague*".

5.2.5 Translation from physical configuration of circuits to schematic circuits

This study found that although learners were presented with a real simple series circuits consisting of 2 batteries, a bulb, ammeter and a switch, to translate into a schematic one, majority of learners (about 80%) opted for schematic circuit diagrams which had their meters (either voltmeter or ammeter) connected in parallel. It was evident from the results that majority of learners did not understand how ammeters and voltmeters should be connected in a direct current resistive electrical circuit. Although more than half of the rural school learners could not differentiate between parallel and series circuits, they knew that a voltmeter is connected in parallel. The differences of rural and peri-urban school in transforming from a realistic circuit to a schematic one were statistically significant.

Learners should be taken through what an ammeter is, how it works, why it has to be connected in series and its role in a direct current resistive circuit. The same can be said for voltmeter.

The results obtained in this study contradicted the findings of Engelhardt and Beichner (2004) who reported that learners could easily translate from a real circuit to a schematic one but have difficulties in reverse translation. Since the learners in this study did not have any practical experience with electrical circuits, the simple direct current resistive electrical circuit became too complex for them.

This study also showed that learners had challenges with concept differentiation in line with literature. Understanding the role played by each symbol in the circuit could help learners in understanding electrical circuits.

5.2.6 Flow of charges in a schematic circuit diagram

In this study several models were used to explore a flow of charges. The results showed that about half of the learners preferred the clashing current model as opposed to the acceptable scientific model which indicated the same amount of charges in both wires in a continuous loop. These results contradicted the observed current consumption model suggesting learners did not understand concepts in a meaningful way. They seemed to change their answers according to the challenge presented. The difference between the two schools with regard to knowledge of the flow of charge in a circuit was not statistically significant.

Understanding the working and role played by each symbol in a schematic circuit should be emphasized. This will help learners to develop mental models of flow of electrical charge, which will enables them to understand electrical circuits.

5.2.7 Effects of geographical location of the school

Although materials on electricity had already been covered before the administration of the questionnaires, rural school learners seemed to be acquainted with scientific concepts better than the peri-urban school learners. The differences were in most cases statistically significant. Sencar *et al.* (2001) indicated that learners with theoretical experiences perform similarly in theoretical tests.

The differences observed in this study [such as knowledge of a conductor; interpretation of 2A (number of charges passing a point in 1 second), 220V (energy required to move a charge from one position to another) and 440W (rate at which energy is converted into other forms in 1 second); brightness of bulbs in series and in parallel-series combination; voltage of two batteries in parallel against one in series; relationship between current and resistance; role of a battery; indication of current on the second ammeter in series circuit; translation from realistic circuit to schematic circuit diagram] could have been due to different learning strategies used in the teaching of electricity.

5.3 LIMITATIONS OF THE STUDY

The sample used was derived from two high schools, one from rural area and the other from a peri-urban area within the proximity of the researcher's learning institution. This could be over or under representing the population. Questionnaire used had some incomplete returns which suggest that there might be those learners who were not willing to write everything they were thinking about or some of the questions were not clear. Focus group interviews also resulted in some learners' ideas being influenced by dominant participants. Oatey (1997) indicated that dominant respondents can negatively affect the outcome of the group. Therefore, the results might not be a true reflection of learners' thoughts. This study used structured interviews with standard list of possible answers. Although, learners were encouraged to come up with alternative options if they felt their views were not represented this might not have happened.

This study used English which was the second language for the participants. The findings indicate that majority could not communicate their scientific conclusions using the language of instruction (English). In addition the instrument used to gather the data required a fair amount of reading and decoding which could have contributed to the challenges learners encountered.
The results in this study might be of limited generalizability due to the participants not being exposed to practical experiments because learners with experience could have responded differently. The majority of the Mankweng Circuit's schools are among the 88% of national public schools that do not have laboratories (DoE 2008). However, a thorough investigation of how many schools did perform electricity experiments was not done.

This study was carried out prior to introduction of Curriculum Assessment Policy Statement (CAPS) by the Department of Basic Education. The introduction of CAPS has made some changes to the school system which implies some of the details might be incorrect. However, there is no evidence that the changes due to system has led to major improvements in learners understanding of science concepts. Therefore the findings of this study still stand. The recent Grade 12 physical science results of the CAPS exam shows a decline of 6% from 67% in 2013 to 61% in 2014 (Manyathela, 2015).

5.4 RECOMMENDATIONS FOR FURTHER WORK

The participants in this study were not exposed to practical work. This suggests the results might be different with learners exposed to practical work. It is therefore recommended that future studies look at the understanding of the role played by individual electrical components with learners who had practical experience with real electrical circuits**.**

This study found that learners had difficulties in translation from realistic circuit to a schematic circuit which contradicts Engelhardt and Beichner. However, this study used a pictorial representation of a real circuit. The use of a real circuit to investigate this finding should be considered. Learners should be taken through what an ammeter is, how it works, why it has to be connected in series and its role in a direct current resistive circuit. The same can be said for voltmeter.

It seemed a number of learners had difficulties in differentiating between series and parallel circuits with real circuits. Extensions to this study could be done by focusing learners' varied understandings of voltage and current for series and parallel circuits.

The researcher has also observed traditional approaches which are largely ineffective, as reported in literature. The educators need to combine different methods to foster understanding of electrical circuits, understanding of symbols and their roles in electrical circuit, understanding of the concepts, and relationships between the concepts.

Although it was not one of the objectives of this study to probe language barriers, due to a high number of respondents with unintelligent explanations and unanswered open-ended questions, it could be concluded that language contributed to the challenges experienced in understanding simple direct current resistive electrical circuits for the English second language speakers. It is therefore important for educators to take language barriers into consideration during electricity instructions. It is well known that the majority of South African learners in peri-urban and rural schools have little exposure to English outside the classroom. In South Africa learners start to switch to learn in English at grade four while they are not yet competent in their home language. Language researchers maintain that learners should first acquire deep skills in their home language to be highly competent in that language before they learn another language. They claim this will strengthen learners' ability to learn, speak, understand, interpret and analyze in another language. Gardner (2008) concluded that:

"*unless the home language is learned very well, learners are likely to have very limited linguistic abilities in whatever language they seek to use in their lives*".

REFERENCES

Ammeter impact on measured circuit. Available from http://www.allaboutcircuits.com/vol-1/chpt-8/5.html [Accessed 27/11/2008].

Alokan, F. B. (2010). Influence of sex and location on relationship between student problems and academic performance. *The Social Sciences,* **5**(4), p 340 to 345 DOI:10.3923/sscience.2010.340.345

Australian Council for Educational Research (ACER), (2002). Rural and urban differences in Australian education. *LSAY Briefing Reports*. (LSAY Briefing; n.5) http://reserarch.acer.edu.au/lsay_briefs/4

Baker, D. and Taylor, P. C. S. (1995). The effect of culture on the learning of science in non-Western countries: The results of an integrated research review. *International Journal of Science Education*, **17**(6), 695

Beaty, B. Contradictory definitions: what is electricity? http://amasci.com/miscon/whatdef.html Accessed 2009)

Bell, J. (1995). Doing your research Project: A guide for first-time researchers in education and social science, 2nd edition: Open University Press, USA, p 64-118.

Belski, L. and Gray, D .C. (2007). Enhancing students' systems thinking: Four screen representation of electronic systems. Proceedings of the AaeE Conference: Melbourne. Available from http://www.cs.mu.oz.au/aaee2007/papers/paper_43.pdf [Accessed 27/11/2008].

Bernhard, J. and Carstensen, A. (2002). Learning and Teaching Electric circuit Theory. Available from http://staffwww.itn.liu.se/~joube/fou/didaktik/papers/PTEE2002(Bernhard).pdf [Accessed 27/11/2008].

Bilal, E. and Mustafa E. (2009). Investigating students' conceptions of some electricity concepts. Lat Am J. Phys. Educ, **3**(2)**,** p 193-201

Bryan, J. A. and Stuessy, C. (2006). The 'Brightness Rules' alternative conception for the light bulb circuits. Physics Education, **41** (6), p 522-531.

Caillot, M. (1997). Graphics and Drawings in Physics: Learners' Difficulties and Remediation. Proceedings of the 5th annual meeting of the Southern African Association for Research in

Mathematics and Science Education. University of the Witwatersrand, Johannesburg. January 1997.

Canadian Council on Learning (2006). Lessons in Learning: The rural-urban gap in education.

Carstensen, A. and Bernhard, J. (2007). Threshold concepts and keys to the portal of understanding: some examples from Electrical Engineering. *Threshold Concepts within the Disciplines*, 00 – 00: Sense Publishers, p 1-12.

Clegg, F. (1990). Simple statistics: A course book for the social sciences.UK: Cambridge University press. p 64-65

Corbin, J.M. and Strauss, A. L. (2008). Basics of Qualitative Research: Techniques and procedures for developing grounded theory. Sage Publications, Inc.

Cohen, L. Manion, L. and Morrison, K. (2007). Research Methods in Education. 6th Edition: Routledge London, part 4 and 5.

Contradictory definitions: What is Electricity? Available from http://amasci.com/miscon/whatdef.html. [Accessed 10/05/2007].

Department of Basic Education, (2011). Report on National senior certificate examination results 2010. Available from http://www.info.gov.za [Accessed June 2011]

Department of Basic Education, (2010). National Examinations and assessment report on the national senior certificate examination results Part 2 2009. Pretoria.

Department of Education, (2008). South Africa: National report on the development of education, 48th International Conference on education, November 2008 Available from http://www.education.gov.za [Accessed 21/09/2009].

Department of Education, (2008a). Abridged Report: 2008 National senior certificate examination results, Pretoria, Republic of South Africa. Available from http://www.education.gov.za [Accessed 21/09/2009].

Department of Education, (2005). Report of the ministerial committee on rural education. A new vision for rural schooling. ISBN 1-920054-73-1

Department of Education, (2004). Dinaledi Project: Department briefing, Document handed out Department briefing: National Strategy for Mathematics, Science and Technology Education. Education Portfolio Committee, October 2004

Driver, R. (1989). Learners' conceptions and learning of science. *International Journal of Science Education*, **11**(5), p 481 – 490.

Driver, R. and Erickson, G. (1983). Theories- in –action: some theoretical and empirical issues in the study of the study of learners' conceptual frameworks in science. Science Education, 10, p 37-60.

Duit, R. and von Rhöneck, C. (1998). Section C2, Learning and understanding key concepts of Electricity: *Connecting Research in Physics Education with Physics Teacher Education.* International Commission on Physics Education. Available from http://www.Physics.ohio-state.edu/~jossem/ICPE/C2.html [Accessed 19/10/2010].

Dzama, E. (1997). Towards locating sources of alternative conceptions about Electricity among learners in developing countries. Focus on the learner. Proceedings of the 5th annual meeting of the Southern African Association for Research in Mathematics and Science Education. University of the Witwatersrand, Johannesburg. 22-26 January 1997, p 105-110.

Electronics circuits Reference Archive, Understanding Electricity - an analogy with water. 4QD-TEC. Available from www.4qdtec.com/water.html [Accessed 28/09/2006]

Engelhardt, P.V. and Beichner, R.J. (2004). Learners' understanding of direct resistive electrical circuits. *American Journal of Physics*. **72**(1), p 98-115.

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

Fleer, M. (1994). Determining Children's Understanding of Electricity. *Journal of Educational Research*. **87**(4), p 248-253.

Frederiksen, J. R. and White, B. Y. and Berkeley, U.C. (2000). Sources of difficulty in learners' understanding casual models for physical systems. Paper presented at the annual meeting of the American Educational Research Association, New Orleans, 26 April 2000.

Gardner, M. (2008). Education in rural areas, Issues in education policy number 4, Center for Education Policy Development.

Gilbert, W. (2009). Experiment 7 DC Circuits and Instruments, 'Look for knowledge not in books but in things themselves'. Available from http://www.owlnet.rice.edu/~phys126/labs/expt07. p 37-41. [Accessed 21/09/2009]

Gokhale, A. A. (1995). Collaborative Learning Enhances Critical Thinking. *Journal of technology Education***.** **7**(1), p 22-30.

Grayson, D (1994). A guided inquiry approach to teaching science, using electric circuits as an example. Workshop, University of Natal, Pietermaritzburg January 1994.

Grayson, D (2004). Concept Substitution: A teaching strategy for helping students disentangles related physics concepts. *American Journal of Physics*, Volume **72**, Issue 8, p 1126 -1133

Habash, R. W. Y. (2002). ELG2331, Lab Manual - Experiment 1: DC Circuits. Available from http://www.site.uottawa.ca/~rhabash/ELG2331Exp1.pdf [Accessed 21/09/2009].

Hall, J. R., Lathrop, H .R., and Kirk, S. R. (1987). Multiple Representation Approach to Understanding the Time Behavior of Digital Circuits. A. I. Memo No. 967. *American Association for Artificial Intelligence*. p 1-13.

Hands on Physics: Electricity - Circuit Diagrams. Available from http://hop.concord.org/el/elps.html. [Accessed 01/09/2009].

Hendricks, A. J. (2002). Investigating whether using the computer as a tutor could enhance 1st year Peninsula Technikon science learners' conceptual understanding of electrical concepts. Proceedings of the 10th annual SAARMTE meeting. University of Natal Durban. January 2002. p II-47 – II- 53.

Hendricks, A. J. (2003). Instrument development in a quantitative study on the notions of electricity among first year Peninsula Technikon science students. Proceedings of the 11th annual SAARMSTEC meeting. University of Swaziland. January 2003. p 106 – 110.

Heron, P.R.L, Shaffer, P.S. and McDermott, L.C. (2005). Reasearch as a guide to improving student learning: an example from the introductory Physics. Available at http://www.aaas.org/publications/books_reports/CCLI/PDFs/02_AER_Heron.pdf [Accessed 21/09/2009]

Hopkins, W. G. (2008). Quantitative research design. Sportscience **4**(1). Available at sportsci.org/jour/0001/wghdesign.html [Accessed 12/10/2009]

Jaakkola, T. and Nurmi, S. (2008). Learning objects- A lot of smoke but is there a fire? Academic impact of using learning objects in different pedagogical settings. Available from www.eun.org/eun.org2/eun/include_to_content/celebrate/file/final_report_experimental.doc [Accessed 29/10/2008].

James, A., Naidoo, J. and Benson, H. (2008). CASME's approach to the sustainability of science education in south Africa. XIII.IOSTE Symposium, the use of science and technology education for peace and sustainable development. 21-26 September 2008, Turkey.

Khumalo, L. P. and Naidoo, P. (1996). Survey of Physical Science Educators in Kwazulu-Natal. Preceedings of the 4th annual SAARMSE meeting. University of the North, January1996. p 149-158.

Küçüközer,H and Kocakülah,S. (2007). High School students' Misconceptions about Simple Electric Circuits. Journal of Turkish Science Education. 4(1), p 101- 115.

Lepheane, T. J. (2007). Land Redistribution and its impact on Agri-BEE: A case study of Calcom PTY, Barbeton , Mpumalanga, South Africa. MA Dissertation, Wits University. Available http://wiredspace.wits.ac.za//handle/10539/2142. [Accessed 7/09/2011].

Lewin, K. M. (1993). Planning policy on science education in developing countries. *International Journal of Science Education*, **15**(1), p 1-15.

Lubben, F., Netshisaulu, T. and Campbell, B. (1999). Students' use of cultural metaphors and their understandings related to heating. *Sci Ed* 83, p 761-774.

Mahapatra, M. (2006). Exploring Physics Educators' Concepts of Simple DC Circuits. Available from www.girep.org/proceedings/conference2006. p 666-680. [Accessed 29/03/2011]

Manyathela, N (2015) Equal Education: on the 2014 matric results. http://www.equaleducation.org.za/article/2015-01-07-on-the-2014-matric-results [Accessed 11/03/2015]

McClelland, J. A. G. (1984). Alternative framework: Interpretation of evidence. European Journal of Science Education. **6**(1), p 1-6.

McDermott, L.C and Redish, E. F (1999). RL-PER: Resource letter on Physics Education Research, *American Journal of Physics*. **67** p 755-767

McDermott, L .C. and Shaffer, P .S. (1992). Research as a guide for curriculum development: an example from introductory Electricity, Part I: Investigation of student understanding. *American Journal of Physics*. **60**, p 994 -1003.

Mosoloane, R. and Sanders, M. (2007). Problems relating to textbook diagrams illustrating concepts associated with the earth-sun-moon configuration. Proceedings of the 15th annual conference of the south African association for research in mathematics, science and technology education. Eduardo Mondlane University, Maputo. **1,** p 425 – 432.

Nave, R. (2007). Basic DC Circuit Relationships. Available from http://hyperPhysics.phy-astr.gsu.edu/hbase/electric/watcir2.html [Accessed 25/05/2007].

Netshisaulu, T.T. (1996). Misconceptions and cultural interpretations of heat and temperature amongst UNIFY learners before and after instruction, MA dissertation, University of York.

Nisbet, J.D. (1977). Small scale research: guidelines and suggestions for development, *Scottish Educational studies*, **9**(5), p 13-17.

Nurmi, S. and Jaakkola, T. (2004): Facilitating learners' understanding of simple DC circuits- combining simulation and laboratory work together. Paper presented at the British Educational Research Association Annual Conference, University of Manchester, 16-18 September 2004.

Oatey A (1999). The strengths and limitations of interviews as a research technique for studying television viewers. Available from http://www.aber.ac.uk/media/students/aeo9702.html [Accessed 8/10/ 2009].

Ogunniyi, M. B. (1999). Assessment of Grade 7-9 Pupils' knowledge and interest in science and technology. University of Western Cape: SSME.

Ogunniyi, M. B. (2005). Are South African Grade eight learner's conceptions of Electricity influenced by their sex, age, language, career interests or graphical location? Proceedings of 13th annual SAARMSTEC Meeting, University of Namibia, Windhoek. January 2005, p 653-658.

Osborne, J., and Freeman, J. (1989). Teaching Physics: A guide for non-specialist. Cambridge university press.

Pandor, N. (2004). Statement by Minister of education on the release of the 2004 Senior Certificatee examination results, Cape Town (Parliament). 29 December 2004.

Planinic, M., Boone, W.J., Krsnik, R and Beilfusss, M.L. (2006). Exploring Alternative Conceptions from Newtonian Dynamics and Simple DC Circuits: Links between Item Difficulty and Item Confidence. Journal of research in science teaching. **43**(2), 150-171.

Probyn, M.J. (2003). Learning Science through Two Languages in South Africa. Proceedings of the 4th international Symposium on Bilingualism

Psillos D. (1998). Teaching introductory electricity: Connecting research in Physics education with educators education, Available from www.Physics.ohio-state.edu/~jossem/ICPE/E4.html [Accessed 19/10/2010].

Physics Classroom-Lesson 2: Electric Current: Common Misconceptions Regarding Electric Circuits. Available from www.Physicsclassroom.com/class/circuit/u912e.cfm [Accessed 27/11/2008].

Reid, D. J. (1984). The picture superiority effect and biological education. Journal of Biological Education, **18**(1): p 29-36.

Sacate, A. R. (2003). The impact of mathematics on performance of first-year university students in Electricity and Magnetism. Proceedings of the 11th annual SAARMSTEC meeting, University of Swaziland, January 2003, p 222-228.

Sacate, A. R. (2005). An exploration of the contribution of some strategies to promote conceptual development in the Electricity domain. Proceedings of the 13th Annual SAARMSTEC meeting, University of Namibia, Windhoek. January 2005, p 727-730.

Sefton, I. M. (2002). Understanding Electricity and Circuits: What the Text Books Don't Tell You. Science Teacher workshop 2002. Available from http://sydney.edu.au/science/uniserve_science/school/curric/stage6/phys/stw2002/sefton.pdf [Accessed 27/11/2008]

Sencar, S., Yilmaz, E. E. and Eryilmaz, A. (2001). High School Students' Misconception About Simple Electric Circuits. Journal of Education 21. p 113-120.

Shipstone, D. (1985). Electricity in simple circuit in: Children's ideas in science (Eds). Driver, Guesene and A. Tiberghien, Milton Keynes: Open University Press.

Surty, E. (2008). Address by deputy Minister of Education during the education budget, vote 13, National Assembly, Cape Town, 15 May 2008.

Taber, K.S., de Trafford, T. and Quail, T. (2006). Conceptual resources for constructing the concepts of Electricity: The role of models and analogies and imagination. *Physics Education*, **41**(2), p 155-160.

Tamir, P. (1971). An alternative approach to the construction of multiple choice test items. Journal of Biological Education. **5**. p 305-307.

Tarekegn, G. (2009). Can computer simulations substitute real laboratory apparatus? *Lat. Am J. Phys. Educ. Vol 3. No. 3. pp 506-517.* Available from http://www.journal.lapen.org.mx [Accessed 19/10/2010]

Taylor, N. (2007). How should we think about the 2006 matric results? www.Jet.org.za/artcle.php? [Accessed 10/05/2007].

Thacker, B.A., Ganiel, U., & Boys, D. (1999). Macroscopic phenomena and microscopic processes: student understanding of transients in direct current electric circuits. Pys Educ. Res., Am J. Phys. Suppl **67**(7). p S25-S30.

Torrens, R. (2003). 4QD-TEC Electronic Circuits Reference Archive: Understanding Electricity- An analogy with water. Arachsys, Available from www.4qdtec.com/water.html [Accessed 28/09/2006].

van der Berg, S. (2005). How effective are poor schools? Poverty and educational outcomes in South Africa. Paper submitted SACMEQ conference, Paris, p 1-39.

Weinreich, N. K. (1996). Integrating quantitative and qualitative methods in social marketing research. Available from http://www.social-marketing.com/research.html [Accessed 12/10/2009]

Wolff, P. (1987). Test questions on basic mechanics and simple electrical circuits. Basic Science Projects Unit, Free University Amsterdam.

http://en.m.wikipedia.org/wiki/polokwane_local_municipality [Accessed 9/05/2013]

APPENDIX A: QUESTIONNAIRE FOR THE GRADE 12 LEARNERS

Name and Surname**:** ___________________	Name of School**:** ____________________
Grade: 12	Gender**:** Male / Female
Age group**:** 15-17 / 18-20/ 21-25/ 25- above	Date:

Respondents:

The aim of this study is to investigate the understanding and perceptions of learners about the role of symbols in simple direct current resistive circuits. The information supplied will be used for research purpose only. So feel free to respond to all questions. Please return the completed questionnaire to the researcher. Thank you for your cooperation.

R.T. Mautjana (Researcher).

Instructions:

Use a pen or pencil to answer the questions. Calculator may be used if necessary. Please answer each question by crossing the correct answer or by writing your answer in the space provided.

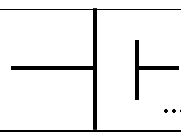
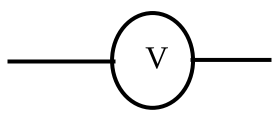
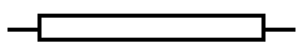
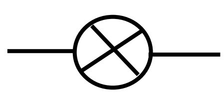
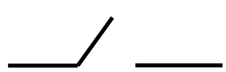
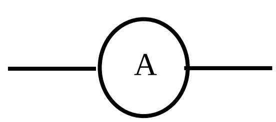
Laboratory Information

Does your school have a laboratory? Yes / No
Does the laboratory have electricity apparatus? Yes / No
Do you perform electricity experiments at your school? Yes / No

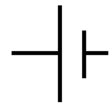
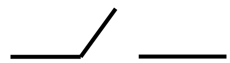
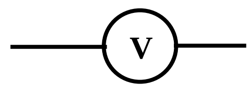
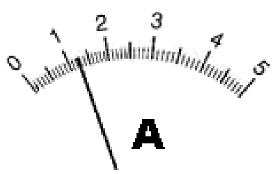
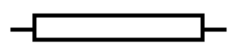
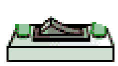
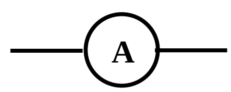
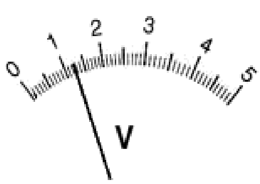
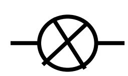
Notes: All light bulbs, resistors and batteries should be considered identical unless you are told otherwise. The internal resistance of the battery is negligible. Also assume that wires have negligible resistance.

Section A

1. Match the symbols in Column A with their names from column B. Write down the corresponding Roman figures (from Column B) on the dotted lines next to the symbol.

Column A		Column B
Symbols	Roman Figure	Names
a) 	....	i) Ammeter
b)	……………	ii) Battery
c) 	…………	iii) Closed Switch
d)	...…………	iv) Light Bulb
e) 	…………	v) Open Switch
f) 	………….	vi) Resistor
g) 	……………..	vii) Voltmeter
h) 	....…………	viii) Wire

2. Match the pictures with their schematic symbols (as used in circuit diagrams) and write down the corresponding roman figure on the dotted line next to the picture

 a) ………	 i)
 b) ……….	 ii)
 c) ………..	 iii)
 d) …………	 iv)
 e) ………..	 v)
 f) ……….	 vi)

3. A bulb is connected to a battery by means of a conductor.

a) Which of the following best describes the role of a battery in an electric circuit?

i) It supplies the conductor with charges/electrons

ii) It provides the same amount of electric current to the circuit.

iii) It supplies the circuit with energy to move charges.

iv) It supplies electricity to the electric circuit.

v) None of the above

b) Which of the following best describe what is meant by the word ‘conductor’?

i) Material which contains electric charges which are free to move

ii) Material which allows moving charges to pass through easily.

iii) Solid material that allows electrical current to pass through.

iv) Material which is able to carry electric current.

v) None of above

c) Which of the following statement about ‘resistance’ is correct?

i) If resistance increases current increases

ii) A long wire will have less resistance than a similar short wire

iii) A greater resistance less the current

iv) Longer wire allows a greater current than a similar short wire.

v) None of the above.

4. Consider the following readings: I = 2A, potential difference = 220V and electrical power = 440W.

a) Which of the following statements is correct about the current I = 2A?

i) 2C of charge passing through a conductor per second

ii) 2C of charges are used up in an electrical circuits by elements such as the bulb.

iii) The 2J of electrical energy is converted into heat and light in a second.

iv) The energy required to move 2C of charge from the positive to the negative terminal

v) None of above

b) Which of the following statements is correct about the potential difference = 220V?

i) The strength of the battery is 220V.

ii) 220J electrical energy is required to move 1C of charge from one terminal of the battery to the other.

iii) The amount of electrical energy the battery supplies to the circuit.

iv) A flow of electricity through a conductor

v) None of above

c) Which of the following statements is correct about the power = 440W?

i) 440J of electrical energy of the moving charges is converted to some other form e.g. heat or light in a second.

ii) 440J of energy is used up as charges move through circuit elements such as bulbs.

iii) The strength of the battery.

iv) 440j of work is done by an electric current in a second

v) 440W of electricity flows through a conductor

vi) None of the above

5. Ammeter and voltmeter play certain roles in electric circuits.

a) Which of the following best describe the role of an ammeter in an electric circuit?

i) To measure the charge passing through a conductor in a second

ii) To measure charges which are used up in an electrical circuits by elements such as the bulb.

iii) To measure electrical energy that is converted into heat and light in a second.

iv) To measure the energy required to move a charge from the positive terminal to the negative terminal

v) None of the above

b) Which of the following best describe the role of a voltmeter in an electric circuit?

i) To measure the electrical energy required to move a charge from one terminal of the battery to the other.

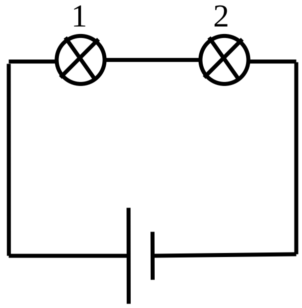
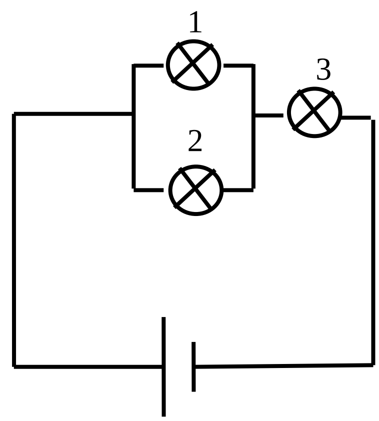
ii) To measure the flow of electricity through a conductor

iii) To measure the strength of the battery in the circuit.

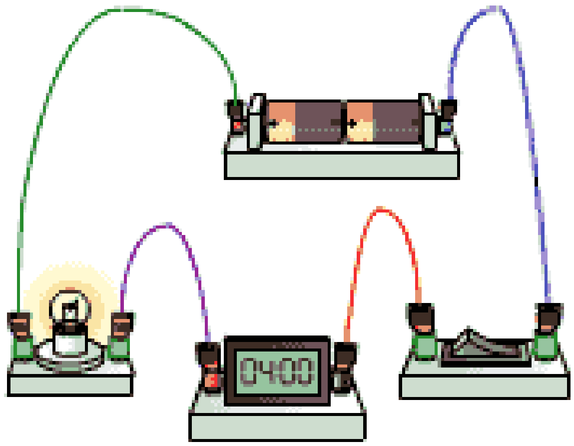
iv) To measure the electrical energy the battery supplies to the circuit.

v) None of the above

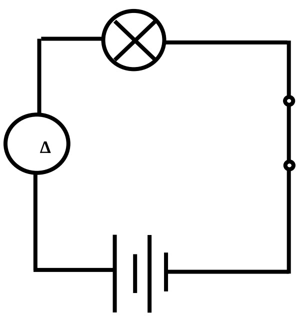
Section B

1. a) Compare the brightness of the two bulbs in circuit 1: (bulbs 1 and 2). Which bulb is brighter?  Circuit 1 i) Bulb 1 is brighter than bulb 2 ii) Bulb 2 is brighter than bulb 1 iii) They are of the same brightness iv) None of the above Explain your reasoning __________________________________ __________________________________ __________________________________ __________________________________	b) Compare the brightness of bulbs 1 and 3 in circuit 2 below. Which bulb is brighter?  Circuit 2 i) Bulb 1 is brighter than bulb 3 ii) Bulb 3 is brighter than bulb 1 iii) They have the same brightness iv) None of the above Explain your reasoning __________________________________ __________________________________ __________________________________ __________________________________

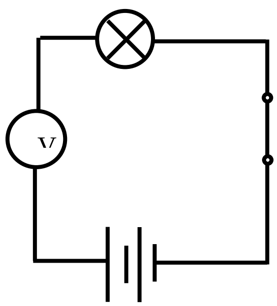
2. A bulb is connected in the circuit as shown below.



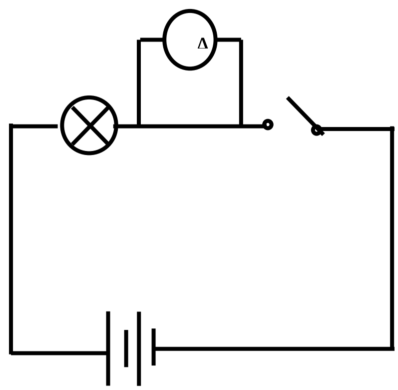
a) Which of the following best represents the realistic circuit? Cross the correct roman figure.



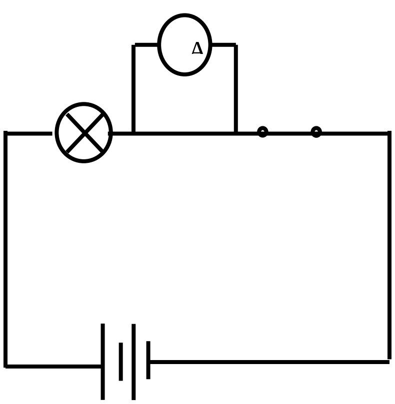
i)



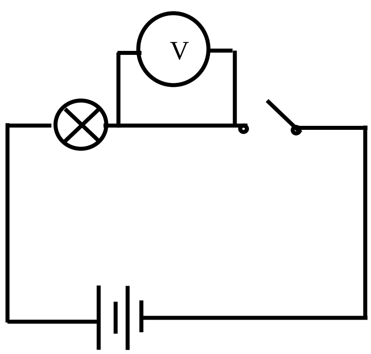
ii)



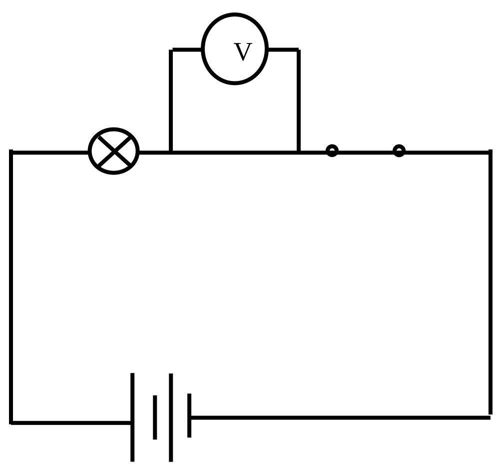
iii)



iv)

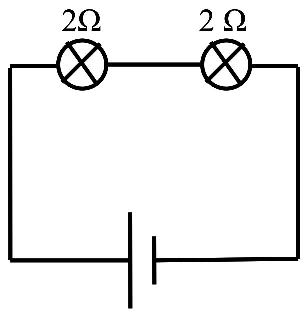


v)

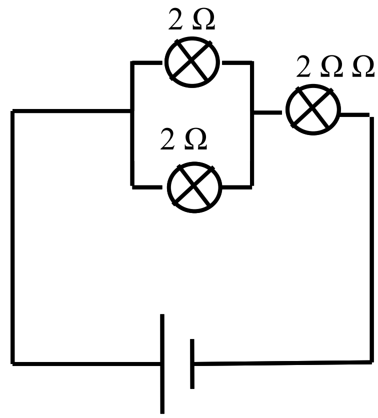


vi)

3. Consider the following circuits below



Circuit 3



Circuit 4

a) Compare the total resistance of the two circuits above

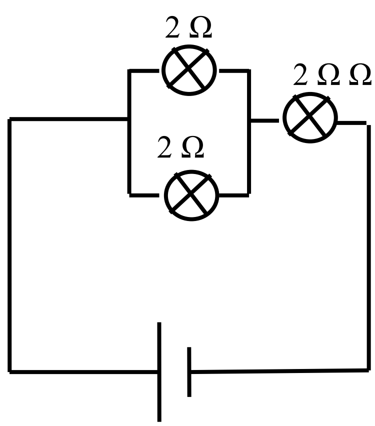
i) Circuit 3's total resistance is greater than that of circuit 4

ii) Circuit 3's total resistance is less than that of circuit 4

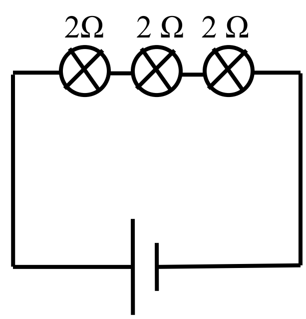
iii) The total resistance of the two circuits is the same

iv) None of the above

b) Compare the total resistance of the two circuits below.



Circuit 4



Circuit 5

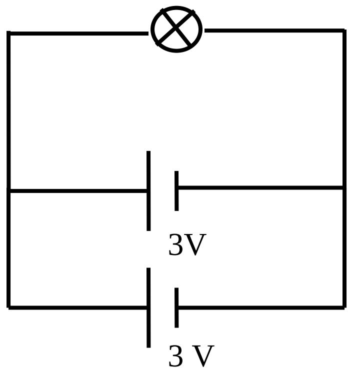
i) Circuit 4's total resistance is greater than that of circuit 5

ii) Circuit 4's total resistance is less than that of circuit 5

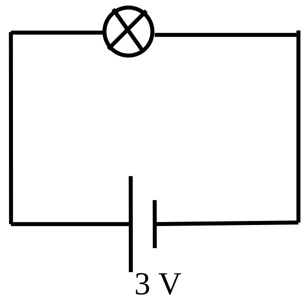
iii) The total resistance of the two circuits is the same

v) None of the above

4. a) Compare the brightness of the bulbs in circuit 6 & 7 below. Which bulb is brighter?



Circuit 6



Circuit 7

i) Bulb in circuit 6 is brighter than the bulb in circuit 7
ii) Bulb in circuit 7 is brighter than the bulb in circuit 6
iii) Their brightness is the same
iv) None of the above

Explain your reasoning

____

____

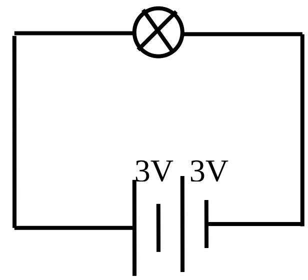
____

Each battery has a potential difference of 3V as shown in circuit 6 above.

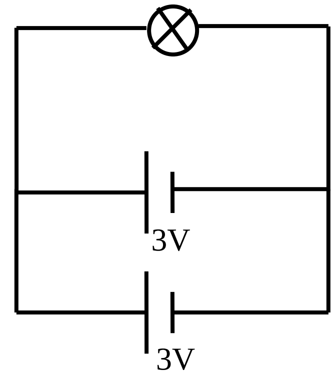
b) What would be the voltage across the bulb in circuit 6?

i) 3 V
ii) 1.5 V
iii) 9 V
iv) 6 V
v) None of the above

c) Compare the brightness of the bulbs in circuits 8 & 9 below. Which bulb is brighter?



Circuit 8



Circuit 9

i) Bulb in circuit 8 is brighter than the bulb in circuit 9
ii) Bulb in circuit 9 is brighter than the bulb in circuit 8
iii) Their brightness is the same
iv) None of the above

Explain your reasoning

____

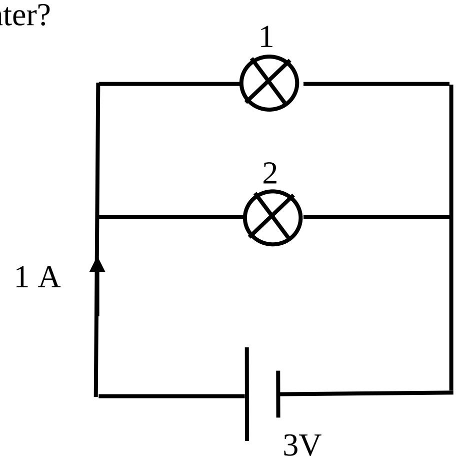
____

____

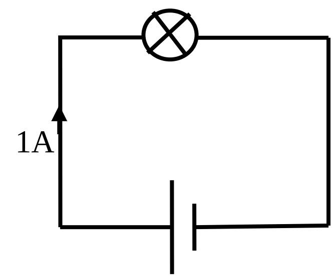
d) What would be the total voltage for circuit 8?

i) 6 V
ii) 3 V
iii) 12 V
iv) 1.5 V
v) None of the above

5. a) Compare the brightness of the bulbs in the two circuits below. Which bulb(s) is/are brighter?



Circuit 10



Circuit 11

i) Their brightness is the same

ii) Bulb in circuit 11 is brighter than those in circuit 10

iii) The two bulbs in circuit 10 are brighter than the bulb in circuit 11

iv) None of the above

Explain your reasoning

____

____

b) What would be the potential difference across bulb 1 in circuit 10?

i) 1.5 V

ii) 1 V

iii) 3 V

iv) 0.5 V

v) None of the above

c) What would be the power delivered to bulb 1 in circuit 10?

i) 6 W

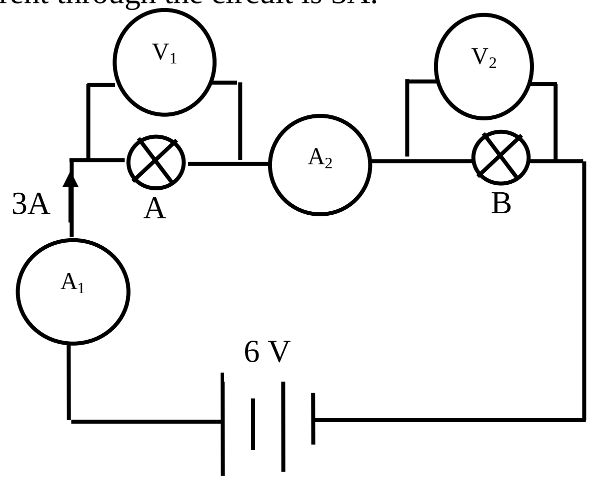
ii) 1.5 W

iii) 1 W

iv) 3 W

v) None of the above

6. Circuit below has potential difference of 6V and the current through the circuit is 3A.



Circuit 12

a) What would be the meter v_1 reading across A?

i) 1.5 A

ii) 6 V

iii) 3 V

iv) 3 A

v) None of the above

Explain your reasoning

____

____

b) What would be the meter reading v_2 across B as above?

i) 6 V

ii) 1.5 A

iii) 3 A

iv) 3 V

v) None of the above

Explain your reasoning

____

____

c) What would be the meter reading A_2?

i) 1080 J

ii) 0

iii) 3 A

iv) Less than 3 A

v) None of the above

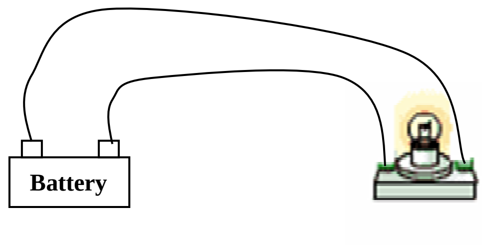
Explain your reasoning

____

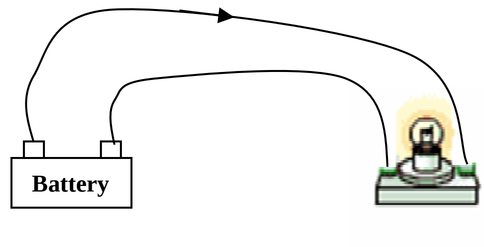
____

7. A bulb is connected to a battery. The bulb is lit.

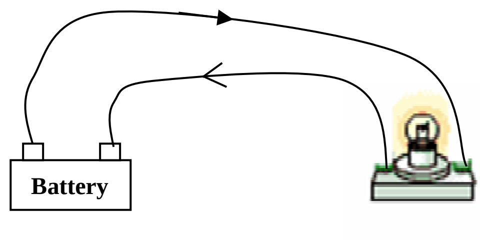
Choose the best option you believe to be true.



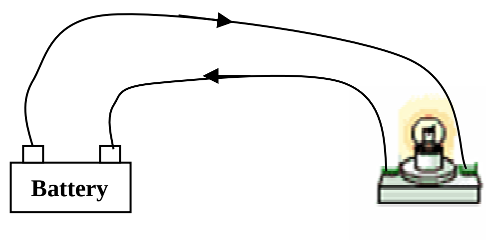
a) There is an electric current through wire to the bulb.
It is used up in the bulb. So there is no current in the other wire.



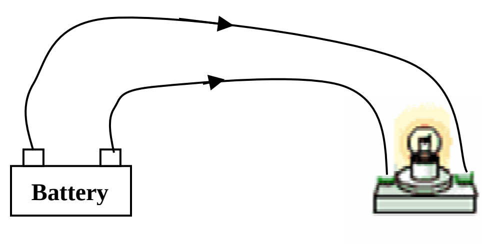
b) There is an electric current through wire to the bulb.
Some of it is used up in the bulb. So there is a smaller current in the other wire.



c) There is an electric current through wire to the bulb.
It passes through the bulb and back to the battery.
The current in the other wire is same size.



d) There are two electric currents from the battery to the bulb.
They meet at the bulb and this is what makes it light.



e) None of the above

APPENDIX B: CODING SCHEME FOR WRITTEN RESPONSES

Written responses were analyzed using a coding system. Each code corresponded to a particular group of responses supplied by learners. The first letter A - E indicates the selected option corresponding to i - v. The three digits are for reasoning. A similar approach was applied to all questions however each question had its own coding scheme. Below is a table indicating the general scheme applied.

Summary of the coding scheme used

Main/Key Concept/idea/term/point		Examples of explanations
Type of connection (first digit)	100 = series	Because they are connected in series
Series	110= series electricity same	The two bulbs are connected in series thus have the same electricity
	120= series current same	The two bulbs are connected in series thus have the same current
	150 = series power is the same	The two bulbs are connected in series thus have the same power
Bulb of same size	200	The bulbs are equal in size/ brighter because it is big (size)
Battery is the same	300	Because they are connected to the same battery therefore have same brightness
Parallel	600	
Wrong/ incomplete infomation	700	
Uncodeable	UN	Responses not related to key issues/unclear or difficult to understand (e.g. wrong connection)
No explanation	000	Learners did not write any explanation supporting their choice or they repeated the the expression given in the alternative of multiple-choice part of the question

Main/Key Concept/idea/term/point Second digit	Variables/specifics/degree Third digit	Examples of explanations
01=Electricity related category	0 =same/conserved/not used up 1=less/decreases/lost/consumed 2=more/increases/high/gain 3=shared/divided	
02=Current related category	0 =same/conserved/not used up 1=less/decreases/lost/consumed 2=more/increases/high/gain 3=shared/divided	
03=Voltage related category	0 =same/conserved/not used up 1=less/decreases/lost/consumed 2=more/increases/high/gain 3=shared/divided	
04=Energy related category	0 =same/conserved/not used up 1=less/decreases/lost/consumed 2=more/increases/high/gain 3=shared/divided	
05=Power related category	0 =same/conserved/not used up 1=less/decreases/lost/consumed 2=more/increases/high/gain 3=shared/divided	
06=Resistance related category	0=same 1=less 2=more	
07= Light related category	0=same 1=less 2=more	

Typical example:

000 = No Explanation given
UN = Uncodable
100= because they are connected in series
110 = The two bulbs are connected in series thus have the same electricity through them
120 = The bulbs have the same current through them, because they are in series
143 = Because they are connected in series Energy is shared
130 = Because they are connected in series voltage will be the same.

010 =same electricity
020 =same current
041 = Energy is less
030 = same voltage
200 =The bulbs are equal in size

300 =Because they are connected to the same battery
040 = Energy is the same
060=Same resistance
600 = because they are in parallel

NAME	GENDER	Q No	Response		CODE	ANSWERS
D50	F	Q1A	iv	D	0	they have the same brightness
D23	M	Q1A	iii	C	0	They are of the brightness because
D36	F	Q1A	iii	C	10	They receive the equal amount of electricity flow
D38	F	Q1A	iii	C	10	Because they share the same amount of electricity
D43	F	Q1A	iii	C	10	The electricity in the bulbs are equal
D57	F	Q1A	iii	C	10	The amount of electricity applied is the same
D24	M	Q1A	iii	C	10	since they are of the same brightness, they will receive equal amount of electricity thus they are on the same conductor and will shine/bright the same
D27	M	Q1A	iii	C	10	They use the same amount of electricity flowing in a circuit
D59	F	Q1A	iii	C	20	Because the are on the same level and have the same current
D14	M	Q1A	iii	C	20	Because the current that flows in the bulb numbered one is the same as the current in two
D19	M	Q1A	ii	B	21	because bulb 2 get the electric current before bulb 1 and pass less current to bulb 1 to can light
D28	M	Q1A	i	A	21	Cause the bulb 1 has the most current electricity than bulb 2
D20	M	Q1A	iii	C	40	Because they share the same amount of Energy
D08	M	Q1A	iii	C	40	They receive the same amount of Energy from the cell.
D15	M	Q1A	iii	C	40	they are using the same amount of Energy from the battery in the circuit
D07	M	Q1A	iii	C	40	Because this two bulb are connected in one circuit and the Energy is the same in circuit.
D13	M	Q1A	iii	C	40	They are in the same circuit and they share equal amount of Energy.
D16	M	Q1A	iii	C	40	they are connected in the same circuit and Energy flow is the same Energy at 1 is equals to Energy passing 2
D49	F	Q1A	iii	C	41	because the negative and positive bulb attract each other so the used up all the Energy
D26	M	Q1A	i	A	41	Bulb 1 is brighter than bulb 2 because it receive more Energy first and bulb 2 recieves less Energy which was unable to be absorbed (used up) by bulb 1
D31	M	Q1A	ii	B	41	Because Energy that is lost by bulb 1 is gain bulb 2. They are not connected parallel.
D35	F	Q1A	i	A	42	bulb 1 is brighter than bulb 2 - the Energy flow from the highest potential to the lowest, the first will receive much Energy
D25	M	Q1A	i	A	42	Bulb 1 is connected to a battery with high Energy i.e the Energy from that battery makes bulb 1 to be brighter than bulb 2 which is connected to a battery with low Energy
D21	M	Q1A	ii	B	52	Because is negative charge it receive more power than 1
D41	F	Q1A	iii	C	100	because a bulb is connected to each other
D44	F	Q1A	iii	C	100	because both of them are connected in series
D45	F	Q1A	iii	C	100	they are both connected in series meaning they have got the same brightness
D46	F	Q1A	iii	C	100	Because they are connected in series
D55	F	Q1A	i	A	100	Bulb 1, because the bulbs are connected in series and that's why is more brighter
D58	F	Q1A	iii	C	100	They are connected in series
D42	F	Q1A	iii	C	100	Because the two bulbs are at the same wire and the

						brightness are the same
D56	F	Q1A	iii	C	100	They are connecetd in series
D01	M	Q1A	iii	C	100	Because they are connected in series.
D04	M	Q1A	iii	C	100	Because they are connected in series
D05	M	Q1A	iii	C	100	They are connected in series, the flow of charge in one direction
D12	M	Q1A	iii	C	100	They are connected in series
D32	M	Q1A	iv	D	100	There are connecetd in series
D29	M	Q1A	iii	C	100	Because they are in the same wire which supplies Energy and that mean they both have equal brightness
D54	F	Q1A	iii	C	120	because they connected in series so they have the same current flow
D03	M	Q1A	iii	C	120	If the bulbs are in series they use equal current.
D09	M	Q1A	iii	C	120	they are connecetd in series the amount of bulb 1 will be equal to the amount of light at 2, same current.
D10	M	Q1A	iii	C	120	Current at bulb1 & 2 are the same because of the series connection
D02	M	Q1A	i	A	121	Because bulb connected in series have the same current which must pass through 1 before going to two. The potential difference is not the same.
D30	M	Q1A	i	A	121	If current flows to the left from the battery bulb1 will be brighter than bulb 2 since they are connected in series
D47	F	Q1A	iii	C	200	The bulb are equal in circuit
D22	M	Q1A	iii	C	200	they are of the same brightness, because they are equal with conductors same size of cond fro batt
D33	M	Q1A	iii	C	200	Their bulbs are both eqaul in all sides and are supplied by the same resistor
D18	M	Q1A	ii	B	202	the bulb 2 is brighter because is too big than bulb 1. And also will till of more brighter because of bulb 2 is big
D39	F	Q1A	iii	C	300	Because they share the same battery
D40	F	Q1A	iii	C	300	Because the two bulb had connected by the same battery
D11	M	Q1A	iii	C	300	Because the bulb is connected to the same battery in the circuit.
D52	F	Q1A	iii	C	610	Because they receive the same amount of electricity and they are connected in parallel
D53	F	Q1A	iii	C	640	Because they are receiving the same amount of Energy and they are also connected in parallel
D37	F	Q1A	iii	C	UN	Because they are conducted by the same conductor
D48	F	Q1A	iii	C	UN	Because they are connected in the same circuit
D51	F	Q1A	iii	C	UN	Because they are of the same bright. They flow through the same conductor.
D60	F	Q1A			UN	Because there is + charges on this bulbs
D17	M	Q1A	i	A	UN	because bulb 1 is on the positive charge of the battery
D06	M	Q1A	iii	C	UN	Because , they receive the same amount every cell
D34	M	Q1A	iii	C	UN	The electric current flow easily through to the bulb because there is no ammeter and voltmeter

APPENDIX C: ENROLMENT STATISTICS AT MANKWENG CIRCUIT

LIMPOPO PROVINCE
DEPARTMENT OF EDUCATION
CAPRICORN DISTRICT
MANKWENG CIRCUIT OFFICE

SUMMARRY OF GRADE 12 ENTRIES: OCTOBER/NOVEMBER 2007

Number	Name of School	Physical Science HG	Physical Science SG	TOTAL
1	Bjatladi	5	16	**21**
2	Ditlalemeso	10	61	**71**
3	Hwiti	18	10	**28**
4	Makgoka	119	44	**163**
5	Makgongoana	6	6	**12**
6	Mamabudusha	28	14	**42**
7	Marobathota	84	0	**84**
8	Mountainview	41	64	**105**
9	Mphetsebe	0	26	**26**
10	Ramashobohle	0	0	**0**
11	Sekitla	7	0	**7**
TOTAL		**318**	**241**	**559**

Circuit Manager: Mankweng
(Thupana M)

APPENDIX D: SAIP 2011 PAPER

Learners' understanding of ammeter and voltmeter in direct current schematic circuits

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Abstract. This study explored learners' knowledge of measuring devices in a direct current resistive circuit. It investigates learners' understanding of how ammeter and voltmeter are connected and why they have to be connected in a particular way. Ammeter and voltmeter are used to determine the behaviour of a circuit by indicating the readings of current and voltage, respectively. To an educator an ammeter does not change the characteristics of a circuit; it is therefore an invisible component. However, a learner views an ammeter differently. A pen and paper questionnaire was administered to grade 12 learners and group interviews were used as additional evidence. The results that learners lacked the basic understanding of the role played by measuring devices. It was also evident that because of lack of practical experience with real circuits, some learners did not know how measuring devices should be connected. A majority of learners had difficulties with concepts differentiation as a result the role played by the measuring devices was not understood.

1. Introduction

The present study investigated the understanding of measuring devices and the role they play in electrical circuits. A clear understanding of the measuring devices is essential, if one is to introduce a scientific vision of electrical circuits to learners. After high school education, learners are expected to have developed mental models of what is going on in electrical circuits that enables them to demonstrate an understanding of key concepts like current and potential difference [5]. The measuring devices help to visualize the abstract concepts that cannot be seen with a naked eye. Connecting devices such as ammeter and voltmeter in a circuit, their roles should be understood and taken into consideration. Their presence to a good degree should not affect the functioning of the circuit [6]. Learners are expected to appreciate the effect of changes made by adding measuring devices in parallel or series in a circuit. It is expected that they should be able to connect measuring devices and also to offer explanations in terms of scientific principles [9]. However, numerous studies on current, potential difference and brightness of bulbs have shown that learners still have difficulties and misunderstandings after systematic instruction [7]. This study focused only on learners' knowledge of the use of ammeter and voltmeter in a direct current resistive circuit. It investigated learners' understanding of how measuring devices are connected in a circuit and why they had to be connected in that particular way.

2. Research Methods

2.1 Instruments

In this study, a closed and open-ended questionnaire was administered to grade 12 high school learners. Most of the items were drawn from diagnostic instrument on conceptual difficulties developed by [4] and the author added a part where learners had to provide reasons for their responses. Structured group interviews were used to support the questionnaire data. Due to limited space, this paper only presents the quantitative data. To check for content and language validity, questionnaire was checked by two Physics and one English (Extended Degree Programme) lecturers.

2.2 Sampling

A total of 137 grade 12 learners comprising of males and females from two public schools (township and a rural school) in Mankweng circuit participated in this study. Cluster sampling technique [2] was used where the author selected the two schools and tested all the grade 12 learners. The selected schools did not have laboratories or apparatus to perform experiments. A relatively larger percentage (56%) of the respondents came from the rural school whilst 44% were from the township school. The average age group for the sample was 18 to 20 years old. Learners had completed their electricity topics at the time of collecting the data.

2.3 Data analysis

The collected data was analyzed by counting the frequencies of selected options from each multiple-choice question. Reasons provided were analyzed by extracting patterns and or themes emerging from the responses. Responses were then categorized and frequencies were counted for each category.

3. Results and Discussions

3.1 Role of ammeter

An Ammeter is used to measure current. To measure the current, one need to break the circuit and insert the ammeter at the point where current is to be measured. An ideal ammeter has zero internal resistance, so as to drop as little voltage as possible as charged particles flow through it. However, real ammeters have as little resistance as practically possible [5]. To an educator an ammeter does not change the characteristics of the circuit; it is therefore an invisible component used to indicate current readings in a circuit [9]. However, a learner views ammeter differently.

Learners were requested to indicate what they thought to be the role of an ammeter in a circuit and the results are summarised in figure 1 below.

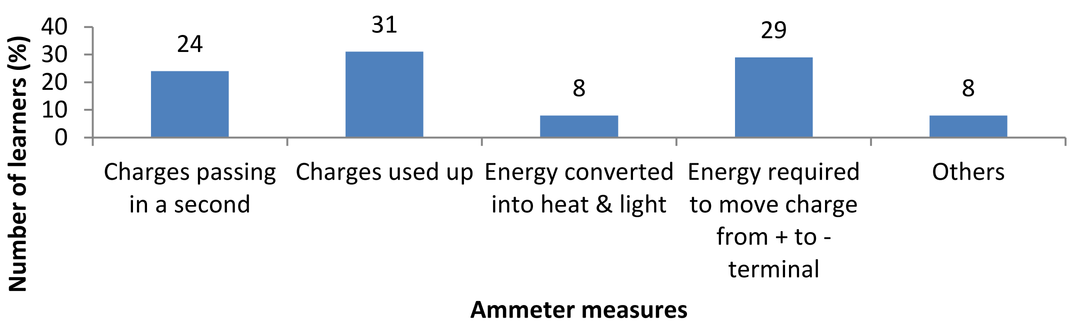


Figure 1. Learners' responses about the role of an ammeter in a circuit

Figure 1 shows that majority of learners 60% held well documented misconceptions about electricity concepts [1, 9]. Of the given misconceptions, 31% of the learners indicated that the ammeter measured the charges which were used up by circuit components (like bulbs, resistance, etc.).Learners thought current value decrease as charges move through circuit elements. In addition, 29% of the learners thought that ammeter measured the energy required to move a charge from one point to the other. This view was evident from the interview with learners from both schools. This misconception has been attributed to confusion from not relating concepts properly (namely, potential difference, current and resistance) [1, 9].Only 24% presented scientifically acceptable responses. Therefore, the role of the device is not understood.

3.2 Role of voltmeter.

Voltmeter is connected between two points because a real voltmeter has the highest resistance possible to prevent draw of current from the circuit [6, 5]. Learners were requested to indicate what they believed to be the role of a voltmeter in a circuit and the results are summarised in figure 2 below.

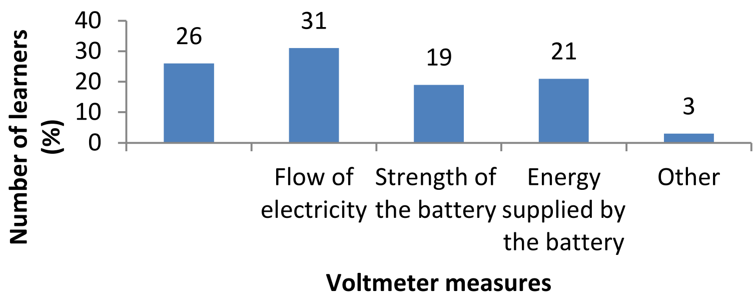


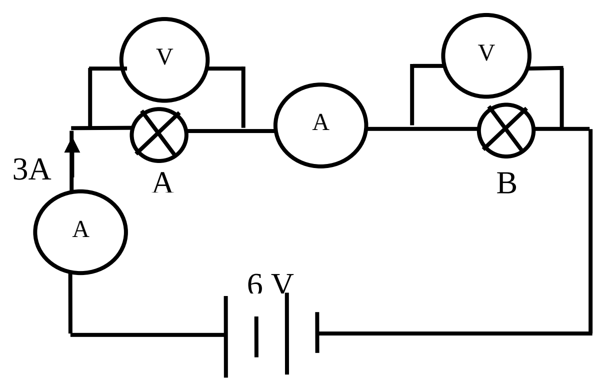
Figure 2. The role of a voltmeter in a circuit

Figure 2 depicts that majority of learners (71%) held misconceptions about electricity. Of these, 31% of them thought that the voltmeter measured the electricity flowing through the conductor. Learners refer to the substance flowing within the wires as electricity. This indicates learners were using electricity to refer to current. Difficulty with concepts differentiation is well documented in literature [1, 3]. The usage of the term electricity can be traced to African's everyday languages where electricity, power and current are used interchangeably [7]. This finding is consistent with literature. A voltmeter which is connected across components is said to measure the flow of charge. Only 26% of learners chose a correct option.

About one in five of the learners thought that the voltmeter was measuring the energy supplied by the battery to the circuit and the interview with learners confirmed this view. It was apparent that learners did not understand the role played by voltmeter in a circuit. Not understanding voltage as shown by Gilbert [5] could be attributed to not understanding the device and its role in a circuit.

3.3 Voltmeter and ammeter in a series circuit

Learners were presented with a schematic circuit diagram (see circuit 1) below.



Circuit 1

The circuit consisted of two identical dry cells, two identical light bulbs and two ammeters all in series and two voltmeters across each bulb. Ammeters and voltmeters were labeled A_1, A_2, V_1 and V_2, respectively. The light bulbs were labeled A and B as shown in circuit 1. The total current and voltage of the circuit were presented as 3A and 6V respectively.

3.3.1 *Using voltmeters correctly in circuits.* Learners were required to indicate the expected readings on the two voltmeters. The results are presented below in figure 3.

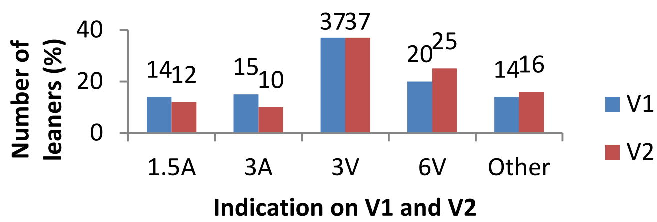


Figure 3. Learners' responses to readings on voltmeters V_1 and V_2

Figure 3 shows that 57% and 62% correctly identified V_1 and V_2 respectively (shown by 3V and 6V). This suggests that majority knew that voltmeter had to be connected in parallel in electric circuits. On the other hand, 30% and 22% of the learners thought V_1 and V_2 were ammeters (1.5A and & 3A). Thus, these learners had difficulties with how measuring devices should be connected in a circuit, they thought ammeter should be connected in parallel. Only 37% presented correct indications for both V_1 and V_2. This result shows that majority of learners did not understand that potential difference across each element in series sums to equal the total voltage from the battery. This finding confirms literature that learners who fail to apply the basic rules had difficulty in understanding the concept [1, 5, 7].

3.3.2 *Using ammeter correctly in circuits.* Learners were also required to identify A_2 (ammeter) and to indicate the current through it. They were expected to apply the conservation of current rule in a series circuit. The results about A_2 are presented in figure 4 below.

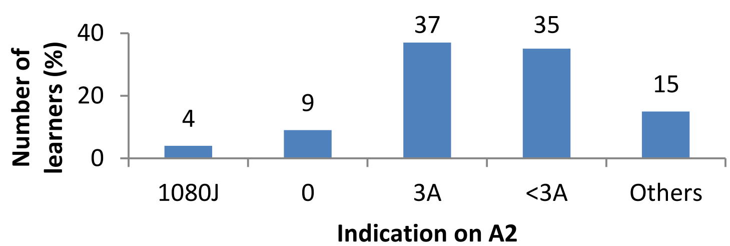
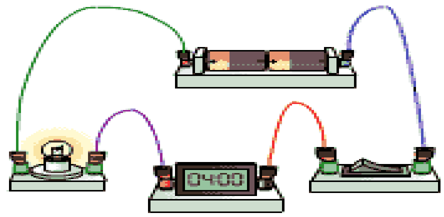


Figure 4. Learners' responses about the indication on A_2

Figure 4 indicates that majority of learners (72%) correctly identified A_2 to be an ammeter (indications 3A and <3A). This suggests majority of learners knew how ammeter should be connected in a circuit. However, only 37% of them provided the correct reading meter A_2 would have, while the other 35% thought ammeter A_2 would indicate less current. The results imply learners did not understand the conservation of current in a series circuit. This result confirms the observations made in figure 1 where 31% of learners preferred the current consumption model. Some studies shows that learners believed that an ammeter consume current for it to function [8]. Although majority of learners seems to know how ammeter is connected in a circuit, results suggest that learners do not understand the device's role in the circuit and why it had to be connected the way it is connected.

The learners were also presented with a pictorial representation of a realistic circuit (as in circuit 2 below), which they had to evaluate to identify the corresponding schematic circuit diagrams.



Circuit 2. Representation of a realistic circuit.

Figure 6 shows learners' responses to matching realistic circuit to a schematic diagram.

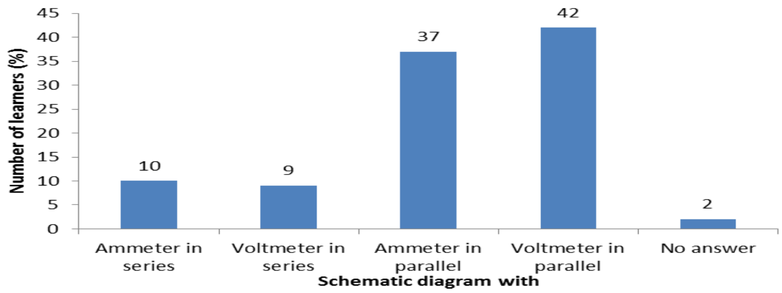


Figure 5. Learners responses to matching realistic circuit to a schematic diagram

Figure 5 depicts that 51% of the learners were unable to recognise the measuring device in question to be an ammeter, as they have chosen circuits with voltmeters. During the interview, learners were requested to identify the components. Majority of learners positively identified battery, bulb and switch however, almost all failed to identify the ammeter. One learner said "*...not sure whether there is voltmeter or not*". Some of the learners (46%) chose options which ammeter and voltmeter connected incorrectly. Only 10% gave scientifically accepteble responses. Carstensen et al. [1] indicated that learners who cannot differentiate between voltage and current tend to struggle in connecting their measuring instruments.

Dzama [3] in their investigation with London and Malawian students found that learners were unlikely to make mistakes of how measuring devices are connected if they had practical experience with electrical circuits. Engelhardt et al [4] found that learners had difficulties in translating from schematic circuits to real circuits not vice versa. This study showed that learners had difficulties in translation from realistic circuit to a schematic circuit which could be attributed to not understanding the role played by measuring devices, not understanding the concepts and lack of paractical experience with electrical circuits.

4. Conclusions and Recommendations

This study investigated learners' knowledge about the role played by the ammeter and voltmeter in an electrical circuit. The results that majority of learners knew how measuring devices should be connected in a circuit but lacked the basic understanding of the role played by these devices. There were also findings such as current consuption and difficulty with concept differentiation which are well documented in literature thus not supprising. It also emerged that learners could not translate a realistic circuit into schematic circuit due to lack of practical experience with electrical circuits, and not understanding concepts and the role played by the measuring devices. It is therefore necessary for educators to take into considerations the role played by measuring devices in planning their instructions. Learners need to understand why devices have to be connected in a particular way.

References

[1] Carstensen A and Bernhard J 2007 Threshold concepts and keys to the portal of understanding: some examples from Electrical Engineering. *Threshold Concepts within the Disciplines*, (Sense Publishers) p 1-12

[2] Cohen L, Manion L and Morrison K 2007 Research Methods in Education. 6th Edition. (Routledge London), part 4 and 5.

[3] Dzama E 1997 Towards locating sources of alternative conceptions about Electricity among learners in developing countries. Focus on the learner. Proceedings of the 5th annual meeting of the Southern African Association for Research in Mathematics and Science Education. University of the Witwatersrand, Johannesburg. 22-26 January p 105-110

[4] Engelhardt P V and Beichner R 2004 Students understanding of direct current resistive electrical circuits *Am J. Phys*. **72** (1) p 98-114

[5] Gilbert W 2009 Experiment 7 DC Circuits and Instruments "Look for knowledge not in books but in things themselves" http://www.owlnet.rice.edu/~phys126/labs/expt07 p 37-41 [Accessed 21/09/2009]

[6] Habash R W Y 2002 ELG2331 Lab Manual - Experiment 1: DC Circuits http://www.site.uottawa.ca/~rhabash/ELG2331Exp1.pdf [Accessed 21/09/2009]

[7] KÜÇÜkÖzer H and KocakÜlah S 2007 Secondary school students' misconceptions about simple electrical circuits. *Journal of Turkish Science Education*, **4**(1) p 100-115

[8] Planinic M, Boone WJ, Krsnik R and Beilfusss M L 2006 Exploring Alternative Conceptions from Newtonian Dynamics and Simple DC Circuits: Links between Item Difficulty and Item Confidence. *Journal of research in science teaching*. **43**(2) p150-171.

[9] Taber K S, de Trafford T and Quail T 2006 Conceptual resources for constructing the concepts of Electricity: The role of models and analogies and imagination. *Physics Education.* **41**(2) p155-160