An evaluation of student's understanding of DC circuit concepts through students' written explanations

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Abstract. One of the topics that is regarded as challenging to learn for conceptual understanding by students from secondary to tertiary levels is simple electric circuits. The topic is said to be challenging to learn for qualitative understanding due to the presence of misconceptions brought by or derived from every day prior experiences about the topic. In literature, the word "misconception" is mostly interchanged with alternative conceptions, naïve conceptions etc. The results of various studies from different countries showed that students have the same pattern of learning difficulties in understanding electric circuits and ultimately pass their grade with vague or inconsistent understanding of the topic. The use of multiple-choice concepts tests is common in probing students' understanding of physics concepts but less has been done in probing students' understanding of the concepts by using students' responses to explanation-type questions. However, the study that dealt with the analysis of explanation-type question to physics grade 12 examination scripts concluded that the analysis of the explanations written by students in exams "does offer researchers and teachers a reliable and efficient way by which written student explanations can be probed for conceptions". Departing from the norm of using multiple-choice concept tests to probe students' understanding of some concepts in DC circuits the current study used the scientific explanations to achieve the following two aims: (a) To explore pre-service students' understanding basic DC concepts through their responses to written explanations. (b) The impact of using the explanation-type questions on diagnosing students' misconceptions of DC circuits prior to formal instruction

1. Introduction and background

One of the topics that is regarded as challenging to learn for conceptual understanding by students from secondary to tertiary levels is simple electric circuits [1].The topic is said to be challenging to learn for qualitative understanding due to the presence of misconceptions brought by or derived from every day prior experiences about the topic. In literature, the word "misconception" is mostly interchanged with alternative conceptions, naïve conceptions etc. [2]. Clarifying what a misconception is, literature related a misconception with a model [3]. According to [3], "a misconception exists if the model constructed by an individual fails to match the model accepted by the mainstream science community in a given situation". The explanation by [3] was accepted as the operational definition of misconception in the context of this study. The results of various studies from different countries showed that students have the same pattern of learning difficulties in understanding electric circuits [4] and ultimately pass their grade with vague or inconsistent understanding of the topic [5].

Attempts made to enhance student's conceptual understanding of simple DC circuits suggested various ways in which learning difficulties can be addressed and conceptual understanding about the topic enhanced. For example, the use of: system approach [6], constructive approach [7], concept substitution as a conceptual change strategy [8], the field model instead of electron-transfer model [9] and the preference of introducing potential difference first instead of current, as seen in many textbooks [10] etc. Even when all these attempts have been done, research shows less gain in terms of conceptual understanding of DC Circuits.

Other different approaches which were used to enhance understanding of different topics in different subjects which were "under-researched in physics"[11] included the use of explanation type-questions to diagnose and challenge students' naïve conceptions [12] and the analysis of students and teachers' written and verbal explanations [11]. Geelan argued that "the understanding of teacher explanation offers significant potential for enhancing the education of physics teachers"[11] because how the teacher explains concepts to students is regarded as the key to effective science teaching and learning [11] Research shows that both the explanation-type questions and the analysis of written explanations can be used to achieve various aims and objectives in physics like: "the diagnosis of student conceptions, challenging student naïve conception, and correcting problems with students' interpretation of new conceptions and lastly, to apply the scientific conception to the new phenomena" [12]. The use of explanation-type questions is regarded as a crucial aspect of teaching for conceptual change [12] but at the same time it was regarded as very challenging process to construct a good explanation for a scientific viewpoint [13]. The challenging process is worthwhile because the use of explanation is very helpful in physics in order to understand the natural world.

In terms of probing students' understanding of physics concepts, the use of multiple-choice concepts tests is common [14] but less has been done in probing students' understanding of the concepts by using students' responses to explanation-type questions. However, the study that dealt with the analysis of explanation-type question to physics grade 12 examination scripts concluded that the analysis of the explanations written by students in exams "does offer researchers and teachers a reliable and efficient way by which written student explanations can be probed for conceptions" [15]. Departing from the norm of using multiple-choice concept tests to probe students' understanding of some concepts in DC circuits [14] the current study used the scientific explanations [16] to achieve the following two aims:

(a) To explore pre-service students' understanding basic DC concepts through their responses to written explanations.
(b) The impact of using the explanation-type questions on diagnosing students' misconceptions of DC circuits prior to formal instruction.

2. Theoretical Framework: Scientific explanations

Scientific explanation answers three types of questions: philosophical, psychological and educational [17]. The philosophical question answers the question: what is a scientific explanation, a psychological question answers the question on how one can learn scientific explanation and lastly the answer to educational question prescribes instructional methods that can be used enhance learning. In the present study the main focus was on the knowledge we can gain from scientific explanations hence it focused on the philosophical question.

Various models are used to describe what a scientific explanation is, however in the present study the one considered relevant to this study was the scientific explanation framework model. The scientific explanation framework was created by adapting Toulmin's model of argumentation [16].According to the scientific explanation framework model, the scientific explanation consists of three components: a claim, evidence and reasoning. A claim was referred to as the a conclusion about the problem, evidence was conceived as data that supports the claim and lastly reasoning as the justification built on scientific principles, for why the evidence supports the claim [16]. In the study, the correct understanding of the concept was evaluated using the three components of scientific explanations as show in figure 1.

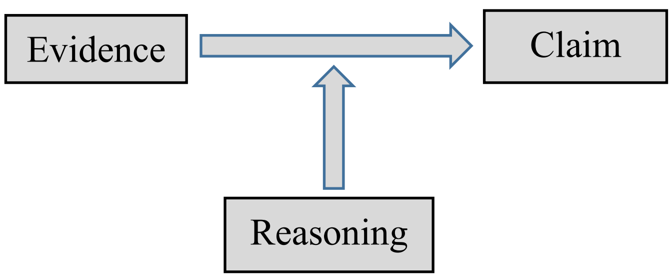

Figure 1: Simple Scientific Explanation Framework adapted from figure 2.1 McNeil (2012, p.22)

From figure 1, the reasoning part is used to explain why the evidence obtained supports the claim.

3. Methodology

3.1 Participants in the study

The participants were 39 B.Ed. (FET) second year physical sciences pre-service teachers taking the physics module PSFTOA2 either as a first or second major at University of Johannesburg. In South African schooling system, physical sciences is the secondary school subject that combines physics and chemistry. The participants were from diverse backgrounds in various provinces in South Africa. Most students registered for the course did not choose it as first choice but opted for the course after being rejected by other science and engineering streams due to the low grades they obtained in grade 12 or due to poor status, they were attracted by Fundza Lushaka Bursary aimed at attracting students to be teachers in scared skilled subjects like physical Sciences.

3.2 Instrument used for data collection

Pre-instructional questionnaires was developed by the researcher and validated by 4 experts in the field. The questionnaires consisted of a variety of questions that focused on students' understanding of DC circuit especially the concepts of current, series and parallel circuits. The questions used were either adopted or adapted from literature based on their suitability to simultaneously elicit responses that reflect misconceptions students have and the quality of explanation students wrote.

3.3 Research procedures

The study is a snapshot of the exploratory case study aimed at assessing students' conceptual understanding of DC circuits and the quality of students' written explanation before instruction. Data was collected using pre-instructional questionnaire worksheets. Students answered the questionnaire by writing the correct answers justifying their answers with evidence or reasons on the space provided. The answered questionnaires were collected, copied and then handed back to students the following day. Specific focus during the analysis of students' responses was on their written explanations.

Table 1: Rubric to analyse components of scientific explanation

Components of scientific explanation	**Category of written explanations**		
	Incorrect	Partially Correct	Correct
(a) Claim. A conclusion that answers the original question	Makes an inaccurate or incorrect claim	Makes an accurate but incomplete claim.	Makes accurate and complete claim.
(b) Evidence: Scientific data that supports the claim	Does not provide evidence or provides inappropriate evidence	Provides appropriate but insufficient evidence to support the claim.	Provides appropriate and sufficient evidence to support claim
(c) ***Reasoning:*** A justification that links the claim and evidence	Does not provide reasoning or provide reasoning that does not link evidence to claim	Provides reasoning that links evidence to claim. Reasoning does indirectly link evidence	Provides reasoning that links evidence to claim. Includes appropriate and sufficient principles or laws

Students' written responses to questionnaire were categorized into correct, partially correct and incorrect explanations based on the rubric in table 1.

4. Results and Discussion

The results are presented and discussed per question. The question whose results are presented and discussed will be shown first.

Question 1: Using your own words, explain what you understand by the word "current" in the context of electricity

The question was asked to elicit students' understanding of current. Research shows that students' failure in understanding electric circuits is caused by students' inability to distinguish between the concepts of current, voltage, energy, power and the combination of these concepts [18]. Before distinguishing these concepts, students must know or understand the definition of each concept, hence the question. The word "understand" was included on the question to minimize students' chance of reproducing the definition of current from textbooks. Students were expected to write: "current is the movement of charges in the conductor" or a variation that will include charges in motion etc. The answers for students' written explanation are shown in figure 2 that follows.

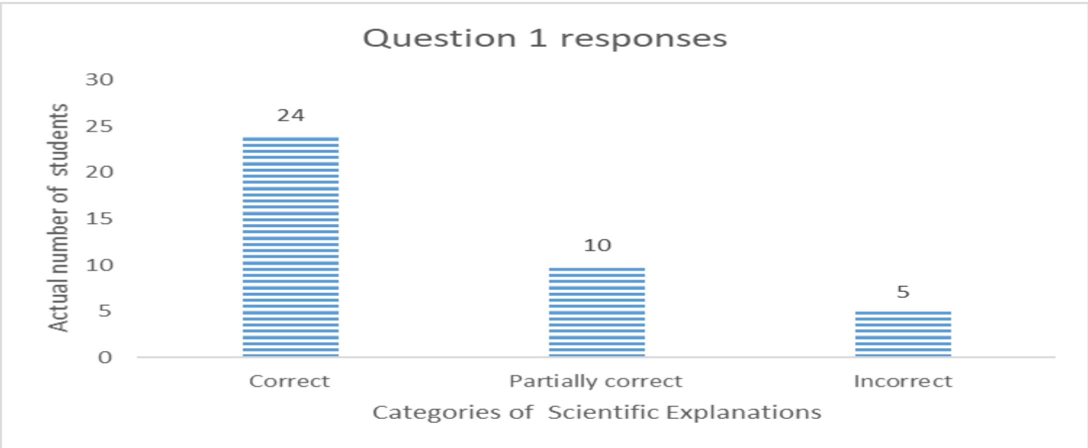

Figure 2: Question 1 Responses

The results in figure 2 show that the explanations written by 24 (62 %) students qualified to be accepted in a scientific register [3] of the meaning of current, because the students gave enough evidence and reasoning to show that their explanations described what is scientifically called current. However, 10 (26 %) students' written explanations were partially correct and lastly 5 (12 %) answered incorrectly. According to the rubric in table 1, those who answered partially correct made an accurate but incomplete claim. Which means that the answer they gave did not show clearly what current is. One of the example of the correct explanations is the following: *Explanation 1: current is directed flow of charges.* Explanation 1 is consistent with Drude's Model's explanation of the movement of charges in the conductor. An example of the partially correct explanations: *Explanation 2: charges that move around a circuit and is the one that makes the bulb to light.* Explanation 2 partially qualify to be scientific explanation because according to the scientific explanation framework, the charges that move around a circuit can be regarded as the claim of what current is, but the last part which was classified as the reasoning part of scientific explanation justify insufficiently the description of current using shining of the bulb. It can be argued that, whether the bulb shines or not in the circuit cannot be singly used to determine the presence of current in the circuit. For example, when the switch is ON and the bulb has a very low resistance it might happen that it cannot shine even when the circuit has current. Generally, students who associate current with the shining of the bulbs are likely to develop a misconception that *current will only be available when the bulb connected shines*. The reasoning part was helpful to elucidate the misconception that the presence of current will always cause the bulb to shine.

The example of one of the incorrect explanations is represented by explanation 3 that follows: *Explanation 3: the number of charges in the conductor or charges that exist in a conductor.* The explanation revealed a misconception that current is the number of charges in the conductor. The overall results of this question revealed that some of the students do not have qualitative understanding of current. The qualitative understanding of current is crucial when dealing with the impact of current in a circuit that consists of resistors/bulbs connected in series and/ or in parallel.

Question 2: Answer the following questions using diagram in figure 2, where two circuits with 3 identical bulbs connected in series. In circuit 1 the switch is OFF while in circuit 2 the switch is ON.

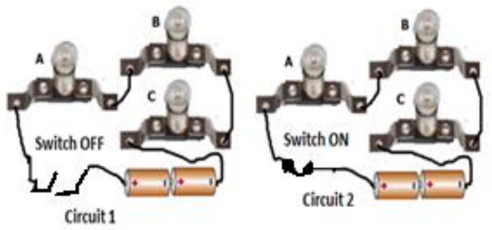

Figure 3: Diagram representing two circuit diagrams

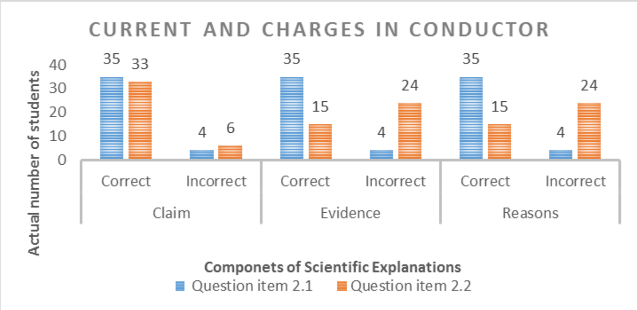

Figure 4:Responses to question 2

2.1 Which circuit will have current through it?
2.2 Which circuit will have charges?

The questions probed students' understanding the relationship between current and charges in conductor. Students were expected to indicate the absence and presence of current and/ or charges when the switch is OFF (circuit 1) and when it is ON (circuit 2) and then explain their reasoning based on the identification of a circuit which have current and also the availability of charges in the circuits. Using the scientific explanation framework, it was expected that students would answer question 2.1 by claiming that circuit 1 has no current because there is evidence that the switch is off and the reasoning would be "when the switch is off no charges moves around an open circuit and visa-versa". For question *2.2* it was expected that they would claim that both circuits have charges because they knew (evidence component) that all circuits are made of materials and lastly all materials have charges (reasoning component). It was predicted that students who have a functional understanding of current will correctly answer both questions correctly justifying with the scientifically accepted explanations.

Figure 4 shows that for question 2.1, only 4 students out of 39 answered incorrectly and some of the explanations they gave were summarized as follows:

Explanation 1: … both have charges, but charges are only flowing in circuit 2 since the switch is closed
Explanation 2: In circuit 1 the current is not flowing while in circuit 2 it is flowing
Explanations 3 & 4: In circuit 2, current can flow while in circuit 1 current flow but it won't be able to reach the negative terminal due to open switch.

Some of the explanations revealed that students were not sure of the differences between charges and current. For example student who wrote explanation similar to explanation 2 said the following as a justification for response: *"In circuit 2 there is a flow of charges and in circuit 1 charges are not flowing".* The reason shows that this student did not understand the difference between charges and current. Another explanation indicating the confusion about charges and current was: "the switch of the circuit is **ON/Closed (evidence component) and current is free to move (reasoning component)".** The statement suggests that current is available but can only move when the switch is ON or closed**. This is an indication that some students' still do not understand the difference between current**

and charges because what can move are charges. The use of current and charges interchangeably shows that students lack qualitative understanding of these two terms in the context of electric circuits.

Interestingly, in the second question (2.2), the majority of students (33 out of 39) agreed that all circuits have charges (claim), but as previously noticed their explanations were not consistent and the reasoning given did not justify evidence to support the claim and revealed some of the misconception already discussed in literature [14], for example: "*They both have batteries, charges are produced by batteries"*. Some of other explanations that students wrote as responses to question 2.2 were as follows:

Explanation 1: There is a cell that has electric charges
Explanation 2: Since connected to a battery that has positive and negative charges
Explanation 3: In Circuit 1 charges are neutral since the switch is off
Explanation 4: Charges are found in the terminals
Explanation 5: Even a neutral object has charges
Explanation 6: Circuit 1 has no charges since the switch is closed
Explanation 7: They are in electric field
Explanation 8: Charges are there (claim) but require voltage to move them (reasoning component)

Those who said that not all circuits have charges based their reasoning on the switch, for example Explanation 6 mentioned that: "Circuit 1 has no charges (claim) since the switch is closed"(evidence) and Explanation 3 mentioned that: "Only circuit 2 has charges Claim) in circuit 1, there are no charges because the switch is off". The results suggest that students do not understand the role of the switch in a circuit. The reason could be in high school textbooks, for example, they introduced current first and later the switch was shown in the circuit diagram without any emphasis of its role [19]. The other reason for the lack of emphasis could be the assumption that everyone knows the switch as used in many appliances and that assumption is causing a challenge in terms of learning electric circuits. It can be concluded that explanations 3 and 6 could qualify as misconceptions defined by [3]. The rests were just incomplete statements that need further clarity in terms of interview to be better classified [3] as misconceptions or not. These are shortcomings of using only written type explanations without further interview, however the aim was only to assess if they can write a complete scientific explanation.

Question 3: Three circuit diagrams were shown in figure 4, each with two batteries connected in series with the switch. Bulbs labelled A, B, C, D and E are identical and have same resistances. Circuit 1 has 1 bulb, while circuits 2 and 3 each have bulbs connected. In circuit 2, bulbs are connected in series and in circuit 3 they are connected in parallel. With reference to figure 4, answer the following questions and explain your reasoning.

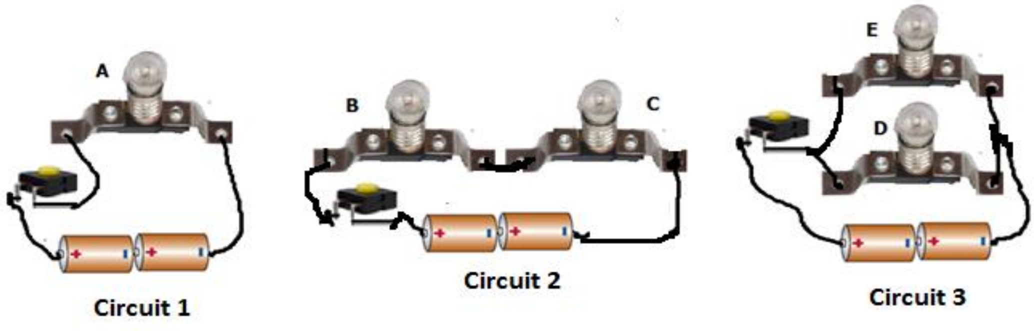

Figure 5: Series and parallel connection of bulbs

3.1 Which circuit(s) is/are connected in series?

3.2 Which circuit(s) is/are connected in parallel?

3.3 Rank all the bulbs' brightness in figure 4 from dimmest to brightest.

3.4 Which circuit(s) will have more current through it?

This activity was aimed to assess students if they (a) have a consistent model that can be used to differentiate between a series and a parallel circuit, (b) can use the model correctly to predict or compare the brightness of the bulbs in series and parallel and (c) can use the model to relate the brightness of the bulbs with the total current in the circuit. We expected students to give justified explanations that both circuits 1 and 2 have bulbs connected in series while bulbs in circuit 3 bulbs are connected in parallel basing their arguments on the loop model. For example, circuits 1 and 2 are in series (claim) because they form a single loop (evidence) in such a way that if the path is cut everything in the circuit stop to work (reasoning). In circuit 3, bulbs are connected in parallel (claim) because the circuit branches to form two loops (evidence) in such a way that if one bulb in one loop dies, the other bulb remains lit (reasoning)

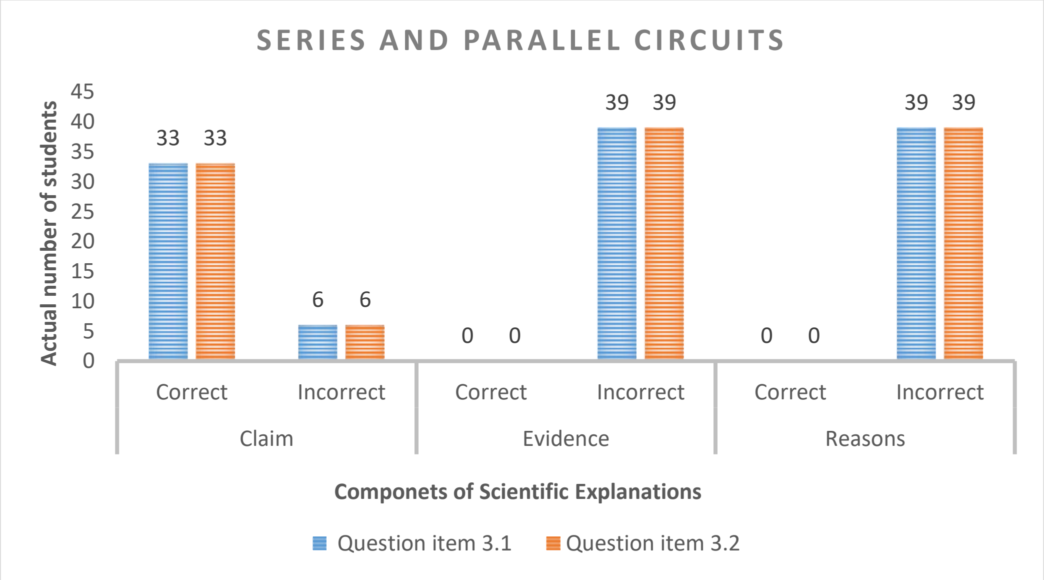

Figure 6: Students' understanding of a series and a parallel circuits

The analysis of students' explanations as in figure 6 shows that 33 (85 %) students identified both series and parallel circuits correctly but most of their explanations revealed a lack of consistent model of differentiating between a series and a parallel circuit as presented in subsections 3.1 and 3.2. Students claimed correctly but unable to justify their evidence with reasoning that supports the claim. The results suggest that students have a superficial understanding of the difference between a series and a parallel circuits.

3.1 Responses for explanations of the series circuit

Students' evidence and reasoning for the justifications of why the circuit is connected in series are shown on the graph in in figure 7 that follows. From the graph in figure 7, it can be seen that 12 (31 %) students answered that circuit 1 and 2 are connected in series (claim) and the horizontal alignment of bulbs as evidence and reasoning. The reasoning and evidence did not support the claim, hence these types of explanations were categorised as those of poor quality: *5 (13 %) students mentioned that the bulbs are in series (claim) because they share current (reasoning).* On the same vein, *7 (18 %) said it is a series circuit because current is undivided.* While it is true that in series circuit, current is the same, further exploration to determine the true meaning of 'share' or 'undivided' was necessary to avoid ambiguity and to be able to classify these explanations as misconceptions. According to [3] this can be done through interview.

The further analysis of the explanations students gave revealed that they could have 'just memorized that in series circuit, current is shared' from prior instruction or text books. For example, one of the prescribed books defined series wiring "as the connection of devices in such a way that there is the same current through each device" [20]. Those who defined series and parallel circuit based on whether current is divided or not, seem to have also memorized the definition from their textbook. A series circuit was defined as "the arrangement of circuit where two or more loads are linked along a single loop of wire" [21]. They further emphasised that the basic idea that students should have is that "in a series circuit, the same current flows through each circuit element [21]

Some students*, 7 (18 %)* used the *direction of current to identify the series and parallel connection,* which should also be further explored. The last group, *8 (21 %)* gave the explanations that cannot be classified.

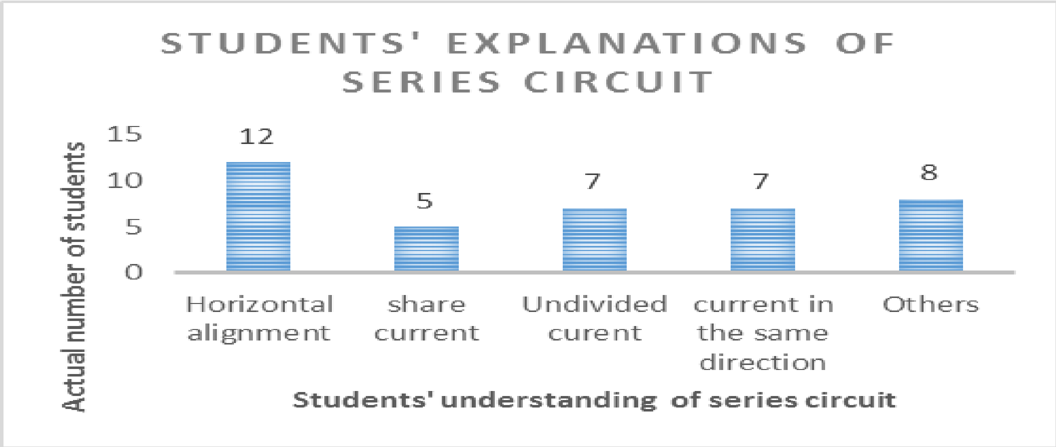

Figure 7: Question 3.1 responses

3.2 Responses for explanations of the parallel circuit

The responses of the students' explanations of what a parallel circuit is (see circuit 3 in figure 5) were categorised into the following categories namely vertical alignment, two lines, equidistant, on top of each other, different directions, don't share current, current divided and lastly not in the same line. The categories of students' explanations are shown in figure 8.

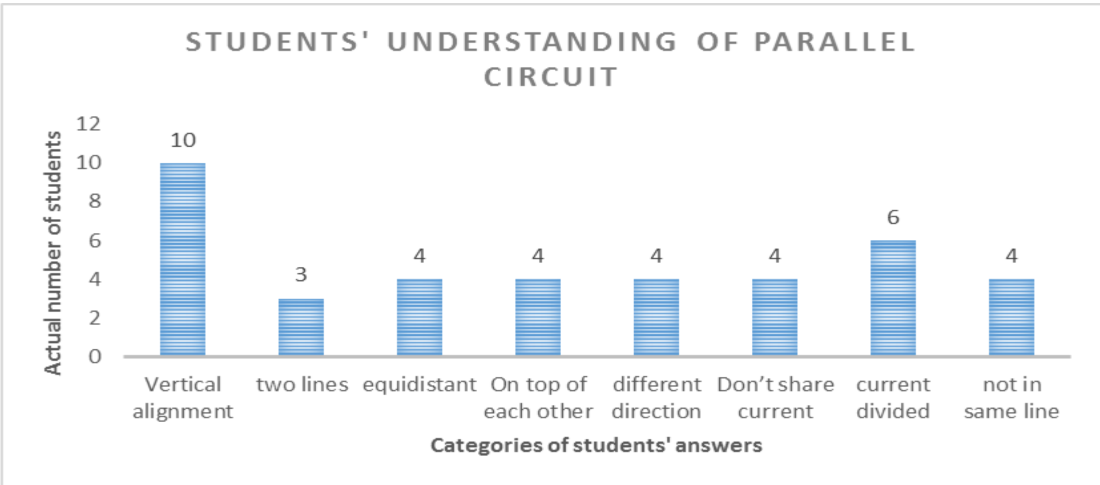

Figure 8: Students 'understanding of parallel circuit

Figure 8 shows that students defined a parallel connection as: the vertical alignment of bulbs 10 (26 %), when bulbs are placed on top of one another 4 (10 %), when current flows in different directions 4 (10 %), bulbs that don't share current4 (10 %), when current is divided 6 (15 %) and lastly as bulbs not in the same line 4 (10 %). Based on the answers given by students, it can be concluded that the majority of students do not use macro - microscopic reasoning [22] when justifying their answers. The answers they gave are similar to what is normally emphasized by teachers in high schools while teaching the topic. Students used a geometric representation of parallel lines as defined in mathematics. The visual representation of circuits as done in may textbooks are also not realistic because bulbs in parallel are usually represented on top of each other and that's why students use the horizontal and vertical alignment of bulbs when defining a series and a parallel connection of bulbs.

Some students use direction literally as a criteria to determine if bulbs are connected in series or not. For example, bulbs in circuit 3 are in parallel (claim) because current move in different directions (evidence /reasoning) or current move in more than one direction. The response shed light to the fact that assumptions made that students were familiar with conventional direction of current was incorrect. Others make use of the word direction as follows: Circuit 3 is in parallel because they do not share current or current is divided (Reasoning component)

3.3 Responses for the ranking of bulbs' brightness.

Students were expected to rank the bulbs in all circuit based on their brightness from brightest to dimmest. The ranking results are shown in figure 9

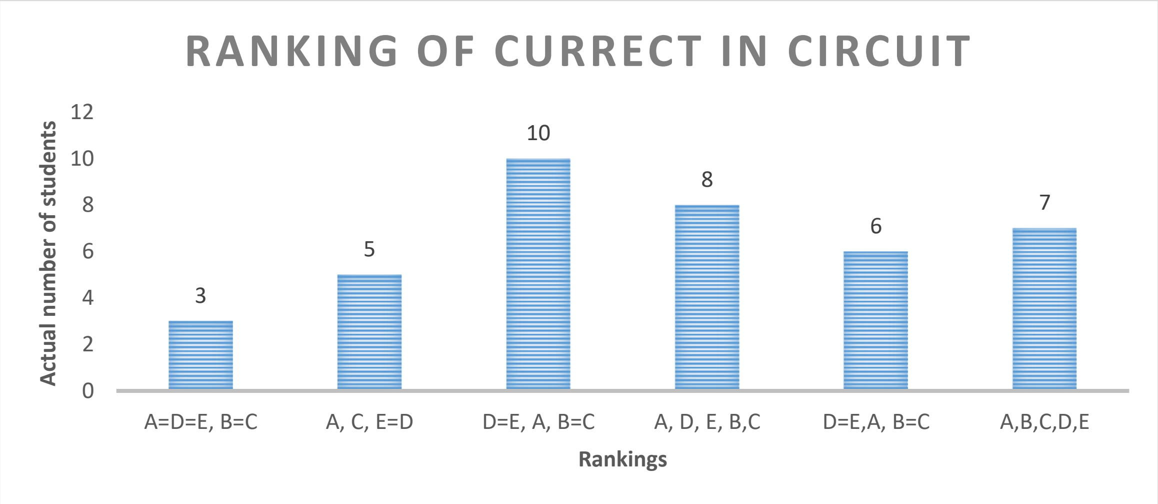

Figure 9: Current ranking

Figure 9 shows that only 3 (8 %) of the 37 students responded to the question ranked bulbs correctly. Majority of students, 10 (27%) opted for the ranking $D = E, A, B = C$. The actual number and the percentages for other rankings are: 5 (14 %) A, C, E=D, other rankings selected as displayed on figure 9 are: 8 (22 %). To rank the bulbs correctly required qualitatively understanding of the difference between series and parallel circuits, and the impact these connections have on current. Similar results where many students answered this question incorrectly was also reported in literature [23]. The results shows that students do not have a good qualitative model of explain the relation between current and the brightness of the bulb in series and parallel circuits. However, the use of ohm's law was recommended as an alternative to those who cannot answer qualitatively, but at the same time it was highlighted that success in using formula is not a reliable indicator of functional understanding [23]

4. Conclusion

The study described how the written answers for the explanation type of questions were used in probing students' conceptions of students' understanding of DC circuits and in diagnosing students' misconceptions about current in a simple circuit. The findings suggest that the quality of scientific explanations depends on students' understanding of the concepts, in other words, students with deep knowledge of the topic can explain better. The analysis of students' written explanations can be promising tool to identify the gaps students have about the topic and can also reveal unfamiliar students misconceptions or alternative conceptions. The study concur with the fact that the analysis of the explanation-type questions helped to detect students' misconceptions prior to instruction. If students' understanding is judged by students' ability to give sufficient evidence and reasons that support the claim, hence it can be concluded that most of the pre-service students lacked the conceptual understanding of the concept of current and the difference between a series and a parallel circuit. The results confirm that even pre-service students' have some difficulties in terms of learning the concepts of DC circuits qualitatively.

4.1 Suggestion for future implementation

The current study dealt with the analysis of students' written explanations using the scientific explanation framework. Further research on instructional strategies to enhance students' understanding by the construction of scientific explanation is needed to answer to an educational question described earlier. Since the findings were based on the results from pen and paper, and many students had challenges to differentiate (a) current and charge (b) a series and parallel connection of bulbs and lastly (c) the lack of consistent model to rank or predict the brightness of the bulbs in series and parallel circuits, the suggestion made would be to use the Predict, Observe and Explain model (POE) with the use of a computer simulations during an observation stage in class.

Since students lacked deep understanding of current and also associated current with the lightness of the bulb and the charges in the conductor, it was necessary to develop another activity that foster deep students' understanding of current using charges in the conductor and the availability of current as part of the action research processes

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References

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

[2] Fujii, T. (2014). Misconceptions and Alternative Conceptions in Mathematics. *Encyclopedia of Mathematics Education*, 453-455.

[3] Clerk, D., & Rutherford, M. (2000). Language as a confounding variable in the diagnosis of misconceptions. *International Journal of Science Education, 22*(7), 703-717.

[4] Shipstone, D., von Rhoneck, C., Jung, W., Karrqvist, C., Dupin, J., Johsua, S., & Litcht, P. (1988). A study of students' understanding of electricity in five European countries. *International Journal of Science Education, 10*, 303-316.

[5] Litcht, P. (1991). Teaching electrical energy, voltage and current: an altenative approach. *Physics Education, 25*, 272-277.

[6] Härtel, H. (1982). The Electric Circuit as a System: A New Approach. *European Journal of Science Education, 4*(1), 45-55.

[7] Arnold, M., & Millar, R. (1987). Being constructive: An alternative approach to the teaching of introductory ideas in electricity. *International Journal of Science Education, 9*(5), 553-563.

[8] Grayson, D. (1994). Concept Substitution: Instructional Strategy for Promoting Conceptual Change. *Research in Science Education, 24*, 102-111.

[9] Stocklmayer, S., & Treagust, D. (1996). Images of electricity: How do novice and experts model electric current? *International Journal of Science Education, 13*(2), 163-178.

[10] Rosenthal, A., & Henderson, C. (2006). Teaching about circuits at at an introductory level: An emphasis on potential difference. *American Journal of Physics, 74*(4), 324-327.

[11] Geelan, D. (2013). Teacher explanation of physics concepts: a video study. *Reserach in Science Education, 43*(5), 1751-1762.

[12] Anderson, C., & Smith, E. (1986). Teaching Science. In V. Koehler, *The Educator's handbook: A research perspective.* New York: Longman.

[13] Wittwer, J., & Renkl, A. (2008). Why Instructional Explanations Often Do Not Work: A Framework for Understanding the Effectiveness of Instructional. *Educational Psychologist, 43*(1), 49-64.

[14] Engelhardt, P., & Beitcher, R. (2004). Students' understanding of direct current resistive electrical circuits. *American Journal, 72*(1), 98-115.
[15] Ramnarain, U., & van Niekerk, C. (2012). Student naive conceptions in their explanations in a grade 12 physics examination. *African Journal of Research in MST Education, 16*(1), 112-125.
[16] McNeill, K.L& Krajcik, J. (2008). "Scientific explanations: Characterizing and evaluating the effects of teachers' instructional practices on student learning." *Journal of Research in Science Teaching*, 45(1): 53-78.
[17] Mayer, R. (1992). Knowledge Thought: Mental Models that Supports Scientific Reasoning. In R. Duschl, & R. Hamilton, *Philosopy of Science, Cognitive Psychology and Educational Theory and Practice* (pp. 226-243). Albany: State University of New York Press.
[18] Hewitt, P. (2007). Circuit happenings. *Latin American journal of Physics Education, 1*(1), 1-3.
[19] RADMASTE. (2005). *Physical Sciences for the Classroom.* Sandton: Heinemann Publishers.
[20] Cutnell, J., & Johnson, K. (2013). *Introduction to physics: International Student Version* (9th ed.). Haboken, NJ: John Wiley & Sons, Inc.
[21] Trefil, J., & Hazen, R. (2004). *The Sciences: An Integrated Approach.* Wiley.
[22] Eylon B and Ganiel U 1990 Macro–micro relationships: the missing link between electrostatics and electrodynamics in students' reasoning Int. J. Sci. Educ. 12 79
[23] McDermott, L. (1993). Guest Comment: How we teach and how students learn? A mismatch? *American Journal of Physics, 61*(4), 295-298.