TEACHING ELECTRIC CIRCUITS: TEACHERS' IDEAS AND UNDERSTANDING OF MISCONCEPTIONS

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Abstract

This study explored the relationship between teachers' ideas on teaching electricity and their awareness of learners' misconceptions. A sample of six participants was conveniently selected from six different schools in an urban setting. A multi case design was used, treating each participant as a separate case. Data were collected using a questionnaire and interview. Questionnaires were designed to probe teachers' knowledge, understanding and addressing of well-known misconceptions about circuits as reported in the literature. Interviews focused on teachers' ideas about content and teaching methods. Results were interpreted using an existing Pedagogical Content Knowledge (PCK) model as conceptual framework. It was found that teachers' understanding of misconceptions ranged from minimal to insightful while the strategies to correct misconceptions included teaching factually, mathematically, practically and conceptually. It was found that those teachers who were well aware of their learners' misconceptions also held ideas that science teaching should focus on conceptual understanding and that various teaching methods should be used. Conversely, teachers who demonstrated poor understanding of misconceptions tended to view and teach concepts as isolated facts. It is argued that the relationship between teachers' ideas and their awareness of misconceptions is one of cyclic reinforcement rather than simple cause and effect. The results show that teachers' qualifications play a significant role in their ability to facilitate understanding of concepts in electric circuits. A new hierarchical model of pedagogical content knowledge is proposed to explain the results of this study.

Key words: Misconceptions, Electricity, Pedagogical Content Knowledge, Subject Matter Knowledge.

Introduction

Modern life depends on electricity, from simply lighting our homes to using sophisticated computers. It goes without doubt that as learners enter science classrooms; they have a wide range of ideas and beliefs about electricity that they have developed from their everyday experiences (Shipstone, 1984). These ideas shape the understanding and construction of knowledge as they are taught (Jones, Carter and Rua, 1999). Unfortunately, many learners' intuitive ideas are incomplete and conflict with scientific explanations of electrical circuits (Lee & Law, 2001).

Misconceptions have been identified in different science topics and have been described as preconceived notions, non-scientific beliefs, naïve theories, mixed conceptions or conceptual misunderstandings (Hanuscin, 2001). There is a gap between what research has revealed about misconceptions and whether this research could be used to bring about some change in instruction in a classroom. “What limited research exists regarding teachers and misconceptions has shown that preservice and novice teachers are often unaware that their students may have misconceptions.” (Zwiep, 2008, p 438). Even in cases where teachers are aware of their learner’s misconceptions, they are unlikely to use this knowledge in their teaching (Halim and Meerah, 2002).

The aim of my study is to explore the relationship between teachers’ ideas on teaching electricity to their awareness about typical misconceptions. In this study, ideas refer to what content and methods are regarded as important, while awareness of misconceptions refer to knowledge, understanding and addressing of misconceptions. The results of my study would provide insights on not available in current literature and may ultimately contribute to improved classroom practice.

Literature

Studies from as early as 1973 (Driver & Easly) show misconceptions amongst learners about electrical circuits. A number of studies found common misconceptions in circuits by learners in different countries, and described these common ideas as misconception models (see for example: Sencar & Eryilmaz, 2004; Shipstone, 1985; Engelhardt & Beichner, 2004; Chang, Liu, & Chen, 1998; Pesman, & Eryilmaz, 2010) A South African study distinguished preconceptions originating from different cultures, experiences, teaching etc. and misconceptions which are created based on poor understanding of pre-existing knowledge. (Kriek, Nkopane, Basson & Lemmer, 2011)

Factors that influence misconceptions are gender and background, (Engelhardt et al. 2004; Sencar et al., 2004), cognitive perspectives (Sencar et al, 2004., Shipstone, 1985), lack of knowledge (Chang et al., 1998; Smith & Nel, 1997), inadequacies in textbooks (Kucukozer & Demirci, 2006; Smith & Nel, 1997), and languages (Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008; Shipstone, 1988). These factors together with teachers’ beliefs of teaching (Muhall et al., 2001, Mellado, 1997), their conceptual understanding (Gunstone, Mulhall, & McKittrick, 2009) and various teaching methods i.e. practical work, simulations, analogies, etc. form the bases of conception forming.

Aspects of difficulty in the use of terminology have been found in literature with regards to learners' conceptual understanding (Tallant, 1993). The confusion of words such as current, charge, energy, power and potential difference being used interchangeably and out of context seems to be one of the greatest causes of misconceptions (ref).

Conceptual framework

Recent literature (Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008; Hill, Ball & Shilling, 2008) shows that learners' misconceptions are strongly related to the manner in which they are taught. It is therefore expected that teachers' pedagogical content knowledge (PCK) may impact on misconceptions amongst learners. Studies on PCK and showed that teachers are often not able to link PCK to subject matter knowledge (SMK) (see for example Loughran, Gunstone, Berry, Milroy, & Mulhall, 2000).

The concept PCK was introduced by Shulman (1986a) and it was assumed that this type of knowledge would contribute to effective teaching and learning. Shulman distinguished three types of knowledge, i.e. subject knowledge, pedagogical knowledge and curricular knowledge. Shulman (1986b, p. 9) described PCK as, "the ways of representing the subject that make it comprehensible to others." Different scholars attempted to provide descriptions of PCK (Kind, 2009) which demonstrate that PCK is not viewed as knowledge of one single entity in teaching, but rather a sound understanding of all types of knowledge that relate to how a subject is thought.

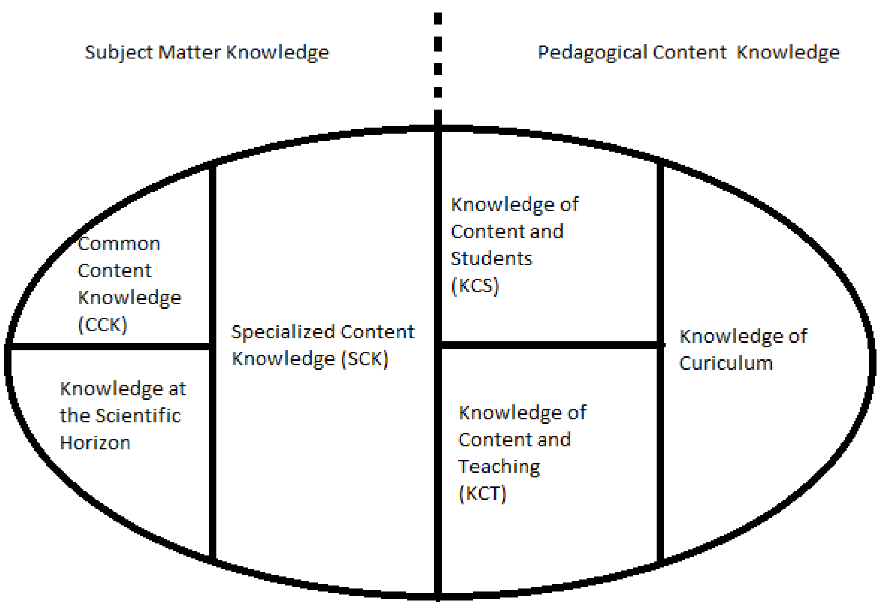


Figure 1. Domain map of scientific knowledge for teaching adapted from (Hill et al., 2008)

According to Hill et al., (2008) there is no evidence of studies done on whether PCK is beneficial to students. In fact, the field has not been developed to assess programs designed to improve teachers' PCK. Hill et al. developed a frame of 'mathematical knowledge for teaching' shown in figure 1. This frame will be adopted for my study, focusing on science instead of mathematics. The frame identifies various knowledge strands within the domains of SMK and PCK. In particular, the strand knowledge of content and students (KCS) was a new construct which is useful in the area of misconceptions. The left hand side of the domain map, Subject Matter Knowledge (SMK), involves two new strands beyond Schulman's original SMK. While common content knowledge (CCK) corresponds to Schulman's SMK, knowledge at the horizon and specialized content knowledge (SCK) are added. The latter knowledge strand enables teachers to perform particular teaching tasks related to the specific topics in the subject. On the right hand side, PCK includes KCS, knowledge of content and teaching (KCT) and knowledge of curricula. While KCT corresponds to Schulman's original PCK, the added strand of KCS entails teachers' understanding of how students learn specific content independently of curricular knowledge. The frame is particularly suited to my research question, as teachers' understanding of learners' misconceptions clearly falls within the strand of KCS.

Methodology

The study followed a qualitative approach in the interpretative paradigm. A multiple case study design was chosen because the study entails one phenomenon in a specific context dealing with different participants (Woolfolk, 2010). Each participant was treated as a separate case and compared to the others during the data analysis. A purposeful and convenient sampling procedure was followed. Six teachers from different suburban government schools of convenient distance from the university were selected. The sample was based on the teachers' willingness to participate in this research. I have used two instruments namely: a questionnaire and an interview to collect rich data and to enhance the trustworthiness of the data.

The questionnaire was designed for this study to test teachers' awareness of common misconceptions summarized by Pesman and Eryilmaz (2010) and Engelhardt et al. (2003). The format of the questionnaire can be described as 'questions about questions' where teachers are questioned about questions suitable for learners (van der Merwe & Gaigher, 2011). The learner questions were ten multiple choice items for Grade 9 learners, with distracters based on common misconceptions. The teacher was not required to answer the learner question. Instead, the correct answer was provided and the teacher was questioned about the incorrect options he/she expected his/her learners would choose. In this way, the teacher's awareness of learners' misconceptions was probed.

The interview was designed to enquire about general matters regarding electric circuits, such as: teachers' ideas about important concepts, learners' difficulties, and teaching methods. The interview was semi-structured to allow the researcher to probe for further information that may be relevant. The interviews not only provided deeper insight but also contributed to trustworthiness of the study. Interviews were audio-recorded and transcribed.

Results

The sample comprised of 6 participants. Four of the teachers held science degrees from universities while two held teaching diplomas from colleges. An example of responses to one of the questions from the questionnaire is shown in Table 1. The question probed the 'short circuit misconception'; option A is the correct answer and option E represents the misconception. The responses revealed teachers' knowledge and understanding of the learners' misconception as well as their approaches to correct the learners' understanding.

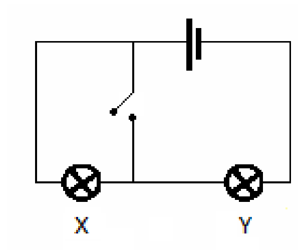
Question 6:

How does the brightness of the light bulbs change if the switch is closed?

(A) y brighter, x=0

(B) both brighter

(C) y=0, x=0
(D) x brighter, y=0
(E) no difference
The correct answer is (A).



6.1. Which wrong option do you expect your learners to choose?
6.2. Why do you think they will choose this option?
6.3. How would you explain to learners why the chosen option is incorrect?

Peter	**Lee**	**Mike**	**Nick**	**Olivia**	**Kate**
6.1. B	6.2. B	6.1. E	6.1. E	6.1. E	6.1. E
6.2. They'll think that this connection will result in equal sharing of a current.	6.2. This question is some what advanced for grade 9. Learners will choose B because they do not understand the switch in the middle.	6.2. They will think that current will still pass through X and then continue to Y.	6.2. They don't see the closing of the switch as creating a short circuit.	6.2. The switch is connected in parallel. There will be equal amount of charges flowing through each bulb.	6.2. They would say that the bulbs are connected series so they must shine equally bright.
6.3. Current takes the shortest path and the path of least resistance.	6.3. By demonstrating it practically and then explain why we see what happened.	6.3. Current will choose the shorter path.	6.3. Closing the switch gives the current an easier path to travel, so it will bypass bulb X. bulb Y will now get the	6.3. There is more resistance in the circuit with two light bulbs.	6.3. By doing an experiment.

			full/higher current and will be brighter while bulb X will not shine at all.		

Table 1: Responses to question 6 of questionnaire

In this question, Kate, Mike, Nick and Olivia demonstrated knowledge of the typical mistake but only Mike and Nick's explanations indicate that they actually understand learners' reasoning leading to this mistake. Lee and Peter believe that learners do not understand the role of the connection with the switch and may think that the bulbs are in series and the current is "shared equally". Explanations by Nick, Mike and Peter indicate that they understand the concept of a short circuit by referring to "short circuit" or "shorter path" or "path of least resistance". Kate and Lee suggest demonstrating the circuit to correct the mistake; Lee offers an appropriate explanation to support the demonstration, but Kate does not offer an explanation, suggesting that she does not understand. Olivia gave an inappropriate explanation which suggests that she, like Kate, does not understand short circuits.

For each teacher the interviews were used to probe teachers' ideas about content and method and also for triangulation with the questionnaire responses. I condensed the data from the questionnaire and interview and formed a profile in terms of their awareness of misconceptions and their ideas of teaching. The profile for Peter is presented below to illustrate the process.

Peter is well qualified having a BEd degree, majoring in Physics, Chemistry and Mathematics. He creatively uses various ways of teaching and explaining. The explanations given in the interview and questionnaire are detailed, showing sound SMK. His answers indicate a good understanding of the problems that his learners face in understanding the content, which indicate well developed KCS. He explains not just the scientific model but actually focuses on the essence of the mistake, showing a good level of KCT. He believes that practical work is beneficial to learners and makes use of analogies and demonstrations to explain concepts, showing rich PCK.

Peter adapts his teaching, using different methods, to accommodate different learning capabilities. With regards to practical work he explains how certain learners are more "hands on" than other and how he accommodates for their different learning styles. He follows a sequence of learning to avoid "disjointed segments of learning". He relates the work to real life situations and believes that learners build on existing knowledge to form new concepts. He regards calculations as important but emphasizes that it should be introduced but at a very basic level for grade 9 learners. Peter introduces the topic of electricity by using an analogy involving toll gates and ATM's:

Well usually I'd start by using an analogy using an ATM 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 response to several of the interview questions refer to this analogy. He explicitly emphasizes how the components of a circuit can be visualized as the components in the analogy, and how these components work together to produce electricity. He integrates concepts well and is able to teach for conceptual understanding of content by focussing on processes rather than products.

Peter shows metacognition and excellent PCK, for example by thinking about a possible reason for the misconception current consumption probed in one of the questions in the questionnaire.

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 the other.

For each teacher, I constructed a knowledge map to summarise their qualifications, teaching experience, PCK, SMK, ideas about teaching and awareness of misconceptions. As an example, Peter's map is shown in figure 2.

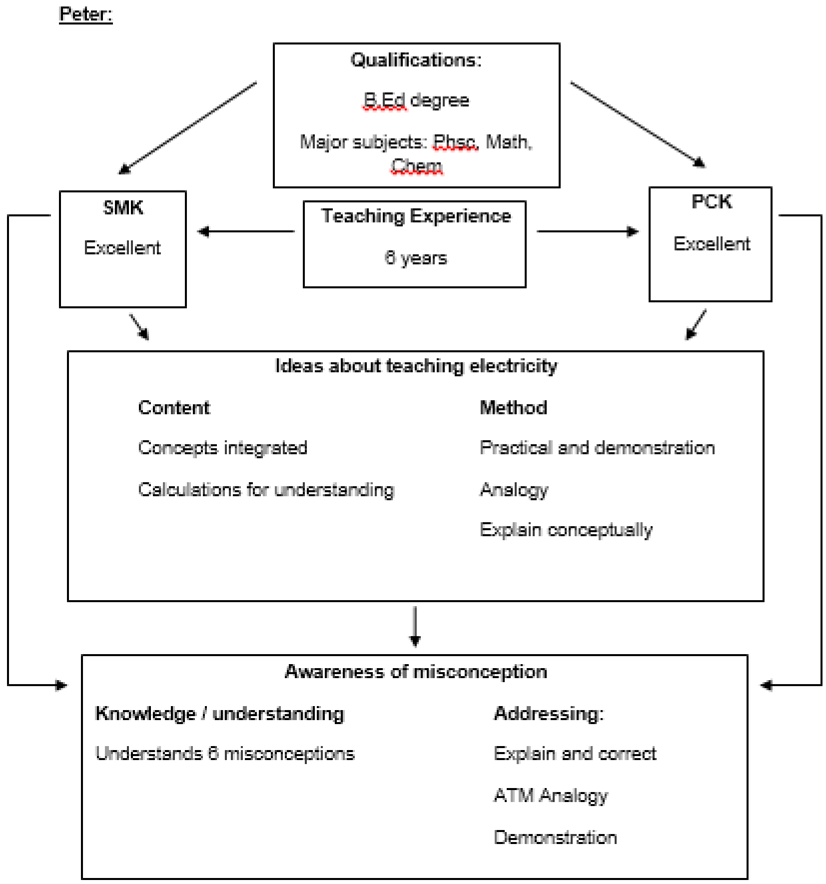


Figure 2: Knowledge Map of Peter

From Peter's map we can see that his qualifications contribute to his excellent SMK and PCK. This influences his ideas of teaching and his awareness of misconceptions. Peter is able to explain conceptually and integrate concepts while making use of various teaching methods. He is well aware of most of the misconceptions probed, understanding how learners think and giving comprehensive explanations aiming to correct mistakes. He is able to explain the scientific model and correct misconceptions using analogies and demonstrations, confirming sound SMK and PCK.

Conclusion

This study showed that teachers' ideas of teaching as well as their awareness of misconceptions are based on their SMK and PCK. From the map constructed for each teacher, it is clear that qualifications play a vital role in their SMK. The four teachers holding university degrees demonstrated rich SMK, being able to discuss relationships between concepts. Furthermore, their awareness of misconceptions and variety of teaching methods demonstrate adequate PCK, in particular KCS, knowing how their learners think. On the other hand, the two teachers holding college teaching diplomas demonstrated poor SMK, evidenced by factual answers about concepts and resorting to demonstrations without explanations to support the demonstrations. Such demonstrations reflect limited, generic PCK that do not aid learners' conceptual development.

From the results of my study, I propose a new PCK model that shows the hierarchy and layered structure of teacher knowledge. It may seem that the Hill, Ball and Schilling PCK model in Figure 1 is simplistic because it does not emphasise the importance of hierarchy of knowledge types. The pyramid shown in figure 3 represents the knowledge hierarchy of teachers' PCK. The knowledge that teachers have about content and teaching (KCT), is supported by their knowledge and understanding of the curriculum (KC) and students (KCS) which in turn is dependent on their SMK. Therefore when a teacher has poor SMK, their KC and KCS is limited and without support, which ultimately results in poor KCT.

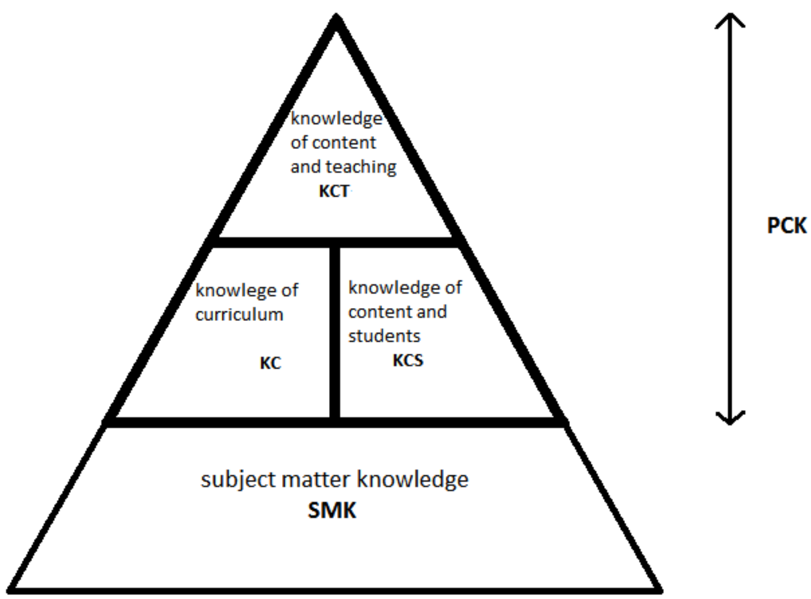


Figure 3. A hierarchical model of PCK

The structure of the PCK pyramid suggests that effective teaching is not possible when SMK is limited to fragmented knowledge of isolated concepts. Using the PCK pyramid we can see that Lee, Mike, Nick and Peter have good SMK supporting their PCK. Now we understand that their strong content knowledge leads to good understanding of the curriculum as well as insight into how their learners understand concepts. Consequently, rather than using generic teaching skills, they can apply these skills to specific content. Kate and Olivia have very poor SMK and struggle to teach the learners even if they use demonstrations, because they have not acquired sufficient SMK in their training to explain concepts further than presenting the scientific model factually.

The data shows that these teachers' ideas about teaching electricity correlate with their awareness of misconceptions. It is not clear as to what comes first in terms of the idea or the awareness. In fact, I propose that these two constructs work cooperatively in teaching. It is not simply cause and effect, but rather a cyclical relationship, the one shaping the other. Peter, Mike, Lee and Nick are aware of most of the misconceptions and they also use a variety of teaching methods to improve learners' conceptual understanding. These teachers understand how their learners think and this contributes to their ideas about the interrelatedness of concepts. Also, addressing these misconceptions contribute to their ideas about effective teaching methods. Conversely, their ideas about content contribute to their understanding of the learners' mistakes, and their ideas about how to teach contribute to the ways to address misconceptions. These four teachers' interlinked ideas about concepts and methods are associated with rich SMK and PCK. The other two teachers, Olivia and Kate, regard limited teaching methods such as demonstrating and presenting factual information as sufficient. Their limited ideas about how concepts are linked do not support understanding learners' mistakes. Although they know about some typical mistakes, they do not understand the misconceptions leading to these mistakes. They propose to address mistakes by doing demonstrations or by presenting factual information, reinforcing their ideas that content can be transferred without offering interpretation. These ideas about isolated concepts and knowledge transmission are related to inadequate SMK and limited PCK.

The study emphasizes that SMK is a prerequisite for effective PCK. In South Africa, policy documents such as the RNCS and CAPS provide knowledge of the curriculum to improve the quality of PCK in classrooms. Furthermore, teachers' personal and professional development is assessed by an Integrated Quality Management System (IQMS). However, the effectiveness of these measures are not guaranteed, especially while many science teachers lack SMK resulting from inadequate initial teacher training. A recommendation to further research is that misconceptions should be explicitly addressed in teacher training programmes. This may develop both SMK and PCK in a mutually supporting way.

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