Teachers' awareness of learners' misconceptions about simple circuits

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Abstract
This paper reports on a case study exploring teachers' awareness of learners' misconceptions about simple circuits. Three grade nine science teachers from schools with different socioeconomic backgrounds participated in the study. The teachers completed questionnaires and were interviewed, focussing on well documented misconceptions about current in simple series and parallel circuits. Results indicated that two of the teachers knew and understood the misconceptions probed. The third teacher was aware of the typical mistakes associated with these misconceptions, but he displayed poor understanding of students' reasoning leading to those mistakes. Furthermore, it transpired that this teacher had poor conceptual understanding of the accepted scientific model of circuits. It is recommended that professional development for senior phase science teachers should address conceptual understanding of the scientific model of simple electric circuits.

Key words: misconceptions, electricity, electric circuits, science teachers, teacher knowledge, teacher understanding

Introduction
Students' misconceptions in electricity have been well documented in the literature (see for example Engelhardt & Beichner, 2004; Shipstone, 1985). Misconceptions, also called alternative conceptions, refer to ideas that are inconsistent with scientific conceptions. These ideas develop from a young age based on children's practical experience with using electricity at home. By the time learners reach the high school, they have well established misconceptions that are resistant to change despite teaching (Chambers & Andre, 1997; Driver & Guesne, 1985).
Similar misconceptions occur in different countries (Küçüközer & Kocakülah, 2007), and South Africa is not an exception. In fact, a survey amongst South African teachers showed poor understanding of the model of conventional current (Smit & Nel, 1993). In view of South Africa's poorly trained science teachers and learners' poor performance in science (Howie, 2001), the question arises to which extent South African teachers are able to assist learners to overcome misconceptions. To answer this question, a case study of three Senior Phase (grade 7-9) teachers was undertaken to explore teachers' awareness of misconceptions about simple electric circuits. It is argued that the Senior Phase is an appropriate stage to target the misconceptions, as formal understanding of electricity is introduced in this phase.

Literature
Research on misconceptions amongst learners became popular in the early nineteen eighties (Wanderzee, Mintez, & Novak, 1994). Researchers are concerned about these conceptions as constructivist theory (Von Glaserfeld, 1993) implies that learners need to use

existing knowledge as a base when constructing new knowledge. Misconceptions which contradict scientific knowledge and accepted scientific theories are therefore of particular concern, as these will create problems with further learning (Pfundt & Duit, 2006).

Electricity is regarded as a difficult but important topic in school science syllabi (Gunstone, Mulhall, & McKittrick, 2009). It is therefore not surprising to find a vast body of literature on alternative conceptions about electricity, in particular about simple direct current circuits. It has been shown that misconceptions are independent of culture, religion and language (Küçüközer & Kocakülah, 2007; Shipstone, Rhöneck, Kärrqvist, Dupin, Joshua, & Licht, 1988) and are held by children, students and university teachers (Stocklmayers & Treagust, 1996).

From the early literature, lists of misconceptions have been compiled, with different names used for very similar conceptions, and sometimes, the distinctions between 'different' misconceptions are not well-defined. According to Sencar and Eryilmaz (2004), the following nine misconceptions are common:

1. ***Sink Model*** – Students tend to believe that a single wire connection allows the electricity to sink from the acting power supply to the component, providing power to the applicable component.
2. ***Clashing Current Model*** – Students tend to believe that positive electricity moves from the positive terminal of the power supply and that negative electricity moves from the negative terminal of the same power supply, thus causing the positive and negative currents meeting one another and clashing. This clash is believed to generate energy to power the component.
3. ***Weakening Current Model*** – Students tend to believe that the current gradually weakens as it passes through components in the circuit, with each component using up a portion of the available current as it moves through it.
4. ***Shared Current Model*** – Students tend to believe that all components in the circuit receive the same amount of current and that less current returns to the applicable power supply than what left it in the start of the circuit.
5. ***Empirical Rule Model*** – Students tend to believe that the further a bulb is away from the power supply, the dimmer it is.
6. ***Local and Sequential Reasoning Model*** – Students tend to believe that any changes that occur in the circuit only affect that local region and does not change the effects on the circuit as a whole
7. ***Short Circuit Preconception Model*** – Students tend to believe that the wire connections without components can just be ignored as they are seen to be irrelevant to the circuit as a whole.
8. ***Power Supply as a Constant Current Source Model*** – Students tend to believe that the power supply releases a fixed quantity of current to every possible circuit.
9. ***Parallel Circuit Misconception Model*** – Students tend to believe that adding resistance in parallel to a circuit increases the total resistance.

Some misconceptions are more popular and persistent than others. The 'weakening current' (or current consumption) and 'constant current source' models are most persistent (Dupin & Joshua, 1987; Engelhardt & Beichner, 2004) while the 'sink' (or unipolar) model is uncommon (Dupin & Joshua, 1987; Gott, 1984, in Engelhardt & Beichner, 2004; Osborne, 1982, in Shipstone, 1985). For the most basic circuits, consisting of a single source and one bulb, Shipstone (1984) found that misconceptions generally decrease with increasing student age, while the use of the scientific model increases, from about 7% at for 12 year olds to about 60 % for 17 year olds. Importantly, the 'weakening current' model showed most resistance to change, with about 30 % of 17 year olds still using it.

Dupin and Joshua (1987) observed that although the qualitative differences between misconceptions could fit into Piagetian developmental theory, some adults display the same misconceptions as children. They also found that some misconceptions are easily overcome by teaching, for example the 'sink model'. On the other hand, some misconceptions persist after many years of teaching. They attributed the persistence of some models to the effects of teaching. For example, addressing the 'weakening current' model by emphasizing that current stays the same (in a particular series circuit), teachers may unintentionally promote the development of the 'constant current source' model.

Morrison and Lederman (2003) argued that teachers need adequate understanding of students' preconceptions in order to develop more effective instruction. During an in-depth study using four experienced teachers, they found that teachers had poor understanding of preconceptions and weak justification for identifying preconceptions. Gunstone, Mulhall and McKittrick (2009) interviewed ten experienced senior high school teachers on difficulties in student learning, and on their own teaching of electricity. Three of these teachers were also authors of textbooks. The researchers found that 'the levels of conceptual understanding of the concepts of DC electricity of some teachers and one textbook author were of particular concern.' (p. 531). Ironically, some of the teachers in this study regarded electricity as easy to teach although hard to learn for students. During the interviews it became clear that two of the teachers had not previously reflected on the nature of some concepts, particularly voltage. The researchers argued that the poor conceptual understanding of teachers may point to inadequate content and/or poor quality of undergraduate university courses in physics.

It is difficult to conduct a study on teachers' knowledge without causing embarrassment. Pardan and Bano (2001) identified five sources of alternative conceptions amongst Pakistani teachers: the way teachers' were taught; lack of hands-on and minds-on experiences; mistakes in textbooks; daily life experiences and everyday use of terminology. The authors expressed concern about embarrassing the teachers in the course of the study. However, when becoming aware of their alternative conceptions, despite being momentarily embarrassed, the teachers were motivated to improve their own understanding. Results showed that teachers could not clearly distinguish between electric current and the energy carried by the current, and realizing their inadequate understanding, they became eager to learn.

The current study explored three South African teachers' knowledge and understanding of learners' misconceptions in electricity. The issue of teachers' own content knowledge was avoided to prevent negative feelings amongst the teachers. Well known misconceptions reported in the literature were used in the design of the instruments. For series circuits, the 'sink model' and the 'weakening current model' were explored, while for parallel circuits, the 'parallel circuit misconception' and 'power supply as a constant current source' were targeted.

Method

Participants were purposively selected to represent schools of high, average and low socioeconomic backgrounds. Experienced science teachers were selected, as to be sure that all had sufficient experience of teaching electricity as well as first hand experience of learners' difficulties with the topic. Pseudonyms are used to ensure anonymity of the teachers and schools. All three were male, although gender was not a factor when selecting teachers. Richard taught science in an upmarket suburban school, he was well experienced, aged between 40 and 45. Moses was between 25 and 30 years old, teaching science in a school in a middleclass suburb. Peter's school was located in the inner city, with learners from low socioeconomic backgrounds. He was a well experienced science teacher, aged between 45 and 50.

Data were collected by means of a questionnaire and semi-structured interview. These instruments are suitable to gain in-depth information on the participant's awareness of misconceptions. The two data sources allowed for triangulation to enhance trustworthiness of data.

Redish and Steinberg (1999) suggested that student misconceptions can be probed amongst large numbers of students using multiple choice questions with distracters selected from typical wrong answers given by students in interviews. In the current study, we used this principle to explore teachers' awareness of learner misconceptions. Multiple choice questions were designed with distracters representing well known misconceptions, and teachers had to indicate which distracters they expected to be popular choices amongst their learners. Next the teachers had to explain why they expected their learners to choose particular distracters. In this way teachers would reveal firstly whether they had knowledge of the typical wrong answers, and secondly, whether they understood how their learners think.

The questionnaire, given in the appendix, was designed not to embarrass teachers. The aim was not to test the teacher's own subject knowledge. Instead, the correct answers were given, and the teachers had to identify which of the wrong answers were most likely to be chosen by their learners. They also had to explain why they thought their learners would choose those particular distracters. In this way, the teacher's choices and explanations revealed whether they were aware of the typical reasoning associated with the particular misconceptions. For each question, they were also given opportunity to identify an additional distracter which the learners might choose. In this way, awareness of more than one misconception could be detected.

Results

Questionnaires

<u>Series circuits</u>

Question 1 (see Appendix) probed whether the teachers were aware that learners often did not know that current remains constant throughout a series circuit. The correct answer is A, which indicates that the current stays the same throughout the circuit. The distracter B was designed to be chosen by learners holding the 'weakening current' misconception, and E to be chosen by learners holding the 'sink model' misconception. Distracters C and D represent the same misconceptions as B and E, for thinking in terms of electron current rather than conventional current.

Both Richard and Moses answered that their learners were likely to choose distracter B. When asked to supply reasons for their answers, Richard indicated that the learners would argue that the current is larger in ammeter 1 because it is 'closer to the battery'. Moses said 'they think current decreases when passing through resistors'. These justifications are in agreement with the 'weakening current' misconception probed by distracter B, so it is clear that these two teachers were well aware of this particular misconception amongst their learners. When asked to indicate a second possible answer, both indicated the correct answer, and explained that some learners do actually have the correct understanding.

Peter displayed knowledge of the misconceptions, but his explanations suggested poor understanding of learners' way of thinking. He chose distracter E, indicating no current in ammeter 2; this distracter represents the 'sink model'. His explanation that learners 'think that electricity is only a flow of electrons in one direction' indicates that he does not understand the 'sink model'. His explanation may indicate that he himself holds the 'clashing currents' misconception. When asked for another possible wrong answer he expects from his learners, Peter chose B, the 'weakening current' distracter. He explained 'because they feel the ammeter marked A_1 is the one which offers more resistance and hence must consume more current'. This explanation contains elements of the 'weakening current' model, but it appears that Peter himself believes that an ammeter offers resistance, consumes current, and registers a value which indicates the amount of current consumed. It therefore appears that Peter himself lacks conceptual understanding of current in simple series circuits.

<u>Parallel circuits</u>

Question 2 (see Appendix) probed whether teachers were aware of misconceptions about current in parallel circuits. The correct answer is A: removing a resistor from a parallel combination increases the total resistance, thereby reducing the total current but not influencing current in the remaining parallel resistors. Distracter C represents the 'parallel circuit misconception', thinking that removing a resistor from parallel connection decreases resistance, thereby increasing the total current. Distracter E represents the 'power supply as a constant current source' misconception, implying that removing a resistor from a parallel connection redirects current to remaining resistors.

Answer C was chosen by both Richard and Peter. Their explanations confirmed that both understood the 'parallel circuit misconception'. Richard said 'there are less bulbs in the circuit' while Peter explained 'because they think that the current will increase as resistance is reduced. As a second option, both indicated E. Richard's explanation 'A_1 is already in series and will not be affected by the removal of [resistor] Q' confirms that he understands 'constant current source' misconception. On the other hand, Peter's explanation 'they feel that the first ammeter in the connection is gaining more current' does not support the 'constant current source' misconception associated with option E. In fact, this explanation suits distracter C, which he chose and explained earlier. Once again, Peter displayed knowledge of a typical wrong answer, without understanding the idea leading to it.

Moses chose E as the most popular mistake, and explained 'they expect current to remain constant in the circuit, so all current should now move through A_2', a clear formulation of understanding of the ‘constant current source’ misconception. He chose C as another possible mistake, and explained ‘they think taking a resistor out of the circuit decreases resistance and increase current, confirming his understanding of the ‘parallel circuit misconception’.

Interviews

When asked if he knew of incorrect ideas that persist despite teaching, Richard said ‘they… a lot of them… and even in matric still have the idea that light bulbs closer to the battery have more energy than light bulbs further away in a series circuit’. Moses mentioned that learners keep thinking that potential differences across parallel resistors should be added up to equal the total potential difference. This problem amongst learners is related to the ‘parallel circuit misconception’ which essentially treats parallel resistors similar to series resistors. Clearly, both of these teachers’ interviews confirmed their knowledge and understanding of learners’ misconceptions as revealed by the questionnaires.

During the interview, Peter deviated from the topic of simple circuits, saying learners have difficulties to distinguish between direct current and alternating current, ‘usually the difference comes from the setup with the sources which is the commutator, the one with the slip rings and the other one with, …uh… the slip rings...’ The interviewer then refocused the attention on series and parallel circuits, to which Peter replied:

> Right, uh…. Actually they understand that but when it comes to calculation of resistance now in parallel and series connection. In series connection they don’t have a problem. But now I realised that there is another formula which can easily be grasp by learners….now, I’ve come up with …uh, another method . .. then I write the products of the … resistance over the sum of resistance. Maybe I can illustrate…’

These answers indicate that Peter does not think in terms of conceptual understanding when reflecting on learner’s problems. He refers to the algebra of calculating parallel resistance, but does not mention learners’ problems to understand that adding resistances in parallel decreases total resistance. Not mentioning this important fact indicates that he has not linked the implications of the algebra to the characteristics of parallel circuits. It seems that Peter believes that algorithmic problem solving is sufficient ‘understanding’. His responses in the interview and questionnaire are well aligned, indicating that he has poor conceptual understanding of the behaviour of current in circuits.

Discussion

Richard and Moses displayed knowledge and understanding of typical misconceptions about circuits. On the other hand, Peter displayed limited understanding of learners’ ways of thinking. Although he was able to predict which incorrect choices the learners would make, his explanations of why he expected those mistakes showed that he did not understand the misconceptions. In addition, it seems that he himself does not know the accepted scientific explanations for the correct answers. We argue that his own conceptual understanding is poor, leading to his inability to understand the incorrect reasoning associated with misconceptions.

The current study gave an in depth look into three teachers’ knowledge and understanding of misconceptions. One of the teachers displayed poor understanding of the learner’s misconceptions and poor understanding of the accepted scientific model for simple series and parallel circuits. The study therefore emphasises the importance of science teachers' subject knowledge.

Being limited to three teachers, results of this study cannot be generalized. In particular, the finding that the teacher from a disadvantaged school happened to be the one who displayed poor understanding cannot be generalized. Also, the study did not explore differences in the initial training and professional development experiences of the three teachers, which is a further limitation. Despite being a case study of three teachers, it was clearly shown how one teacher’s poor conceptual understanding prevents him from understanding learners’ misconceptions about simple circuits. It is recommended that professional development for senior phase natural science teachers should address conceptual understanding of the scientific model of simple electric circuits.

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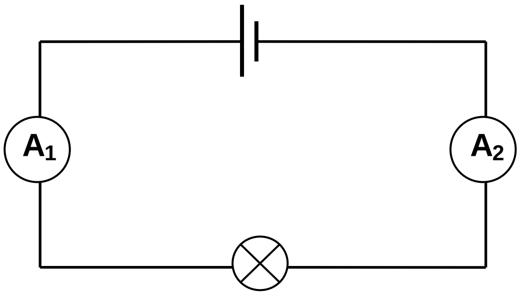
Appendix: Questionnaire

Question 1

Suppose your learners were given the following question in a test.

How do the readings on the ammeters A_1 and A_2 compare?



A $A_1 = A_2$
B $A_1 > A_2$
C $A_1 < A_2$
D $A_1 = 0$
E $A_2 = 0$

The correct answer is A.

Please answer the following questions:

1.1 Which one of the incorrect answers B, C, D or E do you think your learners are most likely to choose?

1.2 Why do you think they are likely to choose this answer?

1.3 Which of the remaining options do you think some of your learners might choose?

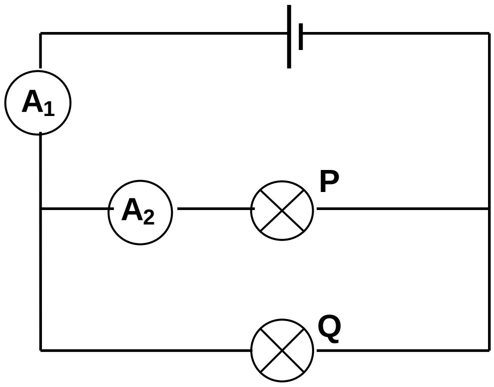
1.4 Why do you think they might choose this answer?

1.5 How would you teach circuits to help your learners develop the correct understanding about the circuit?

Question 2

Suppose your learners were given the following question in a test:

Suppose bulb Q is removed from the socket, how would the readings on ammeters A_1 and A_2 change?



A A_1 decreases, A_2 stays the same.
B A_1 decreases, A_2 increases.
C both increase.
D A_1 stays the same, A_2 decreases.
E A_1 stays the same, A_2 increases.

The correct answer is A.
Please answer the following questions:

2.1 Which one of the incorrect answers B, C, D or E do you think your learners are most likely to choose?
2.2 Why do you think they are likely to choose this answer?
2.3 Which of the remaining options do you think some of your learners might choose?
2.4 Why do you think they might choose this answer?
2.5 How would you teach circuits to help your learners develop the correct understanding about the circuit?