An investigation of pre-service teachers' conceptual understanding of basic DC circuits

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Abstract
The case study reports about the preliminary results of pre-service and in-service teachers' understanding of DC circuits at the University of Johannesburg. A survey questionnaire on electric circuits was constructed guided by literature. The results of the questionnaire indicated that pre-service teachers had ideas about electric circuits which are similar to in-service teachers currently teaching natural sciences at some selected high schools in Gauteng. Pre and In-Service teachers' ideas identified were mostly similar to those reported in literature as standard misconceptions about electric circuits.

Key words: misconceptions, electric circuits, educational reconstruction, pre-service teachers

Introduction

The learning and understanding of electric circuits is regarded as challenging to students from secondary to tertiary levels due to the presence of misconceptions about the concept. (Jaakkola & Nurmi, 2008). Researchers classified misconceptions about electric circuits according to whether they are consistent with the scientific Ohm's law model or not. Some of the model names given to misconceptions about dc circuits are: unipolar model, consumption model, constant current model and the clashing current model (Jaakkola & Nurmi, 2008). The results of various studies from different countries showed that students have the same pattern of learning difficulties in understanding electricity (Shipstone, et al., 1988). Addressing misconceptions students have is reported as a challenging activity that requires the use of conceptual change strategies. Literature on misconceptions, suggested a further research on whether teachers are able to prescriptively address students' misconceptions is such a way that learning is improved significantly and also if teachers are gathering insights into students' preconceptions and thought processes (Soong, 2008).
The misconceptions students have in basic electric circuit generally affect the overall performance of physics and hence Physical Science as a subject. Failing physical science by students has a negative impact in terms of gaining admission to institutions of higher learning in the Faculty of Science and that explains the shortages of science related skills and professionals in South Africa

Aim of the study

Many studies internationally investigated primary and high school students' ideas about electric circuits, and less has been done about pre-service and in-service teachers' ideas about simple electric circuit (Kuçüközer & Demirci, 2008). This study was aimed at achieving the following two objectives:

(a) To identify misconceptions pre-service and in-service teachers have about DC electric circuits and
(b)To compare pre-service and in-service teachers' misconceptions with those reported in the literature.

Rationale for the study

The fact that most students leave physics instruction with less or no understanding of concepts taught is now common knowledge amongst physics education researchers (Dewey & Dykstra, 2008). Students are reported to have some challenges in the manipulation of basic facts in electrical circuits. Even some of the university students are unable to reason qualitatively about electric circuits (Brna, 1988). The study provided a local perspective on background information about misconceptions students have. Knowledge of the background information about misconceptions of local students' reasoning can help when making decisions on what to emphasize when teaching DC circuits for deep understanding of the concept. The deep understanding of basic electric circuits is very important in improving students' performance in science and which could sequentially improve their decision making capabilities concerning the usage and handling of electricity.

Theoretical framework

The study adopted the educational reconstruction framework (ER). The central idea about the ER framework is that science content should not be prescribed, but has to be (re) constructed. The construction should take into consideration aims of the instruction, students' needs and capabilities. The ER also takes into account a clear demarcation between content structure for instruction and content for science(Duit, .Gropengießer, & Kattmann, Duit, R-.Gropengießer, 2005).
This model has been developed as a theoretical framework to studies that ask the question whether it is worthwhile and possible to teach a specific or particular area or topic to enhance conceptual understanding (Duit, 2007). According to Duit (2007) the framework holds that the content issues and students' learning needs and capabilities have to be given same status and attention in attempts to improve the quality of teaching and learning developments, and again at the same time, intertwining research, teaching and learning activities. The framework was based on The German educational tradition of "*Bildung*" and "*Didaktica*" (Duit, 2007, p.5). The literal translation of the words are "formation" which includes the analytical processes of transforming human knowledge into knowledge for schooling which again contributes to formation of human knowledge. In other words the main focus of ER is on the reconstruction of science knowledge in order to help students understand key points by identifying scientific knowledge gaps and then later bridge the connection gaps between scientific knowledge and students' alternative frameworks or misconceptions about everyday world (Viiri & Savinainen, 2008). In this context, the scientific knowledge is viewed as the product of the process of abstraction and reduction with an aim of making the science point of view understandable and meaningful to learners via the teaching and learning sequences developed with an aim of rectifying misconceptions students have (Viiri & Savinainen, 2008). The Education Reconstruction framework is cyclic whose pillars for continuous improvements are the three domains of science education,

namely: analysis of content, empirical investigations, development and evaluation of instruction as shown fig 1 that follows.

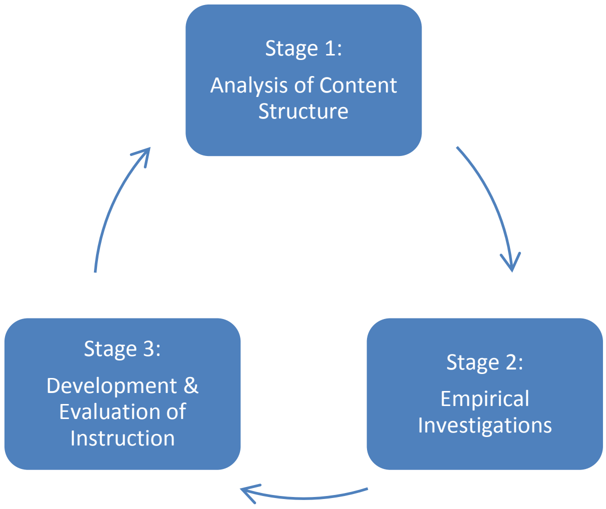

Figure 1: Educational Reconstruction Framework adapted from Duit (2007, p6)

In this paper, only stages 1 and 2 will be discussed, stage 3 which involves the development of material and the evaluation of instruction will be dealt with in a future paper.

Stage 1: The analysis of content structure

The analysis of content structure involves two closely linked and related processes, which are: the clarification of subject matter and the analysis of educational significance. The clarification of subject matter is guided by the literature on the topic and the analysis of leading textbooks. The analysis of educational significance also includes the significance of content that will be useful for students' future life. The analysis is based on searching for solutions for some key questions like the following:

- Which scientific terms are being used and which of them constrain or promote learning?
- What are the origins, function and meaning of scientific concepts and in which educational level are they placed?
- What are the ethical and social implications associated with these scientific concepts?

Stage 2: Research on teaching and learning

ER takes into consideration the literature on students' perspectives about teaching and learning, that includes their pre-instructional conceptions and epistemological positions. The research on in-service teachers' view and their conceptions of science content is also taken into consideration.

Participants in the study

The participants in this case study were composed of three groups, namely pre-service B.Ed Natural Sciences senior phase with code PHY1T10, pre-service B.Ed Physical Science Further Education and Training with code PHS1FET and Natural Sciences in-service teachers who volunteered during in-service teachers' development workshops conducted at University of Johannesburg with code SENTEA. Table 1 that follows shows the actual number of participants and their respective percentages of the whole participants

Group	PHY1T10	PHS1FET	SENTEA
Number per group	8	33	12
Percentage Total	15	62	23

Table 2: Groups and number of participants

Pre-service student teachers in the faculty of science at the University of Johannesburg at Auckland Park Campus were formally registered in the Faculty of Education but are offered science related modules in the Faculty of Science.

Procedures

The survey questionnaire which was composed of 8 questions was developed guided by the literature on student's conceptual difficulties in learning and understanding DC circuits. The questions were handed to five experts in physics and in physics education to validate the alignment of questionnaire items to content covered in the curriculum. Questions on the questionnaire focused on the topics: conventional direction of electric current, current consumption model, and the impact of bulbs connection on potential difference and current. Questionnaires were then handed to pre and in-service teachers who volunteered to fill in answers based on their abilities and understanding of the content. Ethical issues were taken into consideration when administering the questionnaires because participants volunteered and also told that the answers they provided would only be used for research purposes. Questionnaires were collected after about 45 minutes. Answers given by participants were analyzed by grouping similar answers and / or explanations together, taking into account literature on pre-instructional conceptions and epistemological positions (Duit, Niedderer, & Schecker, 2007).The next section dealt with the analysis of results per question.

Analysis of the results per question

Question 1: *Why do lights in your home come on almost instantaneously when switched on? Explain your answer*.

Students' responses were grouped into six categories (A- F) based on the similarities of their explanations as follows:

A*: Current flows freely and active even when the switch is off or closed*
B*: Bulbs are connected in series*
C*: Charges move very fast with the speed approximately that of light*
D*: Current already in the conducting wires waiting to be switched on*
E*:High volts cause light to be on instantaneously*
F*: Cannot be classified*

This question which was slightly adapted from question 11 of DIRECT V1.2 test (Engelhardt & Beichner, 2004). All participants answered this question and the results are given in figure 2.

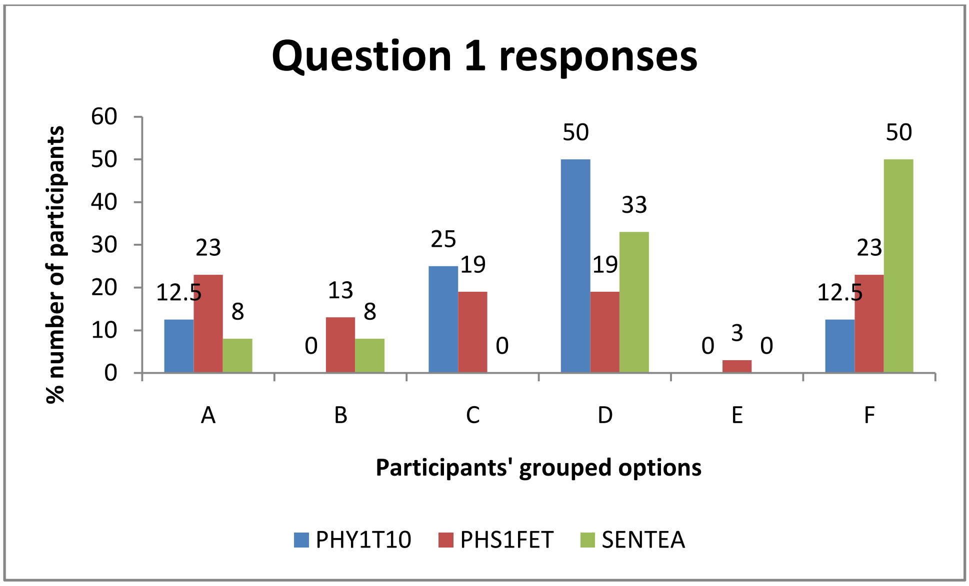

Figure 2: Results of question 1

Group A: 23 % of participants who responded to this question claimed that electric current is active even when the switch is off or closed. These participants seemed to have confused charges with current because it is true that there are charges that are "free to move" in a conductor when a switch is off.

Group B: This group did not give a clear reason except for the fact that bulbs are connected in series which can be interpreted as the lack of clear distinctions between series and parallel connections. In many textbooks, it is mentioned that "in series all bulbs light at the same time, but when they are in parallel if one is off the other remain lit" But here the fact is that regardless their connections, they will light almost at the same time.

Group C: This group had misconception that charges travel very fast, almost at the speed of light. This seemed logical taking into consideration the distance covered by a speed of light in a fraction of a second, but the explanation is not consistent with that of scientists and was also previously reported (Engelhardt & Beichner, 2004). In contradiction, charges are reported to flow slowly, less than few millimeters a second and the fastest thing is energy flow which is approximated with the speed of light. (Duit, Niedderer, & Schecker, 2007).

Group D: This group (19 %) had misconception that "current is already there in the conductor waiting to be switched on" The results suggest that the group lacks knowledge about the difference between charges in motion (current) and stationary charges. Another notable explanation was as follows:

> *"The current always want to flow but it is stopped by resistance of the resistor. Switching the switch on deactivate the resistance of the resistor and hence current starts to flow"*

Group E: This group claimed that high voltage will cause charges to move faster when compared to low voltage. This explains the statement of Ohm's law which refers to the direct proportionality of voltage and current when applying the mathematical formula. Combining ideas from groups E and C, one can say perhaps students think high voltage source will cause the charges to move very fast approaching the speed of light.

Group F's explanation did not have any bearing that can help in understanding what's happening in their minds however,

Misconceptions identified:

- Electricity is already in conductor waiting to be switched on
- Electric current travels with the speed of light (similar to misconception reported)
- Electric current is active even when the switch is off
- High voltage causes light to be on instantaneously
- The function of a switch is to activate or deactivate the resistance of the resistor to either allow or stop current.

The results of this question indicated that all students did not have a clear understanding of what is happening about the movement of charges in the conductor. The explanations they gave were all scientifically incorrect. They have an idea that there are free electrons, but what makes these electrons to move again is not clear from their answers. In this question, students gave one of the responses similar to what was given as option C in the test which says that: "charges in the wire travel very fast" and they added that the speed is approximately that of light. The acceptable explanation for light to come on almost instantaneously is caused by the rapid rearrangement of surface charges in the circuit that takes place in about the speed of light (Chabay & Sherwood, 2011) and enables the circuit to reach its final steady state in nanoseconds.

Consider figure 3 below to answer question 2 and 3 by saying whether the following statements are TRUE or FALSE giving reasons.

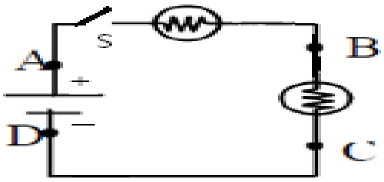

Figure 3

Question 2: Based on the conventional direction of electric current, when the switch is closed, the electric current will first flow through A, and then through B, C, and then cycle continues from A again

The correct answer was FALSE, but those students (32 %) who opted for this answer had various reasons which were also not consistent to the scientific explanation that same current will be flowing all over the circuit at the same time. The reason that the conventional direction is opposite the current flowing also make sense since it is believed that mobile charges are electrons.

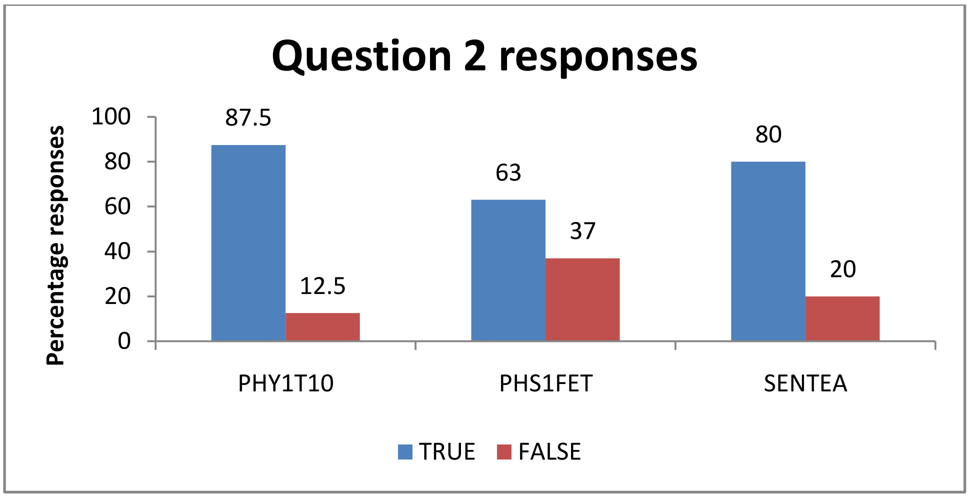

Figure 4: Results of question 2

The total number of students who answered this question was 53 (100 %). Most students who answered this question opted for true (68 %) basing their reasons on the conventional direction of electric current. The conventional direction of current states that" electric current flows through a conductor from positive terminal to the negative terminal of the battery" Literally it makes sense for them to conclude that the electric current will first flow through A, and then through B, C and lastly through D before the cycle is repeated.

Other said the statement is false because current flows in all directions and that were consisted with the current clash model, which is also believable looking at the fact that in series circuit, we have the same current flowing throughout the circuit, before and after the bulb.

Another noticeable answer was related to our everyday usage of the word "*closed*". In everyday language, for example, when the door is closed, people cannot leave or enter the place. This can be analogous to electrons, when the switch is closed, hence, no electrons should pass through. This is a contradiction to scientific understanding of electric circuits because when the switch is closed, current or electrons are able to pass through and when opened nothing happens. The advice to teachers could be to change terminologies and substitute *open and close* with "*off and on",*

The misconceptions students have about this question are logically correct in terms of explaining the process of movement of charges, the question is why internationally, the conventional direction of electric current was accepted even if it pauses lots of challenges when it comes to understanding how current flows. The concept of current is abstract and defined in terms of movement of charges that have two forms, positive and negative is a cause of concern (Gomez & Duran, 1998). The study also concur with the postponement of the teaching of basic circuit phenomenology if the end result of the process of learning is understanding

Question 3: *When the switch is on, point A will have more current than point D.*

Results and discussions:

The correct answer was false. Results on figure 5 that flows shows that few students (18 %) opted for the scientifically incorrect choice which is similar to the current-consumption model or sequential model where it moves in stages passing a point at a time and become weaker (Brna, 1988). However the majority (82 %) had the correct choice but incorrect explanations, for example, some thought current clashes (bi-polar model) as it moves in both directions other thought D will have more current than A because electrons move from negative terminal towards the positive terminals. As indicated in the previous discussion, some thought no flow of current since the switch is closed

Answers from this question indicate that some of the misconceptions identified from the literature were also common to the students of this study. For example, the bi-polar, current consumption and sequential models were there on the minds of students. At the same time those students who opted for the False which is scientifically accepted did not have appropriate explanations but they know that it is not true. The explanation given by some participants suggests that they might be reasoning according to the electron flow model

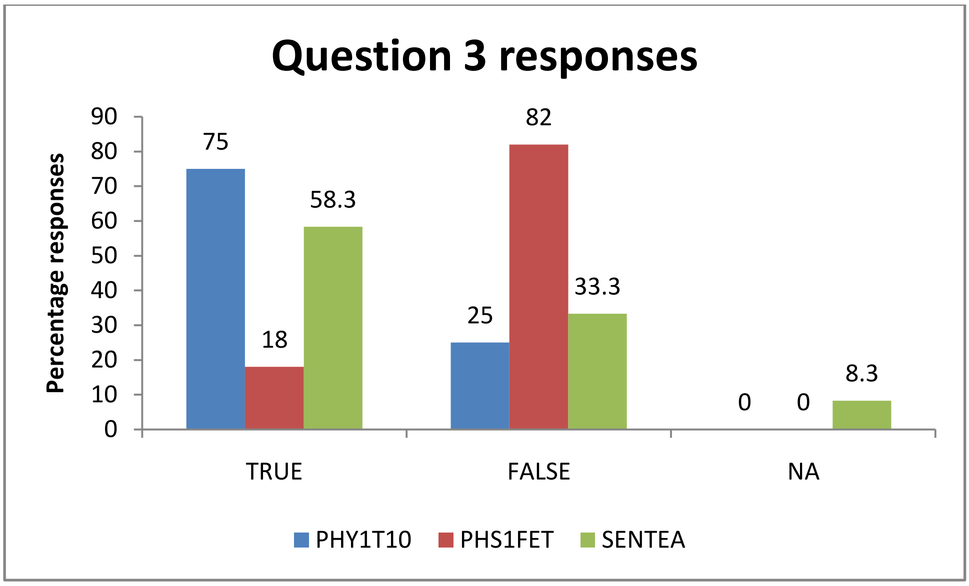

Figure 5: Results of question 3

Misconceptions identified:

- Current moves in both directions (bi-polar)
- No current flow when the switch is closed
- Current is lost when flowing (becomes weaker)
- Current is lost after passing through a resistor (resistor consume current)
- The point near the negative terminal will have more current than others that follow after it.

Question 4: *The five bulbs in figure 6 are identical and the batteries are identical and ideal. Rank the five bulbs from brightest to dimmest. Explain your answer*

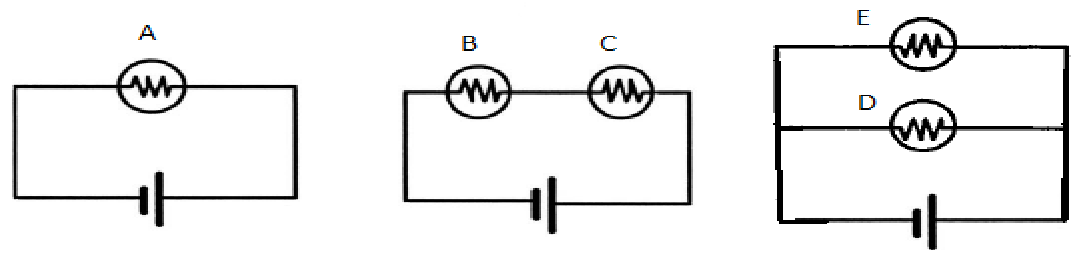

Figure 6: Different circuit diagrams

Results and discussions:

The explanations given by pre-and In-service students were coded as follows:
C for correct order$A = E = D$; $B = C$; **IC** stands for incorrect order and the number indicates the group the incorrect order falls. For example, **IC-1** the order is$A = B = C, D = E$; **IC-2** the order is A, B=C, D=E; **IC-3** the order is $A, E = D, B = C$; **IC-4**the order is$A, B = C, D, E$ and **NCP** for no clear patterns.
The correct sequence was $A = E = D$then$B = C$ and was only answered by only 10 % of the participants as seen on figure 7 that follows.

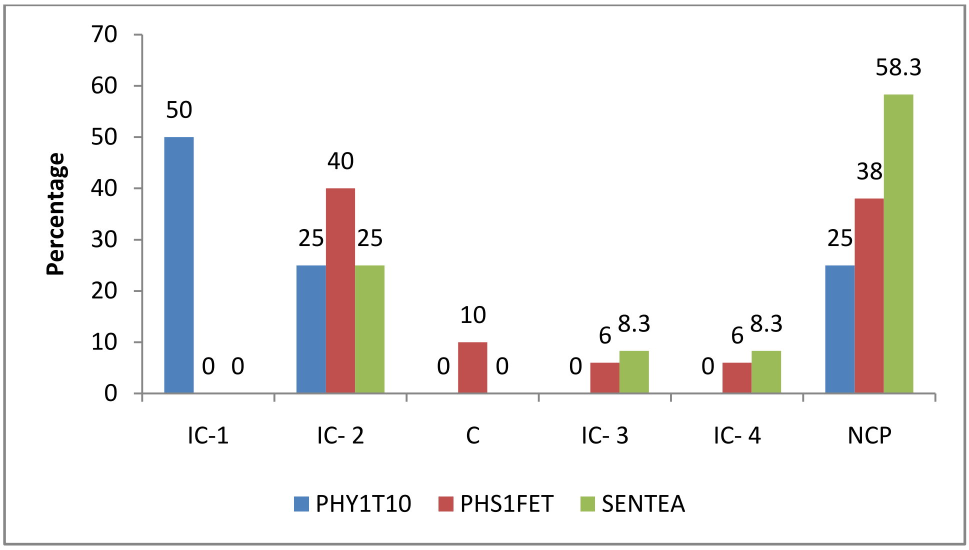

Figure 7: Results of question 4

It was a tricky question as most students thought the total current in each circuit is the same because all circuits have the only one identical cell. That indicated the misconception that same cell will supply same current regardless of the connections of the bulbs or resistors. Students knew the fact that in parallel circuit current is divided but at the same time ignored the overall impact of resistors on current when they are connected in series and in parallel. For example, those who opted for A, B=C , D=E mentioned that order because they said in parallel current divides which is true, what seems to be missing was the fact that "even when the same voltage is used, current supplied will depend on the resistance and the connection of the resistors. That implied that they hold the model" battery is a constant current supplier in a circuit" " The fact that current divides could have been the main reasons why students thought E=D will be the dimmest because they thought the same current was flowing in all circuits.

The results of this question have shown that it is important to take in to consideration the fact that the same cell or battery can supply different magnitudes of current depending on the connection of the resistor and their connection when designing the teaching and learning sequences. NCP stand for no clear patterns of reasoning were given students.

Question 5: *Consider the power delivered to each of the resistors shown below, assuming that the resistance of each resistor is the same, which circuit or circuits have the least power delivered to it? Explain your answer*

A. Circuit 1
B. Circuit 2
C. Circuit 3
D. Circuit 1 =Circuit 2
E. Circuit1 = Circuit 3

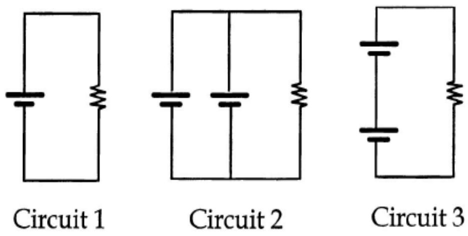

Figure 7: Different combination of cells in the circuit

Results and discussions:

The distribution of answers is shown on the table that follows. The correct answer was D and was answered by only 10 % .The result of this question was consistent with the results found by. (McDermott, Shaffer, & Constantinou, 2000).

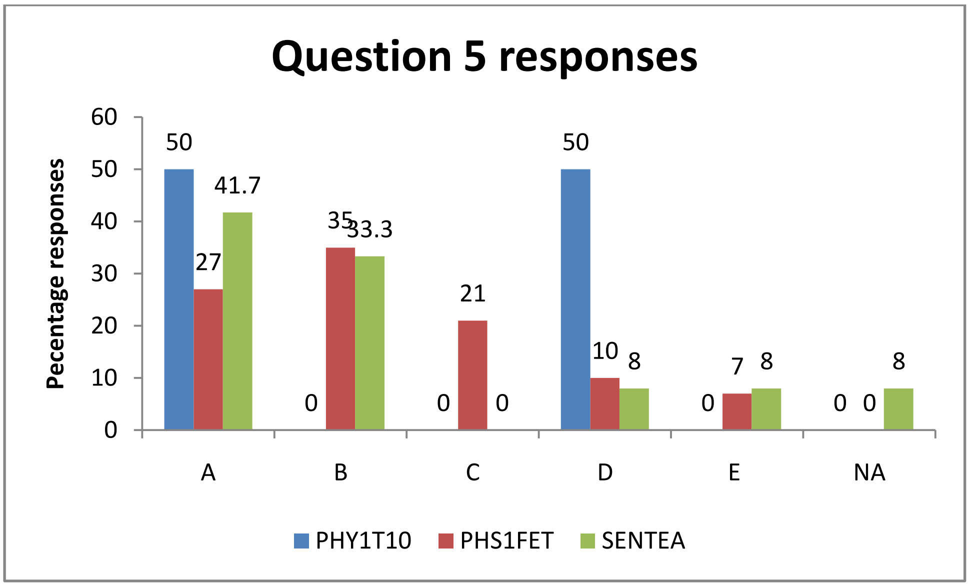

Figure 8: Results of question 5

The same question was internationally administered to more than 1000 students yielding the same results regardless whether being pretest or posttest and to variety of introductory physics calculus based students. It was claimed that the results were also the same when administered to high school physics teachers (McDermott, 2000).Students don't understand the impact of connecting cells in parallel to current. In most textbook they give an example of series or just mentioned the potential difference. Those who opted for B (35%) failed to differentiate between potential difference and current. The result of this question implies students have some difficulties on the impact of connecting cells in series and parallel to current should be designed. It is hoped that once students are able to understand the concept qualitatively, then more problems would be solved.

Question 6: *All bulbs in figure 9 are identical. What happens to the potential difference between points 1 and 2 if bulb B is removed? Explain your answer.*

A: Increases
B: Decreases
C: Stays the same
D: None of the above

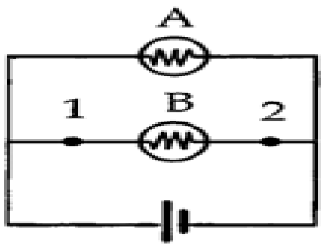

Figure 9: All bulbs are identical

Results:

The correct answer is C and 41 % of students got it correctly as seen on figure 10. The removal of a resistor in parallel will increase the total resistance of the circuit hence less current will flow.

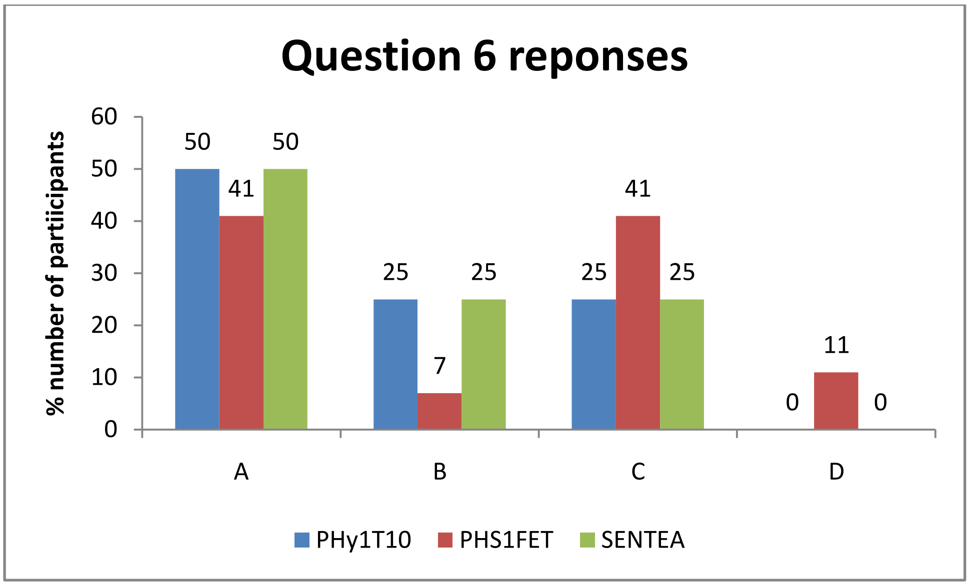

Figure 10: Results of question 6

But at the same time the potential difference is always measured across a resistor or bulb which means that no bulb, the voltmeter will read the potential difference across the source. Those who chose A (41 %) mentioned the reason related to the current consumption model and at the same time were also aware about the proportionality between current and potential difference.

Misconceptions identified

- Bulb use current (similar to current consumption model)
- Bulb absorb potential difference

Question 7: *Consider circuits 1 and 2 in figure 11. Do you think the resistance of the resistor will change after increasing the number of cells connected in series? Give reasons for your answer.*

A: Increases
B: Decreases
C: Stays the same
D: None of the above

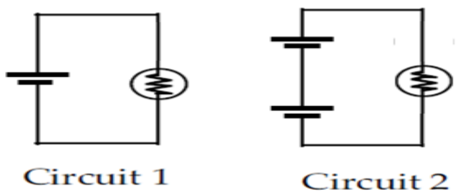

Figure 11:Relationship between cells and resistance

Results and discussions:

The correct answer is C and only 26% gave the correct explanation that resistance is not affected by potential difference and the current flowing in the conductor. Participants in group A (33%) might have experienced the problem caused by the mathematical manipulation of Ohm's law.

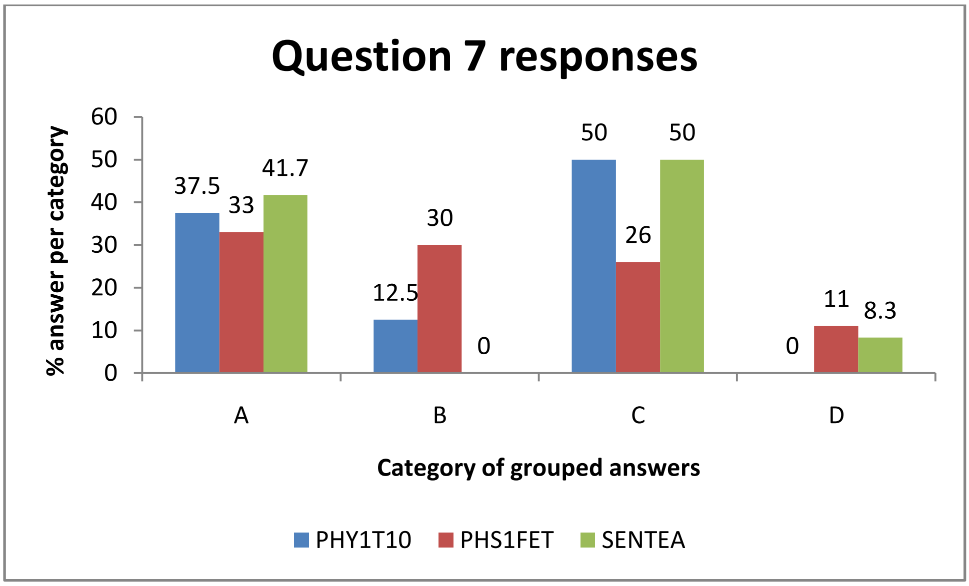

Figure 12: Results of question 7

For example the mathematical formula used in calculations implies that potential difference is directly proportional to resistance. Which means that increasing potential difference will automatically increases the resistance which is not correct because the resistance is the physical property of the resistor and not the physical consequences of $\frac{V}{I}$ as derived from the formula $= \frac{V}{I}$. Hence what students think that the resistance of the conductor depends on the potential difference and current flowing is technically incorrect, because in ohm's law, the resistance has to be introduced as proportionality constant. In many textbooks, the emphasis is only on calculations.

Students' ideas identified

- Resistance is directly proportional to potential difference

- Resistance is inversely proportional to current
- Energy supplied overpower the resistor and decreases the resistance

The results of this question gave a clear hint that Ohm's law should not be introduced as a mathematical formula.

Question 8: A torch bulb is connected to a cell with negligible internal resistance to form a simple circuit. If a resistor is connected in parallel across a bulb, what do you think will happen to the potential difference and current across the bulb? Give reasons for your answer.

A: Potential difference and current remain the same
B: Potential difference remain the same current increase
C: Potential difference remain the same current decrease
D: Potential difference increases current decreases

E: Both increase

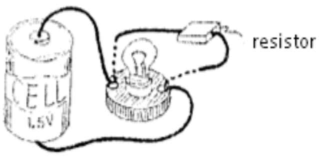

Figure 2

Results:
The correct answer was C as seen on the figure 15 below. Participants were required to choose after knowing how the way resistors are connected can have an impact on current flowing through the entire circuit.

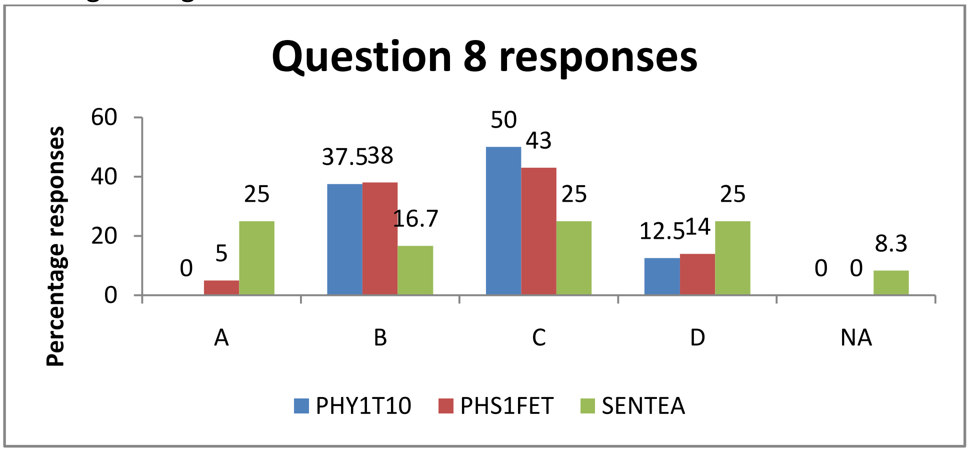

Figure 14: Results of question 8

Based on the answers given, it would be more appropriate if we add another question which deals with the total potential difference and the total current of the circuit, this question will help students to understand the impact of resistor on potential difference and current for the whole circuit. An example of a question that may be asked is as follows: What do you think will happen to the total potential difference and the total current of the circuit when the magnitude of resistance in the circuit is changed?

Misconceptions identified

- Current and potential difference compete for a bulb or bulbs in the circuit
- Potential difference increase with resistance according to Ohm's law

Summary of results

The results in fig 15 that follows show that in-service teachers performed worst (average of 23 %) when compared to pre-service teachers whose overall average was 30 %. When looking at the answers given, in-service teachers gave similar results and explanations and hence the combinations of responses for individual questions with percentage correct scores separated. The fact that similar explanations or reasoning were obtained from both groups implies that that pre-service teachers might have inherited their understanding of DC circuits from their former teachers.

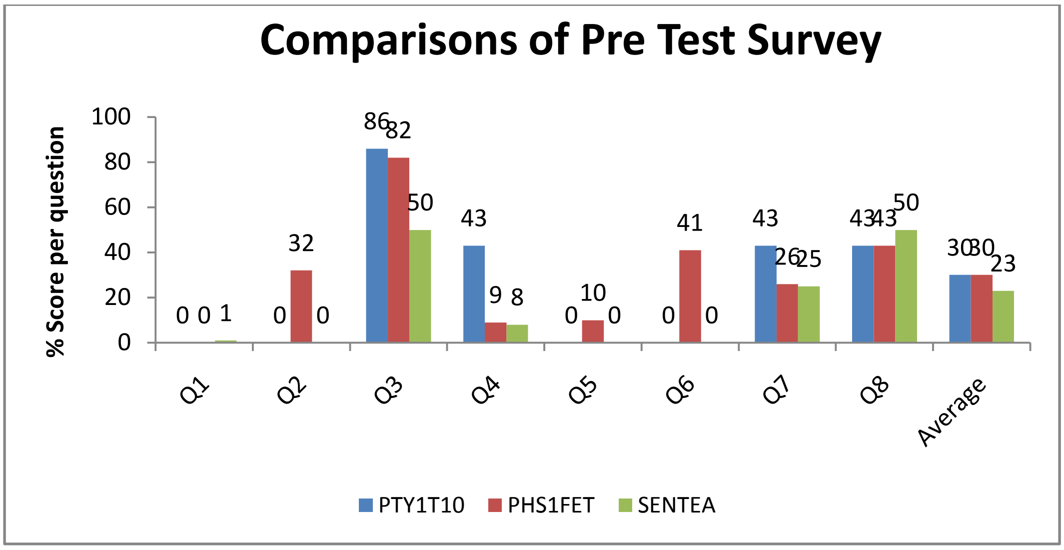

Figure 15: Summary of results per question

The case study reports about the preliminary results of pre- and in-service teachers' understanding of DC circuits at University of Johannesburg. A survey questionnaire on electric circuits was constructed guided by literature. The results of the questionnaire have shown that pre-service teachers had misconception about electric circuits which are similar to in-service teachers currently teaching natural sciences at some selected high schools in Gauteng. The study also provided a list of identified misconceptions. The misconception which was totally different from those identified by literature and came from two groups of pre-service teachers was as follows:

> *"The current always want to flow but it is stopped by resistance of the resistor. Switching the switch on deactivate the resistance of the resistor and hence current starts to flow"*

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