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Teaching Electric Circuits: Teachers' Perceptions and Learners' Misconceptions

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Abstract An exploratory case study involving six grade 9 science teachers was undertaken to probe how teachers' understanding of learners' misconceptions relate to their perceptions about teaching simple circuits. The participants' understanding of documented misconceptions in electricity were explored by means of a questionnaire, while their perceptions about teaching electric circuits were also explored in the questionnaire, followed by a semi-structured interview. Results were analysed using content analysis and interpreted using pedagogical content knowledge as a theoretical lens. The results indicated that understanding learners' misconceptions did not always correlate with conceptual perceptions about teaching electric circuits. While fair understanding of misconceptions was demonstrated by teachers who studied Physics at undergraduate level, only those who also held qualifications in Education showed conceptual perceptions about teaching electricity. Teachers who did not study Science Education revealed technical perceptions, focused on facts, demonstrations and calculations. From these results, a developmental model for pedagogical content knowledge was proposed. It was recommended that teacher education programs should involve misconceptions and also facilitate the development of conceptual perceptions about teaching.

Keywords Electric circuits · Misconceptions · Teacher perceptions · Pedagogical content knowledge (PCK)

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Introduction

Learners' misconceptions about electric circuits are common across the world and have been well documented (see for example: Cohen et al. 1983; Engelhardt and Beichner 2004; Gilbert and Watts 1983; Küçüközer and Kocakülah 2007; Shipstone 1985). However, the teachers' role in supporting learners to overcome misconceptions received less attention in the research literature (Gunstone et al. 2009; Larkin 2012; Pardhan and Bano 2001). Misconceptions are not harmless as they lead to predictions that do not agree with observation and obstruct the development of conceptual understanding of the scientific model. The importance of conceptual understanding (McDermott 1991) and constructivist learning require that misconceptions should be utilized in teaching science to enhance conceptual understanding (Hammer 1996; Morrison and Lederman 2003; Smith et al. 1993). Yet, Halim and Meerah (2002) claim that even if teachers are aware of their learner's misconceptions, they are unlikely to use this knowledge in their teaching. Furthermore, as it is known that perceptions may influence classroom practice (Mansour 2013; Mellado 1998), it is therefore possible that teacher's perceptions may be a hindrance to teach conceptually. Clearly, there is a need to investigate how teachers' understanding of misconceptions relate to their perceptions about teaching.

This article is based on a study (Moodley 2013) which aimed to explore the relationship between teachers' views about teaching simple circuits and their understanding of learners' misconceptions about circuits. The following research question was formulated: How do teachers' perceptions about teaching simple circuits relate to their understanding of learners' misconceptions? The results of Moodley's (2013) study revealed that understanding learners' misconceptions did not guarantee conceptual perceptions about teaching science. This paper reports on further attempts to explore and elucidate that complex relationship.

Literature

Hammer (1996) describes misconceptions as specific stable repeating thought patterns that do not conform to accepted scientific models. Misconceptions have also been described as alternative conceptions, pre-conceptions, children's science, preconceived notions, non-scientific beliefs, naïve theories, mixed conceptions or conceptual misunderstandings (Gilbert and Watts 1983). Many possible sources contribute to misconceptions, ranging from personal experiences, family, friends, analogies, media, teachers and textbooks.

Misconceptions about electric circuits have been identified in numerous studies since the 1970s, and in some cases there is some overlap between *different* misconceptions (e.g. Cohen et al. 1983; Shipstone 1985). Various tests have been published to identify misconceptions about simple electric circuits, e.g. the DIRECT test by Engelhardt and Beichner (2004) and the three tier test by Peşman and Eryilmaz (2010). From the literature, the following misconceptions have emerged: the unipolar model, the clashing current model, the attenuation model, current consumption model, the shared current model, the empirical rule model, local and sequential reasoning, the short circuit preconception, the constant-current-source model, the parallel circuit misconception, and the superposition model (Engelhardt and Beichner 2004; Sencar and Eryilmaz, 2004). Apart from having misconceptions, the concept of voltage is poorly understood (Liegeois et al. 2003), and learners tend to think in terms of current while avoiding potential difference (Tsai et al. 2007).

It is important that teachers understand learners' misconceptions to enable them to address it. (Larkin 2012; Morrison and Lederman 2003). However, Gomez-Zwiep (2008) found that even though most teachers in their study were aware of misconceptions, they did not understand the origin of misconceptions and how it impacts instruction. Also, Morrison and Lederman (2003) found that some teachers do not regard the identification of preconceptions as useful. A study by Gunstone et al. (2009) revealed poor conceptual understanding about DC electricity by some teachers and textbook authors. Mulhall et al. (2001) found many problematic issues about teaching electricity. Teachers are reluctant to discuss their own conceptions about current, voltage and other concepts. Also, many teachers do not know what potential difference is: teachers tend to use wrong terminology and create misunderstanding amongst their learners. According to Mellado (1998), many science teachers do not teach conceptually, instead they prefer algorithmic teaching. Such teaching may enhance students' algorithmic problem solving while conceptual understanding does not develop (McDermott 1991; Mulhall et al. 2001). In a small scale study in South Africa, Gaigher (2014) investigated teachers' awareness of two well-known and resistant misconceptions, i.e. the current consumption and constant current source models. It was found that teachers' awareness of these misconceptions was related to their own subject matter knowledge.

Learners' misconceptions are strongly related to the manner in which they are taught (Hill et al. 2008; Rollnick et al. 2008; Usak 2009). Therefore, teachers' pedagogical content knowledge (PCK) may impact misconceptions amongst learners. Studies on PCK and subject matter knowledge (SMK) showed that teachers are often not able to translate their own knowledge into learners' understanding (Magnusson et al. 1994; Usak 2009). This may imply that even teachers who do understand learners' misconceptions may find it difficult to address these misconceptions. It may therefore be useful to investigate how teachers' perceptions of teaching electricity relate to their understanding of learners' misconceptions, as such knowledge may be useful in teacher development and teacher training.

Conceptual Framework

The concept of PCK was introduced by Shulman (1986, p. 6), following his concern about the research community's disregard for the "organization of content knowledge in the minds of teachers." He described PCK as the "most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations - in a word, the ways of representing and formulating the subject that make it comprehensible to others" (p. 9). Referring to learners' misconceptions, Shulman pointed out that "teachers need knowledge of the strategies most likely to be fruitful in reorganizing the understanding of learners, because those learners are unlikely to appear before them as blank slates" (p. 9–10). Shulman originally distinguished three types of knowledge i.e. subject knowledge, pedagogical knowledge and curricular knowledge. Since 1986, research and theories about PCK have mushroomed, resulting in various knowledge types and models (Kind 2009). Some researchers regard subject knowledge as part of PCK; others view it as a separate knowledge.

Hill et al. (2008) developed a frame of *mathematical knowledge for teaching* which we adapted to scientific knowledge for teaching and used as a conceptual framework for this study as shown in Fig. 1. The frame identifies various knowledge strands within two separate domains: subject matter knowledge (SMK) and PCK. According to this model, PCK comprises of three knowledge strands namely: knowledge of content and students (KCS), knowledge of content and teaching (KCT) and curricular knowledge (CK). The model is therefore well suited to the current study, as teachers' understanding of learners' misconceptions and their perceptions about teaching are located within the dimensions KCS and KCT, respectively. Hill et al. (2008) found that teachers have minimal knowledge about how their learners think, but that they adapt their teaching methods after studying specific material on KCS. The implication for the current study is that inadequate teaching may be a consequence of inadequate understanding of learners' misconceptions, and that studying misconceptions during initial training or professional development may enhance teaching.

Methodology

An exploratory case study was undertaken to gain insight into how teachers' perceptions about teaching simple circuits relate to their understanding of well documented misconceptions about simple circuits. The study focused on teachers of grade 9 learners, arguing that the middle school phase is an appropriate period to prepare a sound foundation for understanding more complex circuits at high school level. Six teachers were purposefully selected to represent experienced teachers with a range of academic and professional qualifications, teaching in government schools, conveniently located in a South African city. Well-resourced schools as well as schools with less resources were included in the sample. Generalizability is limited by the sample size and the South African context. The data collection was restricted to questionnaires and interviews which were considered adequate to explore teacher's understanding and perceptions.

The questionnaire (see appendix) was based on ten items from the DIRECT test (Engelhardt and Beichner 2004), ignoring the effects of internal resistance. The test was therefore suitable for grade 9 learners in South Africa, as internal resistance is introduced later, at grade 12 level in the curriculum. The questionnaire was regarded

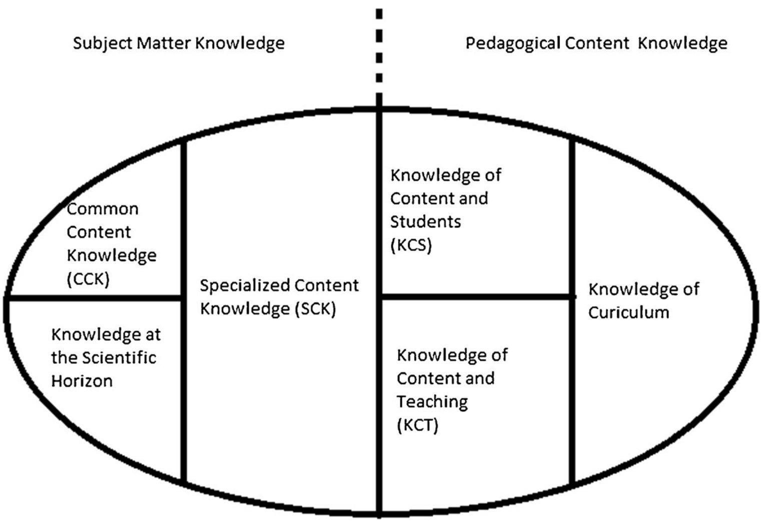

Fig. 1 Domain map of scientific knowledge for teaching, adapted from Hill et al. (2008)

as a valid and trustworthy instrument as the items were based on tests available in the literature (Engelhardt & Beichner 2004; Peşman and Eryilmaz 2010). Distracters were designed to incorporate documented misconceptions, a technique proposed by Redish and Steinberg (1999), to detect misconceptions amongst students. In the current study, teachers were asked questions about anticipated incorrect learner answers, a method used in earlier studies (Gaigher 2014; Moodley 2013). The questionnaire was designed to be non-threatening, by not focussing on teachers' content knowledge. Instead, the correct answers were indicated to the teachers while they were questioned about anticipated wrong answers from learners. They had to indicate which of the wrong options they expected learners to choose, explain why they thought learners would choose those wrong answers and finally, they had to indicate how they would address the anticipated mistakes. Participating teachers' answers revealed their understanding of learners' misconceptions and gave insight into their perceptions about teaching electricity. The questionnaire was followed by a semi-structured interview conducted with each teacher to give further insight into their perceptions about teaching electricity and for data triangulation purposes, thereby enhancing trustworthiness. The semi-structured interview consisted of 30 prepared questions, checked by an experienced physics educator. The questions were based on problematic issues reported in the literature: difficult concepts, analogies, practical work, conceptual understanding, the voltage concept and the role of calculations. The interview also included questions probing how teachers prefer to explain specific phenomena related to the misconceptions probed in the questionnaire. The researchers analysed the responses to the questionnaire independently and discussed different interpretations to reach consensus.

A summary of the participants' background, showing qualifications, experience and school context is given in Table 1, using pseudonyms. Their qualifications range from a doctorate in Physics to a teaching diploma without any training in Physics. Two of the participants have no teaching qualifications despite having postgraduate qualifications in science. The schools all had science laboratories with sufficient apparatus for learners to conduct practical investigations.

The results are discussed in two sections. We first discuss the results of the questionnaire as an overview of which misconceptions were understood and a summary of proposed teaching strategies to correct learner's mistakes. In the second section, the cases are discussed individually.

Table 1 Biographic details of participants

Teacher	Qualifications	Major subjects	Teaching experience (years)	Laboratory resources
Pravin	4-year education degree	Physics, Chemistry	6	Well
Lee	Doctor of Science	Physics	11	Fair
Mike	Master of Science	Physics, Mathematics	13	Well
Nick	Honours in Science; 1-year teaching certificate	Biochemistry, Chemistry	11	Fair
Olivia	4-year teaching diploma	Natural Science, Life Science	8	Well
Kate	4-year teaching diploma	Life Science	6	Fair

Overview of Results from Questionnaire

Teachers' understanding of the targeted misconceptions as revealed by the questionnaire are shown in Table 2. In the analysis, *understanding* a misconception means that the teacher chose the option representing the targeted misconception and also gave an explanation matching the particular misconception as the reason why learners are expected to choose that specific option. In a few instances, teachers' choices indicated the targeted misconception while their explanations were not indicative of the particular misconception. In such cases, it was assumed that the teacher did not understand the misconception, even though he/she recognized the typical mistake. It was also assumed that should a teacher know a misconception, he/she would indeed choose the relevant distracter as the most plausible mistake.

The teachers' responses showed that the attenuation/weakening current model was best known. In fact, it was understood by all the participants. The current consumption model, superposition model, voltage-current and short circuit misconceptions were each understood by only three of the participants. The remaining misconceptions were poorly understood. The parallel circuit misconception and sequential reasoning were each understood by only two participants while the constant current source, the unipolar and the clashing current models were each understood by only one of the teachers. The latter two misconceptions are often found amongst younger learners (Shipstone 1985), which may account for the fact that these were poorly known by the grade 9 teachers in the current study. However, the fact that only one of these teachers (Mike) understood the constant current source misconception is a cause for concern as this misconception is tenacious and common amongst learners of all ages (Dupin and Johsua, 1987), and it embodies poor conceptual understanding of the essential characteristics of parallel circuits.

From Table 2, it is seen that four of the teachers showed fair understanding of the misconceptions while two showed poor understanding. Mike understood seven of the targeted misconceptions, Pravin understood six, Lee and Nick each understood five while Kate and Olivia each understood only two.

Table 2 Summary of teachers' understanding (indicated by X) of misconceptions probed in the questionnaire. O indicates that the participant chose the targeted option, but the explanation did not match the misconception

Question no..	Misconception	Option matching the misconception	Teachers					
			Pravin	Lee	Mike	Nick	Olivia	Kate
1	Unipolar model	C		X				
2	Attenuation	B	X	X	X	X	X	X
3	Clashing current	B			X			
4	Parallel circuit	B	X					
4	Empirical rule	E				X		
5	Superposition	B	X		X		X	
6	Short circuit	E			X	X	O	X
7	Current consumption	C	X	X	X		O	
8	Voltage–current	B		X	X	X	O	
9	Sequential reasoning	B/C	X		X	O		
10	Constant current source	B				X		
10	Parallel circuit	C	X	X				

The teachers' suggestions to address the learners' mistakes were classified as emerging categories and summarized in Table 3. The following categories emerged: conceptual, demonstration, constructivist, analogy, explanation, calculation, numerical, factual, inaccurate, incomplete and incorrect. Conceptual approaches and demonstrations were the most popular suggestions. In some cases, teachers indicated that they would *explain*, without further clarification of what and how they would explain.

Individual Cases Based on the Questionnaire and Interviews

The individual cases of the six participants are discussed below, using a synthesis of results from the questionnaire and interview.

Pravin

Pravin completed a 4-year educational degree, majoring in Physics and Chemistry: therefore, it was expected that he had adequate SMK and PCK. In the questionnaire, he indicated six of the targeted misconceptions as expected learner mistakes as shown in Table 2. His explanations as to why he expected these mistakes indicated that he reflected about learners' ways of thinking, as illustrated clearly in question 2, where he chose B, which represents the current attenuation/consumption model:

Q:Why do you think they will choose this option?
A:I think they'd probably confuse the potential difference across the bulb with the current. They'd think that as potential energy decreases across the bulb, so would the ability of charges to move from one point to another.

Table 3 Summary of teachers' suggestions to address learners' expected mistakes in the questionnaire

Question no.	Suggested ways to address expected mistakes[a]					
	Pravin	Lee	Mike	Nick	Olivia	Kate
1	Constructivist	Constructivist	Constructivist	Constructivist	Factual	Factual
2	Analogy	Demonstrate and explain	Factual	Analogy	Factual and incomplete	Factual, demonstrate
3	Conceptual	Factual	Factual	Factual	Factual	Factual
4	Conceptual	Demonstrate and calculate	Factual and incomplete	Conceptual	Factual and incomplete	No answer
5	Constructivist	demonstrate and explain	Factual	Analogy	Factual and incomplete	Factual and demonstrate
6	Conceptual	Demonstrate and explain	Factual and incomplete	Constructivist	Factual, irrelevant	Demonstrate
7	Conceptual	Conceptual	Factual and incomplete	Constructivist	Factual	Revision
8	Constructivist	Demonstrate and explain	Factual	Constructivist	Factual	Irrelevant and calculation
9	Constructivist	Demonstrate	Conceptual	Conceptual	Factual	Demonstrate
10	Constructivist	Demonstrate and explain	Incorrect	Constructivist	Incorrect	Demonstrate

[a] These suggestions were given by teachers for the options they chose, not necessarily for the targeted misconception; therefore, we refer here to mistakes rather than to misconceptions

Q:How would you explain to learners that the chosen option is incorrect?
A:I would use the analogy of a steering wheel: when one point of a steering wheel moves, all other points of the steering wheel move at the same instant.

In the questionnaire Pravin mostly suggested to address mistakes involving constructivism and conceptual explanations, including analogies, as summarised in Table 3. During the interview, Pravin often referred to analogies, particularly an analogy involving traffic and toll roads to explain circuits:

..... an ATM [automatic teller machine] *for cells and I'd represent different components, the wire, the highway, the vehicles would represent the charge, and the toll gates or e-tolls would represent the resistors and the money that you have to pay would represent the energy and that way, it would make some sort of sense to them how the circuit actually works.*

His responses to several of the questions in his interview were based on this analogy:

Researcher: How do you explain that adding bulbs in parallel does not affect brightness?
Pravin: What I do is on my analogy, what happens is that obviously the current will split, but then each car that has withdrawn money from the ATM has his own money to pay at the toll gate and the toll gates would be the light bulbs.
For parallel cells, he used the same analogy:
Researcher: How do you explain that connecting cells in series increases the brightness of a bulb, but when you connect them in parallel the brightness of the bulb is not affected?
Pravin: I still use the same analogy as well. If different cars are leaving two different ATMs and they have a little amount compared to …. .if you have a series of cells and you collect money from each, you gonna leave .....with a large amount of money……

He also used other analogies, such as a rotating steering wheel to explain constant current and *Red Bulls* [energy drink] as an analogy for voltage, but he found that the tollgate analogy works "perfectly" and learners "often use it to remind themselves how things work."

Pravin demonstrated good understanding of learners' misconceptions. Furthermore, his frequent use of the tollgate analogy created a representation which is a valuable tool to develop learners' conceptual understanding. In terms of PCK, Pravin's perceptions reflected well developed KCT, while his understanding of misconceptions and his focus on learners' thinking reveal well developed KCS.

Lee

Though he had a doctorate in Physics, Lee had no qualifications in education, and it is therefore expected that he had strong SMK but less PCK. He was confident about his own subject knowledge and was aware of the challenges caused by learners' poor background knowledge. In the questionnaire as well as the interview, Lee often mentioned the challenge of learners' poor understanding.

I'm well-rehearsed in my subject and have a very intense knowledge ..... for me to understand there is no problem, but I must explain it to them……From the childrens' aspect, maybe because they …. come from a background where maybe they do not have *experience with it, so it means that one must start with the very basic and connect it with their everyday lives.*

In the questionnaire, Lee displayed understanding of five of the targeted misconceptions as shown in Table 2. His suggestions to address mistakes, summarised in Table 3, often involved demonstrations and explanations. However, he seldom indicated exactly how he would explain, as seen from his answer to question 10, where he chose C, indicating the parallel circuit misconception:

Q:Why do you think they will choose this option?
A:Because they do not understand parallel circuits.
Q:How would you explain to learners that the chosen option is incorrect?
A:By demonstrating it practically and explain it step by step what happens in the circuit. Firstly with series and then with parallel connection.

When asked explicitly about analogies, Lee mentioned the water pipe analogy but never used it in any explanation in the interview or the questionnaire. However, in both the interview and the questionnaire, he often mentioned demonstrations and calculations to help explain, for example:

Researcher: How do you explain that adding light bulbs in parallel does not affect brightness?
Lee: After I demonstrate the fact, then I will say to them the only way to explain to them properly is to do it mathematically after I've demonstrated it and then show them that the resistance actually goes down.

These results indicated that Lee had a good understanding of learners' misconceptions in electric circuits, but that his perceptions were not focused on the development of learners' conceptual understanding. Instead, he suggested that he regarded algebra as explanatory. He did show some understanding of generic PCK by valuing demonstrations and in one case suggesting constructivist teaching, using examples from learners' everyday lives. However, throughout the interview and questionnaire, there was little indication that he applied constructivist principles. Though he mentioned explanations together with demonstrations, he did not reveal how he would explain. Regarding calculations, he suggests that learners would *understand* if they could understand the mathematics. It appeared as if Lee did not think in terms of learners' conceptual understanding: in fact, it seemed that he regards observation and calculation as sufficient understanding of circuits. It was therefore concluded that Lee's KCT was poorly developed, in contrast with high level of SMK and good KCS.

Mike

Mike held a Master's degree in Physics, but no qualifications in education. He showed understanding of seven of the misconceptions targeted by the questionnaire, which was best amongst the participants as is evident in Table 2. With regards to addressing the mistakes, his suggestions were mostly factual statements as shown in Table 3. For example, in question 5, he suggested a factual statement as a way to correct the superposition misconception (option B):

Q: Why do you think they will choose this option?
A: They will think that there are two cells in these circuits, so they should be brightest.
Q: How would you explain to learners that the chosen option is incorrect?

A: Cells in series you add up their voltages but when cells are in parallel you don't add up and they last longer compared to those in series.

This explanation did not address the phenomenon on a conceptual level, which was disappointing given his clear understanding of the superposition misconception as demonstrated by this example. In fact, in his interview, he mentioned more than once to that the connection of cells in series and parallel was difficult to understand, for example:

Researcher: Are there any specific concepts that your learners find difficult in electricity?

Mike: Ja, they have challenges with, if the cells are in series, their voltages are put together, therefore makes the bulb brighter, but if they are in parallel their voltages are not put together to make bulbs brighter. They have difficulties in understanding that.

These examples showed that he did not consider offering conceptual explanations to help students understand how the potential difference was established across a battery.

During the interview, he mentioned using analogies, particularly the blood circulation analogy, to explain circuits. Furthermore, he indicated that he valued practical work and demonstrations, explaining that learners remembered better when they "experience the theory hands on" and "then they see it and it starts sticking to their memory…" He also used a computer simulation to explain short circuits.

The results indicated that Mike had fair understanding of learners' misconceptions, which indicated adequate KCS. Differently, his KCT was inadequate as he often mentioned factual statements and calculations rather than focussing on developing learners' conceptual understanding.

Nick

Nick held an Honours degree in Chemistry and studied Physics at undergraduate level. He also had a post graduate Teaching Certificate. It was therefore expected that he had sufficient SMK and PCK to teach electricity at grade 9 level. In the questionnaire, Nick showed understanding of six of the targeted misconceptions as shown in Table 2. He was the only one who chose the constant current source model in question 10, indicating B and explaining as follows:

Q: Why do you think learners would choose this option?

A: Because bulb P and bulb Q are now in parallel they think the current [in P] would now decrease. They don't take into consideration the effect and resistance and total current.

Q: How would you explain to learners why the chosen option is incorrect?

A: Bulbs are identical so the total resistance will now half. This will have the effect that the ammeter X register twice its former reading. But because the current is split between the two parallel resistors, the reading on Y will stay the same.

In this suggestion, he built on the learners' problem of not thinking in terms of the total effect of resistance where "bulb P and bulb Q are now in parallel." Similarly, he suggested constructivist and conceptual explanations when explaining the other mistakes he anticipated in the questionnaire.

In the questionnaire, Nick suggested constructivist and conceptual explanations to address mistakes, as shown in Table 3. He refered to various analogies when explaining circuits:

athletes running around a track for current, a stretched rubber band pulled in a circular motion to model constant current, water pipes for series and parallel resistors and trucks connected front to back or side by side for series or parallel cells. His explanations were detailed, suitable to develop learners' conceptual understanding, for example:

Researcher: How do you explain what a short circuit is?
Nick: That, I always…, is when you give the current an easier way to travel, it is like when you have to travel over a hill, with all the stones in it, or they make a tunnel through the hill, you will take the tunnel through the hill because it is easier. The current will do the same thing so you will bypass all those other resistors in your way.
Nick emphasised that familiarity with phenomena, and using hands on experiences rather than demonstrations is important, but did not equate this experiential knowledge with understanding. He indicated that calculations were important as preparations for further studies, even though it is difficult at grade 9 level. However, his focus was primarily conceptual, as shown in the following excerpt:
Researcher: Do you think that it is sufficient to observe brightness of bulbs to understand circuits, or do you think measurements of current and potential difference are important for Grade 9?
Nick: In a way it is sufficient to look at brightness of bulbs, but to prepare them for further, eh, further studies in science you must go to measurements.

These results indicated that Nick had a fair understanding of learners' misconceptions, revealing adequate KCS.

Furthermore, his focus on learners' conceptual understanding indicated well developed KCT.

Olivia

Olivia held a 4-year teaching diploma, with Natural Science as one of her majors. It is therefore expected that she had adequate SMK as well as adequate PCK to teach circuits at grade 9 level. In the questionnaire, she anticipated mistakes related to five of the targeted misconceptions, but her explanations revealed that she actually understood only two of these five misconceptions, namely the attenuation and superposition models, as shown in Table 2. Furthermore, to correct learners' mistakes, she suggested to present factual information for all questions, as shown in Table 3. For example, in question 2, she chose B, which indicated the current attenuation model, and explained as factually follows:

Q: Why do you think learners would choose this option?
A: Because current flows from positive to negative.
Q: How would you explain to learners why the chosen option is incorrect?
A: Current in a circuit remains the same at any point in the circuit.

The response above indicated a focus on *facts* without an inclination to consider learners' conceptual understanding. The issue of current conservation was also raised in the interview, where she admitted that she does not know how to explain:

Researcher: How do you explain to learners that a current in a series circuit stays the same throughout?

Olivia: Because it does. I cannot explain it.

The two excerpts given above indicated that though she can correctly state facts, she herself lacks a conceptual understanding.

In the interview, she suggested that practical work would be sufficient to bring understanding:

Researcher: How do you decide which experiments should be done?
Olivia: The ones that is a challenge to the learners. The ones the learners will understand the concepts taught, if I see that this is a concept they struggle with, if I do an experiment with them, so they can see, 'oh this is how it works' and they understand better.

In the interview, it became clear that she had limited knowledge about analogies:

Researcher: When you explain how a circuit works, which analogies do you use?
Olivia: Houses, I use house the lighting up of houses, streets, things like that.

Olivia revealed surface level SMK of electrical circuits, suggesting that the Natural Science she studied did not provide adequate preparation for teaching electric circuits. It seemed that though she knew mistakes that learners are likely to make, she lacked understanding of why they would make these mistakes, reflecting poor KCS. She regarded factual statements and teacher demonstrations as sufficient to produce understanding, while giving no indication that conceptual understanding was important. It therefore seemed that her inadequate SMK limited the efficiency of her studies of Education, resulting in poor KCT.

Kate

Although Kate was not qualified to teach Natural Science, she had been teaching the grades 8 and 9 Natural Science classes in her school due to staff shortages. She held a 3-year teacher diploma for which Life Science was her only science based subject. It was therefore expected that her SMK was inadequate and that her PCK was limited to generic science teaching. In the questionnaire, she revealed understanding of only two of the targeted misconceptions, as shown in Table 2. These were the attenuation and the short circuit models. In both cases, she suggested to use demonstrations to address the misconceptions, and for the remaining questions, she suggested factual statements and calculations to address mistakes, as shown in Table 3. For example, in question 2, she chose B, representing the attenuation model, and explained as follows:

Q:*Why do you think they will choose this option?*
A:They are struggling to understand the concept that the current is the same throughout the circuit. The moment that you connect the two ammeters it throws them off.
Q:How would you explain to learners that the chosen option is incorrect?
A:To tell and show them that the current is the same everywhere in an experiment.

It is not clear what she would tell them, and there is no suggestion about explaining on a conceptual level. In other questions, Kate's suggestions also referred to demonstrations as well as factual statements, calculations and some unclear answers. In the interview, she also revealed that she regarded practical work as a way to develop understanding:

Researcher: It is difficult to do all the experiments. How do you decide which experiments should be done?
Kate: I decide to do experiments which, uhm, I feel will let the learners understand better like between series and parallel connections.

Throughout the interview, her answers were hesitant, sometimes using incorrect terminology and not focused on the meaning of concepts, suggesting that demonstrations would generate understanding:

Researcher: Do you think that the potential difference concept is important in teaching electricity in Grade 9?
Kate: Yes
Researcher: Why?
Kate: Uhm, … because it doesn't help if you have the content correct and give that through to them but they don't have the concept for example by visualizing or seeing a current, how a current works. It doesn't help to say you need 3 most important concepts of a circuit but you can't show them how it works.

While Kate did not reveal concerns about conceptual understanding, she emphasized calculations:

Researcher: What do you find most difficult to explain to your learner?
Kate: Calculations
Researcher: Are there any specific concepts that your learners find difficult to understand in electricity?
Kate: Just the calculations again.

From the data, it was clear that Kate herself had limited conceptual understanding of circuits, despite having taught it for 6 years. She displayed poor understanding of learner's misconceptions, and there were no indications that she reflected about learners' thinking and understanding of concepts. It seemed that she assumed that understanding circuits simply entail knowing facts. The data revealed that her pedagogical repertoire was limited to presenting content as facts in isolation, doing demonstrations and calculations, without supporting it by conceptual explanations. It was clear that her SMK was fragmented and limited, and similarly her KCS and KCT were generic, lacking topic specific depth.

Discussion

A comparison of the individual cases revealed that Pravin, Lee, Mike and Nick displayed adequate KCS, all having a fair understanding of the documented misconceptions about circuits. Differently, Kate and Olivia displayed poor understanding, reflecting poor KCS. Regarding perceptions about teaching electricity, the case studies revealed that only two of the participants, Pravin and Nick, displayed adequate KCT in terms of a focus on developing learners' conceptual understanding. Their perceptions about teaching electricity included categories such as using analogies, constructivism and conceptual explanations, focused on enhancing conceptual understanding. Consequently, we described these as 'conceptual' perceptions. In contrast, the other four participants revealed inadequate KCT. Their perceptions about teaching circuits included factual information, demonstrations and calculations, representing a technical focus, with little indication of concern about developing learners' conceptual understanding. We collectively referred to these perceptions as *technical* in contrast with conceptual perceptions. These two constructs, or types of perceptions, are related to teacher's beliefs such as constructivist, empiricist, process and traditional beliefs described in the literature (Hasweh 1996; Mansour 2013; Tsai 2002).

The results indicated that understanding learners' misconceptions did not necessarily imply that a teacher held conceptual perceptions about teaching electric circuits. Three types of relationships between understanding misconceptions and perceptions about teaching electric circuits emerged: fair understanding combined with conceptual perceptions, fair understanding combined with technical perceptions and poor understanding combined with technical perceptions.

Pravin and Nick showed fair understanding of learners' misconceptions, as well as conceptually focused perceptions about teaching electricity. Both of these teachers made use of rich conceptual explanations, often involving constructivist principles and analogies to scaffold explanations. While they regarded calculations as important for 'further' studies, they did not regard it as a way of understanding concepts. At the same time, their professional backgrounds were similar: Both were well qualified to teach Physics, having studied Physics at undergraduate level. Furthermore, both held educational qualifications.

Mike and Lee showed fair understanding of learners' misconceptions, yet their perceptions about teaching electricity were mostly technical, not focused on developing learners' conceptual understanding. They valued demonstrations, factual knowledge and calculations about circuits. Though both these teachers indicated that they use analogies, they never mentioned it spontaneously, suggesting that they did not hold it in high regard. Instead, Lee mostly offered to demonstrate and 'explain how it works', without clarifying how he would explain, while Mike mostly proposed factual and sometimes incomplete explanations. Regarding their professional backgrounds, both teachers held postgraduate qualifications in Physics, but neither held educational qualifications.

Both Olivia and Kate showed poor understanding of learners' misconceptions. Also, both held technical perceptions about teaching electricity. Neither gave any indication that they valued a conceptual approach to teaching circuits. Instead, factual information, demonstrations and calculations were regarded as self-explanatory. Calculations were regarded as difficult and important and were therefore emphasized. They did not regard a circuit as a system, instead they focused on concepts in isolation, while analogies were unknown or not valued. These two teachers also had similar professional backgrounds, holding 3-year teaching diplomas. Olivia did study some basic Physics as part of her Natural Science course, but Kate never studied any Physics at tertiary level.

Conclusion

Returning to the research question, the data demonstrated that good understanding of learner misconceptions did not guarantee conceptual perceptions about teaching electricity. The implication was that some teachers did not regard the development of conceptual understanding as a priority, despite their insight into learners' misconceptions. This conclusion could be explained in terms of the conceptual frame based on the participants' qualifications. There was a clear pattern visible in the results, suggesting that good understanding of misconceptions in electricity, i.e. well-developed KCS, required at least undergraduate studies of Physics, while conceptual perceptions about teaching electricity, i.e. adequate KCT, did not only require undergraduate studies of Physics but also studies of Science Education. This suggested that apart from conceptual understanding of circuits, some form of domain specific pedagogical content knowledge (DSPCK), a term used by Veal and MaKinster (1999), is required for the development of appropriate KCT. Even those with adequate SMK but lacking DSPCK tended to display inadequate perceptions about teaching circuits. Despite having conceptual understanding themselves, their perceptions about teaching were inadequate, lacking a conceptual focus. It is possible that these teachers did not realise that learners need conceptual scaffolding to develop understanding. In fact, their perceptions about teaching were technical, similar to that of the teachers who lacked SMK themselves. It was therefore proposed that KCS developed from a teacher's SMK while KCT developed from a combination of KCS and DSPCK in a constructivist developmental process. The development of these knowledge types was represented by a simple one way flow diagram as shown in Figure 2, whereby SMK and DSPCK formed the foundation on which KCT is constructed during teaching experiences.

The flow diagram added a hierarchy to Hill et al.'s concepts of KCS and KCT. Furthermore, our model showed some similarity to the hierarchical model proposed earlier by Veal and MaKinster (1999). Importantly, our model was not meant to represent a comprehensive PCK model; it developed from an attempt to understand how misconceptions relate to perceptions about teaching. Our new hierarchical PCK model emphasised the dependence of KCT on SMK as well as on DSPCK. Though it has not been explored in this study, we propose that reflection on teaching experiences may introduce feedback into the model, which may strengthen all knowledge types in the model. It is recommended that more research be undertaken to investigate the generalizability of the process of developing KCT.

This was an exploratory multi-case study with six teachers in South Africa and not intended for generalization. For future research, the results may be used to inform pedagogy and research in different contexts. A further limitation stemmed from the focus on perceptions rather than actual classroom practice as these may differ (Ireland 2011, Mansour 2013). A further opportunity for later research might be to explore to what extent teachers' understanding of misconceptions relates to conceptual teaching practices.

In conclusion, for these six teachers, it was found that understanding misconceptions correlated with conceptual perceptions about teaching electric circuits, provided that they had adequate KCT as well as adequate DSPCK. Importantly, teachers without content related education should not be made to teach in topics they are not trained in; this research indicated that while such teaching might look like successful teaching, a deeper look reveals poor teaching techniques and thin conceptual understandings. Finally, this research supported

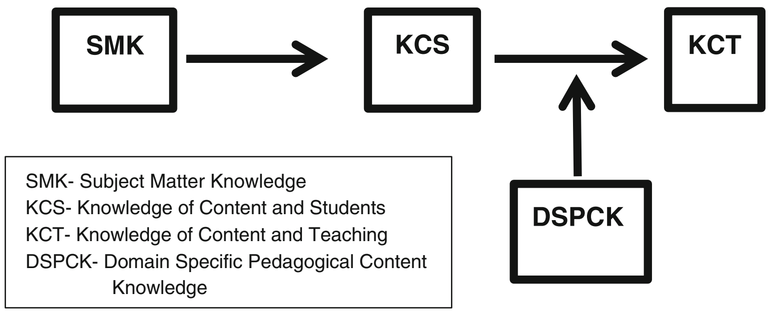

Fig. 2 Development of KCS and KCT components of PCK

recommendations that teacher education programs should involve a study of misconceptions and also support the development of conceptual perceptions about teaching. In this way, future teachers may be better equipped to address learners' misconceptions at a conceptual level.

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