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Student Teachers’ Competence to Transfer Strategies for Developing PCK for Electric Circuits to Another Physical Sciences Topic

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The purpose of this study was to investigate the transfer of the competence to transform content knowledge learned in electric circuits to a new topic in either chemistry or physics. The study was located in a physics methodology class with 10 pre-service teachers, who were in their final year of study. They had a 6-week-long intervention that was underpinned by making explicit the pedagogical transformation effect derived from the interactive use of five content specific knowledge components: (a) learner prior knowledge; (b) curricular saliency; (c) what is difficult to understand; (d) representation; and (e) conceptual teaching strategies. The research design employed qualitative methods for the collection and analysis of data. Primary data was collected at the end of the intervention using Content Representations (CoRe) in the topic of the intervention and another after a 6 week period in a topic of transfer. The prompts of the CoRe were adapted to reveal the five content-specific knowledge components specifically. Supplementary data, which were written descriptions by pre-service teachers of the strategies they used in engaging with a topic of transfer, were also analysed. Findings detail the successful transfer of the learned competence to transform content knowledge, particularly through formulation of Big Ideas derived from topic classification maps, identification of specific concepts likely to pose learning difficulties for learners and the simultaneous use of multilevel representations, all used collectively and interactively in new physics or chemistry topics. We discuss the implications for the further development of topic-specific PCK across science topics.

Keywords: Pedagogical transformation competence; TSPCK; pre-service teachers; electric circuits

Introduction

Learning to teach physics, perceived to be abstract and difficult to understand, is a complex process. One of the possible factors contributing to the complexity is the manner in which prospective teachers are prepared (Erinosho, 2013). There is a need to explore ways of preparing pre-service teachers, in a manner that assists them to recognize the kind of knowledge they need in achieving deep and coherent connections in their knowledge bases (Van Driel & Berry, 2012). Pedagogical Content Knowledge (PCK) has remained a valuable knowledge base recognized for assisting science pre-service teachers to learn about the complex nature of teaching (Nilsson & Loughran, 2012). PCK is widely known to be topic specific (Aydin, Friedrichsen, Bozc, & Hanuscin, 2014). In an effort to bring to sharp focus the
topic-specific nature of PCK, a new construct conceptualized from components that are content specific called Topic-specific Pedagogical Content Knowledge (TSPCK), was presented in a separate study (Mavhunga & Rollnick, 2013). TSPCK is more relevant when exploring PCK in a given topic. It describes the understanding used when teachers reason about the planning and teaching of a topic.

Studies that have explored the use of the TSPCK construct, together with other approaches that employ content-specific tools, such as Content Representations (CoRe), have been noted for the success they registered in enabling improvement in the quality of pre-service teachers’ PCK in a specified topic (Nilsson & Loughran, 2012). Common to these approaches is the distinct attention to pedagogical transformation of content knowledge in a given topic and its reflection of PCK in the topic. Despite the documented success, these approaches have been shown to be both time-consuming and conceptually demanding. This makes them difficult to replicate, topic by topic, in a teacher development programme given the constraints of time. Thus, improving the quality of pre-service teachers’ PCK across all topics in a discipline remains a major challenge, despite being a desirable objective. In this study, we propose that mastering the competence to transform content knowledge for teaching a topic enables pre-service teachers to apply this competence as a framework to develop their TSPCK in other topics. By placing greater emphasis on this competence when learning about teaching, pre-service teachers can better distinguish what they need to know and do when planning for teaching a topic. We therefore addressed the question:

To what extent are pre-service science teachers able to transfer the competence to transform content knowledge learnt in an intervention with electric circuits for the development of TSPCK in a novel Physical Science topic?

We accordingly document the pre-service teachers’ competence in developing PCK for teaching electric circuits, and then trace to what extent this competence is being used to develop PCK for teaching a variety of other physical science, e.g. chemical reaction, sound waves, etc.

Literature Review

**PCK Re-conceptualized: Its Topic-specific Nature**

Increasingly, empirical studies have shown that only certain components of the commonly cited models of PCK reveal its topic specific nature. For example, components such as ‘assessment’ in the model by Magnusson, Krajcik and Borko (1999) and ‘orientation’ in the model by Park and Oliver (2008) were found to be hidden; yet the content-specific components in these models, such as knowledge of learners, instructional strategies and representations, were found to be explicit in the teaching of various topics (e.g. Aydin et al., 2014). The idea of a multilevel PCK construct has been suggested by Veal and MacKinster (1999), who posited that PCK may be located at both disciplinary and topic levels. The difference across these two levels lies in the locus of reasoning when planning for teaching. As hinted in the introduction above, in a separate study, we re-conceptualized PCK to reveal the components that make it topic specific, and their collective power to effect transformation of content knowledge (Mavhunga & Rollnick, 2013). Our argument was based on Geddis and Wood’s (1997) assertion that transformation of content knowledge emerged from the interaction of five content specific components. These are: (a) learner prior knowledge, which includes common learner misconceptions known in a topic; (b) curricular saliency, which refers to the identification of the most important meaning of major concepts of a topic, without which understanding of the topic would be difficult for learners and also includes the knowledge to logically sequence the learning, and the knowledge of pre-concepts needed prior to teaching a topic; (c) what is difficult to understand, which refers to gate keeping concepts which are difficult to understand often because they cause conflict with previously established understanding; (d) representations, which refers to a combination of representations at macro, symbol and submicroscopic levels that may be employed to support an explanation; and, lastly (e) conceptual teaching strategies, which refers to teaching strategies derived from the considerations made from the other four components and excludes general teaching methodologies. The similarity of some the components to those mentioned by Aydin et al.
(2014) is noted. These components were regarded as constituting a construct that described PCK at a topic level, that we termed Topic Specific Pedagogical Content Knowledge. TSPCK was validated through construct validity. The explicit inclusion of the term ‘Topic-Specific’ serves to remain alert of the localised nature of the construct at a topic level. The localized nature of TSPCK has further been acknowledged more recently in the PCK consensus model (Gess-Newsome, 2015). In the model, the layer topic specific professional knowledge refers to content-specific components similar to those of TSPCK. According to Gess-Newsome (2015), these components reveal the understanding of the knowledge for teaching a topic. Hence, without establishing transfer of the ways to develop the construct, TSPCK, the development process would need to be repeated for each topic each time.

The Transfer of Pedagogical Reasoned Planning for Teaching

The identification of competencies to be taught to pre-service teachers has remained a challenge over many generations. However, competencies that have enabled in-service teachers and pre-service teachers to transfer their knowledge to different contexts of teaching have drawn our attention. According to Loughran (2002), teacher development programmes promoting reflection and sound reasoning about teaching have the distinct advantage of making the act of reflection explicit, as well as fostering the practice. Sound pedagogical reasoning is articulated by Shulman (1987) as a process of Pedagogical Reasoning and Action. According to Shulman (1987), the process comprises a cycle of activities where transformation of content knowledge is regarded as ‘the essence’ of the process. Transformation of content requires the content to be reasoned from the perspective of the kind of knowledge identified by Geddis and Wood (1997), mentioned above as TSPCK. This requires (a) a measure of understanding of both the individual components of TSPCK and (b) the ability to use them in an interactive manner, for planning to teach the topic. The success in implementing the process brings out the deep understanding of teaching the topic. A number of empirical research studies across different disciplines report a positive relationship between developed pedagogical reasoning (pedagogical transformation by inference) and classroom practices. For example, in a study of a teacher in a Reading Recovery Language Programme, following an exposure to an intervention on pedagogical reasoning, Elliot (1996) found evidence of teacher–classroom engagement beyond algorithmic practices, transforming her knowledge into ways that mediated learning for learners. In mathematics education, following a discussion on pedagogical reasoning, practising teacher conversations revealed the emergence of diverse classroom instructions that would help learners solve instructional activities (Cobb & McClain, 2011). In this study, we therefore selectively focused on the transfer of the competence to pedagogically transform content knowledge, from one topic of physics for transformation of novel physical science topics, thereby developing TSPCK in the new topic.

Methodology

The study employed a qualitative approach. It was run in a physics methodology class, with 10 pre-service final year science teachers studying towards a four-year BEd teaching qualification. The class was considered a case study, bound by the requirements of the course (Merriam, 2002). The study involved an intervention that aimed at teaching pre-service teachers how to pedagogically transform content knowledge in electric circuits. Electric circuits was selected as a topic of the intervention, because it is contained in the National Curriculum for Secondary Schools (Department of Basic Education, 2011) and therefore, the pre-service teachers were likely to encounter it during their teaching practice in schools. Two of the authors were directly involved with the planning and teaching of the implementation of the intervention and the rest formed part of a reference team. The intervention ran over a period of 6 weeks. Each week, pre-service teachers participated in three consecutive 50 minute periods.
Sequence of the Intervention

The five content-specific components of TSPCK were discussed one at a time starting with learners’ prior knowledge. Reference was made to the common learners’ misconceptions in the topic as described by Borges and Gilbert (1999). These include the misunderstanding created by referring to current as a flow of electrons through the circuit, which is commonly associated with a flow of water from a specific source. Pre-service teachers were provided with copies of this reference.

The second component discussed was that of curricular saliency. This component requires the identification of the most important meanings without which learners are less likely to understand the topic. ‘Big Ideas’ (Loughran, Berry, & Mulhall, 2006) were used as the means to identify such meaning in electric circuits. A concept classification map presenting the major subconcepts and their links was used to pictorially share a common structuring of the topic. The major concepts in the classification map were used as anchors to formulate Big Idea statements that describe their meaning. The major concepts were identified as current, potential difference and resistance. Pre-service teachers were provided an opportunity to formulate ‘Big Ideas’ based on the major concepts listed. While there is no single, specific way to formulate Big Ideas, it is nonetheless important that formulated statements reveal key understanding in a topic. According to Loughran et al. (2006), the identification of Big Ideas in a topic is considered an element of professional practice associated with the broader concept of PCK, and distinguishes it from content knowledge. The two other aspects of curricular saliency, i.e. identification of pre-concepts needed prior to discussing a particular concept and the actual sequencing of the subsequent classroom discussion, were also discussed and illustrated.

The component what is difficult to understand was discussed as the third component, identifying particular concepts that commonly pose problems for learners (Engelhardt & Beichner, 2004). Examples of such concepts include the understanding of current as a consequence of the potential difference created in a battery, and the conversion of electrical energy to heat or light as a consequence of resistance. The component on representations focused on explaining current flow from the submicroscopic explanation of a flow of electrons in a circuit. The explanation also included how electric circuit components such as bulbs and resistors in series and parallel circuits are represented symbolically. The last component of conceptual teaching strategy focused on teaching strategies that responded to the considerations made in the other four components. This component excluded general teaching strategies.

On completion of the intervention, the idea of the Content Representations (Loughran et al., 2006) was introduced as a tool to holistically collate and represent the considerations related to all of the TSPCK components. New questions were added in order to reflect all five components of the TSPCK. These are reflected in the last four rows of Table 1.

Data Collection

Two datasets were collected using the adapted CoRe in Table 1. The first set was collected at the end of the intervention using a CoRe developed for the topic of the intervention, intervention-CoRe. The second data set was collected three weeks after the intervention through a CoRe on the topic of transfer, termed transfer-CoRe. The transfer-CoRe was on various physical science topics of pre-service teachers’ own choice and completed without assistance. The reason for the open choice was to offer pre-service teachers an opportunity to demonstrate the competence to transform content knowledge in a topic other than electric circuits without the possible hindrance of poor achievement in subject matter. In both cases, the pre-service teachers completed the adapted CoRes individually over a period of a week. The completion of the CoRe at the beginning of the intervention was not possible for either topic as it was evident that pre-service teachers were struggling with various prompts of the CoRe, citing insecurities in formulating Big Ideas and lack of classroom experience to respond to prompts such as common learner misconceptions. Supplementary data were collected by requesting pre-service teachers to write a short paragraph describing resources they drew on, and the process they used to develop their transfer-CoRe.
Analysis of CoRes

Learning about teaching electric circuits

Both the intervention-CoRe and the transfer-CoRe were scored using a criterion-based TSPCK rubric (see Appendix). The purpose of the rubric was to offer a means to grade the depth of the responses which reflected the extent of engagement with the topic and the perspective of the individual TSPCK components, as well as their interactive use in responses, thus allowing comparisons between the two kinds of CoRes. The TSPCK rubric was developed and validated in a separate study (Mavhunga & Rollnick, 2013), and theoretically grounded in the TSPCK model depicting pedagogical transformation of content knowledge through the interactive influences of the five TSPCK components. Each TSPCK component is rated using a four-point scale from 1 = 'limited' to 4 = 'exemplary'. The scale used in the rubric is based on qualitative criteria similar to that used by Park and colleagues in grading PCK (Park, Jang, Chen & Jung, 2011). Each rubric category has criteria describing the extent to which a response displays a particular TSPCK component and how it is used in an interactive manner with other components.

The scoring of the responses in the CoRes was done independently by two researchers for the whole sample. Inter-rater reliability Cohen kappa coefficients of 0.93 and 0.73, for the intervention- and transfer-CoRes, respectively, were achieved prior to seeking agreement on disputes though discussion. The scores for pre-service teachers in each CoRe were averaged for each TSPCK component, and those of individual participants were also averaged to represent the overall score of each pre-service teacher. The sensitivity of the scale of the TSPCK rubric is, however, limited by the practice that fractional average scores were rounded up or down to whole numbers in order to locate the score in the appropriate qualitative category of the rubric. It is, however, important to note that, although mathematical average values are calculated, they are not a means of measuring interaction of TSPCK components with each other. However, each category of the rubric has criteria that require visible evidence of a TSPCK component interacting with others. Thus, the calculated group

Table 1. Modifications to the prompts of the CoRe to explicitly reflect TSPCK components

<table>
<thead>
<tr>
<th>Component</th>
<th>Big Idea 1</th>
<th>Big Idea 2</th>
<th>Big Idea 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>All these questions including formulation of Big Ideas are considered to be elements of the component of TSPCK called curricular saliency</td>
<td>What would you consider as Big Ideas for this topic?</td>
<td>What do you intend the learners to know about this idea?</td>
<td>Why is it important for learners to know this big idea?</td>
</tr>
<tr>
<td></td>
<td>What concepts need to be taught before teaching this big idea?</td>
<td>What else do you know about this idea (that you do not intend learners to know yet)?</td>
<td></td>
</tr>
<tr>
<td>What is difficult to understand</td>
<td>What do you consider easy or difficult in teaching this big idea? Provide reasons</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learner prior knowledge</td>
<td>What are the typical student misconceptions in this big idea?</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>How would you go about correcting them?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Representations</td>
<td>What representations would you use in your teaching strategies, and why?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conceptual teaching strategies</td>
<td>What conceptual teaching strategies would you use in teaching this big idea?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Analysis of CoRes

Learning about teaching electric circuits

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average score is used as a proxy for a measure of the overall effect of the individual component interactions. This is in line with the understanding that PCK, even at a topic level (Aydin & Boz, 2013), is not the sum of the individual components, but rather of their interactions.

Content analysis of the paragraphs of qualitative descriptions submitted with the transfer-CoRe was conducted.

**Results**

The pre-service teachers' performances from the intervention- and transfer-CoRes scores are presented in Table 2. The scores in parentheses represent those calculated for the intervention-CoRe and those for the transfer-CoRe are outside the parentheses. The numerical values represent the qualitative category scores according to the TSPCK rubric in the Appendix.

The group average scores for each TSPCK component found in the last row of Table 2 indicate the scores for the intervention-CoRe to be consistently a single category lower than those of the transfer-CoRe across all five TSPCK components. Furthermore, they are consistently of the same order, i.e. score 2, denoting a basic quality of TSPCK with the exception for the component of learner prior knowledge that has attracted a lower score of 1, a 'limited' quality of TSPCK. A similar pattern is observed with the group scores calculated for the transfer CoRe, where pre-service teachers scored at a higher and consistent score 3 across all TSPCK components, except again for the component of learner prior knowledge. Score 3 represents a 'developing' quality category of TSPCK.

The average scores for each individual found in the last column of Table 2 reveal a more holistic picture. Firstly, they confirm the better performance in the transfer-CoRe by most individuals. Only three pre-service teachers, i.e. Phala, Angela and Nomsa, achieved the same score value of 2 in both CoRes. Secondly, in the transfer-CoRe, almost half the number of pre-service teachers (John, Sipho, Duma and Sam) experienced an improvement jump of two quality categories in more than one of the TSPCK components (see shaded), and Ben reflected such a jump in a single component (shaded). Thirdly, pre-service teachers experienced the greatest improvement with the TSPCK component of representations. Four pre-service teachers experienced two quality category improvements in this component, followed by components curricular saliency and learner prior knowledge in a tie with two participants each. Lastly, the component of learner prior knowledge in contrast to the other components registered cases where pre-service teachers' performance remained at the lowest score of 1 across both CoRes. This observation makes the component an interesting case as it became consistently the component in which pre-service teachers performed poorly as a group despite the observed individual improvements. Two pre-service teachers, Phala and Angela, appeared to have had challenges with the component of what is difficult.

**Evidence of Transfer of the Ability to Develop TSPCK to the Chosen Topic**

In order to show pre-service teachers' abilities to transfer the competence to transform content knowledge, we chose to display extracts from TSPCK components that were visibly posing a challenge during the intervention and also from those that introduced a distinct new element to consider in their considerations. These include particularly (a) curricular saliency, (b) learner prior knowledge, (c) what is difficult to understand and (d) representation. Below are examples of the achievement pre-service teachers made in these aspects and more.

**Curricular saliency**

Below is an extract from John’s well formulated ‘Big Ideas’ on chemical bonding derived from the use of a concept map, which is shown in Figure 1.

Big Idea 1: Different types of bond differ through the way electrons are distributed between the bonding atoms

Big Idea 2: Intermolecular bonds affect physical properties of substances

Big Idea 3: Bond strength is influenced by electronegativity and multiplicity of bond between bonding atoms
Table 2. Scores for the Intervention CoRe and Transfer CoRe (various topics)

<table>
<thead>
<tr>
<th>Pre-service teachers</th>
<th>Topic of transfer</th>
<th>Curricular Saliency</th>
<th>Learner prior knowledge</th>
<th>What is difficult to understand</th>
<th>Representations</th>
<th>Conceptual teaching strategies</th>
<th>Average score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nozi</td>
<td>Chemical reactions</td>
<td>(3)4</td>
<td>(2)3</td>
<td>(3)4</td>
<td>(3)4</td>
<td>(3)4</td>
<td>(3)4</td>
</tr>
<tr>
<td>Phala</td>
<td>Light</td>
<td>(4)4</td>
<td>(1)1</td>
<td>(4)2</td>
<td>(1)2</td>
<td>(2)2</td>
<td>(2)2</td>
</tr>
<tr>
<td>John</td>
<td>Chemical bonds</td>
<td>(2)4</td>
<td>(3)3</td>
<td>(2)3</td>
<td>(2)4</td>
<td>(3)3</td>
<td>(2)3</td>
</tr>
<tr>
<td>Angela</td>
<td>Chemical bonds</td>
<td>(2)3</td>
<td>(1)2</td>
<td>(2)1</td>
<td>(2)3</td>
<td>(2)3</td>
<td>(2)3</td>
</tr>
<tr>
<td>Sipho</td>
<td>Kinetic theory</td>
<td>(2)3</td>
<td>(1)3</td>
<td>(2)4</td>
<td>(2)2</td>
<td>(1)2</td>
<td>(2)3</td>
</tr>
<tr>
<td>Thami</td>
<td>Chemical bonds</td>
<td>(2)3</td>
<td>(1)2</td>
<td>(2)2</td>
<td>(2)3</td>
<td>(2)3</td>
<td>(2)3</td>
</tr>
<tr>
<td>Nomsa</td>
<td>Electromagnetism</td>
<td>(2)3</td>
<td>(1)1</td>
<td>(2)3</td>
<td>(1)2</td>
<td>(2)2</td>
<td>(2)2</td>
</tr>
<tr>
<td>Duma</td>
<td>Ideal gases</td>
<td>(2)3</td>
<td>(1)3</td>
<td>(2)3</td>
<td>(2)4</td>
<td>(1)3</td>
<td>(2)3</td>
</tr>
<tr>
<td>Ben</td>
<td>Light optics</td>
<td>(2)2</td>
<td>(1)1</td>
<td>(1)2</td>
<td>(1)3</td>
<td>(1)1</td>
<td>(1)2</td>
</tr>
<tr>
<td>Sam</td>
<td>Sound waves</td>
<td>(1)3</td>
<td>(1)2</td>
<td>(2)3</td>
<td>(1)4</td>
<td>(1)2</td>
<td>(1)3</td>
</tr>
<tr>
<td>Average Group score per component</td>
<td></td>
<td>(2)3</td>
<td>(1)2</td>
<td>(2)3</td>
<td>(2)3</td>
<td>(2)3</td>
<td>(2)3</td>
</tr>
</tbody>
</table>

Note: bold values represent cases where pre-services teachers experienced at least two categories improvement.
A classification map attached as part of the description of the process he followed in completing the transfer-CoRe is provided in Figure 1, where Big Ideas are linked to the identified major concepts. For example, Big Idea 1 is linked to the concept of intramolecular bonds even though the word is not used in the statement of Big Ideas above, Big Idea 2 to intermolecular bonds and Big Idea 3 to bond strength. While during the intervention the use of a concept map was discussed, pre-service teachers provided classification maps with no interconnecting notes between major concepts and subordinate concepts as seen in John’s and Nozi’s extracts (Figures 1 and 2).

Another example where the process of formulating Big Ideas was linked clearly to a classification map, a strategy introduced in the intervention, is the effort by Nozi in the topic of chemical reactions.

**Big Idea 1:** Chemical reactions require absorption of energy to break bonds and its release in the formation of new ones

**Big Idea 2:** Chemical reactions are reversible when in a closed system

**Big Idea 3:** Chemical reactions lead to the formation of new products with different chemical properties from the products [sic] reactants.

**Learner prior knowledge**

The extract below presents an example of the level of engagement demonstrated by Angela in the topic of chemical bonds with respect to common learner misconception. The extract is to be read against the recall of the verbal concern expressed by pre-service teachers at the beginning of the intervention at their inability to respond to the prompts of the CoRe, that knowledge of common learner misconceptions comes with classroom practice, which they lacked. In the intervention

![Figure 1](image1.png)

**Figure 1.** An extract of John’s classification map used in formulating Big Ideas

![Figure 2](image2.png)

**Figure 2.** An extract of Nozi’s classification map used in formulating Big Ideas
they learned explicitly how to access such knowledge, now demonstrated in a new topic—a transfer topic.

Students do not understand covalent bonding correctly, so they just think that atoms share their valence electrons to get an octet. I will show them that the octet rule is just a rule which does not hold all the time. Giving them examples of molecules such as H₂ will help establishing that atoms bond for reasons of reaching stability rather than complying to an octet rule.

What is difficult to understand
The extracts in Figure 3 reflect the attempt to identify what learners may find difficult to understand in the different topics. Knowledge on this TSPCK component was similarly explained explicitly in the intervention, however with a different topic. In the transfer topic, pre-service teachers had to identify it unaided.

Representations
The extracts in Figure 4 are from the component of representation, showing choices of representations by pre-service teachers Sam and Duma for sound waves and ideal gas laws, respectively. The effort to simultaneously use representations at different levels (macro, symbolic and submicroscopic) to interpret a concept is noted from the extracts.

Discussion
The purpose of this study was to investigate the extent to which the competence to develop TSPCK learned in the intervention with electric circuit is transferred for the development of TSPCK in a new chemistry or physics topic. Three major points emerge from the findings. The first point is that pre-service teachers consistently demonstrate a higher performance in the TSPCK components in the topic of choice, which we linked to transfer. Secondly, certain components of TSPCK appeared to be more accessible than others. Lastly, as with the development of PCK (Halim & Meerah, 2002), the role of content knowledge was noted as essential but not enough to facilitate transfer of the competence to transform content knowledge. We discuss each finding in detail below.

TSPCK Quality Improvement in the Topic of Choice Linked to Transfer
The process used in the intervention to formulate Big Ideas required first the development of a concept map as an initial way to structure the topic into its major concepts, from which statements describing the most important learning to be achieved could be derived. Pre-service teachers’ descriptions of the process followed in completing the transfer-CoRe indicate cases where they followed a similar process as in the intervention. An example that illustrates this point is John’s and Nozi’s work, shown above; as in the intervention, they relied on using some kind of a classification map that distinguishes major and subordinate concepts pictorially. The use of a classification map, like a concept map, in this manner was a distinct feature of the intervention. It was purposefully formulated to assist pre-service teachers.
with a teacher task considered difficult and often conducted by practising teachers in a group (Loughran et al., 2006). The higher scores in the component of curricular saliency in the topic of transfer are linked to the success of applying this particular strategy to the new topic of choice. This observation indicates how pre-service teacher transferred a distinct strategy for formulating Big Ideas from the intervention and used it in a new topic. Another example that illustrates successful development of the TSPCK in the topic of transfer as a result of the intervention is the demonstrated efforts in the TSPCK component of representations. It is common knowledge that there is value in using representations to support learning (Boone, Staver, & Yale, 2014). The intervention promoted specifically the simultaneous use of multiple levels of representations to support an explanation of a particular concept. This understanding is demonstrated in the choice of representations shown in the example extracts of Sam in a physics topic (sound waves) and Duma in a chemistry topic (ideal gas laws). The observation is powerful given that the pre-service teachers retrieved these representations from the internet—a resource that has a plethora of alternative representations to choose from. Pre-service teachers demonstrated an eye for representations that have most relevance for learner understanding. This means that they valued the distinct strategy learned in the intervention for using representations in this manner, and their successful effort improved their quality scores in this component. Similar success is observed on other TSPCK components as shown by the extracts on the components what is difficult to understand and learner prior knowledge. The extracts of John, Nozi and Sam reflect an ability to identify specific areas in a new topic that may potentially pose learner difficulty. The ability to identify the specific concepts rather than relegating the anticipated difficulty to broad reasons like ‘the concept is abstract’ reflects a developed insight into the topic from a learner’s perspective. Given that such understanding was explicitly discussed in the intervention, and pre-service teachers openly linked their struggle with TSPCK components earlier in the intervention to their lack of classroom experience, it is reasonable to link their improved performance in the topic of choice to learning in the intervention.

Accessibility of TSPCK Components
The second finding is revealed by the average scores across the components of TSPCK. Certain components of TSPCK appeared to have been easier to engage with, as seen in Table 2 by the number of pre-service teachers who demonstrated more than one quality category improvement. These components are representations, curricular saliency and learner prior knowledge. The component of
representations appeared more accessible over and above others as it registered a higher number (3) of pre-service teachers who demonstrated a multicategory improvement. It was also a component with a higher frequency of pre-service teachers scoring the exemplary quality category, denoted by a score of 4, indicating a high recognition of the value of using multiple level representations in explanations.

The component of learner prior knowledge is however interesting as it is the only component where some (Phala, Nomsa and Ben) pre-service teachers consistently scored a very low score of 1 in both CoRes, denoting a limited quality of engagement. As pre-service teachers are expected to have limited classroom experience (where knowledge about common learner misconceptions could be acquired), they were expected to develop such knowledge from the intervention. More specifically, they were made aware that knowledge of learner prior knowledge may be accessed from research reports rather than from textbooks. However, their low scores in this component in both CoRes indicate that such realization did not occur for them, and this lowered the averaged group score in this component. Nonetheless, the emergence of representations and curricular saliency (including learner prior knowledge) as TSPCK components where individual pre-service teachers demonstrated most exemplary success confirms the observation elsewhere that these components especially reveal the topic-specific nature of PCK (Aydin et al., 2014). In this study, these components have emerged as being more enabling when transfer of the competence to transform content knowledge from one topic into another is attempted.

The Role of Content Knowledge in Transferring the Ability to Develop TSPCK

The final point is the role of content knowledge in the successful transfer of the learned competence. The prominent role of content knowledge in the development of PCK is well documented in the literature (e.g. Magnusson et al., 1999). The findings in this study confirm this role from a perspective of transferring the competence to transform content knowledge. While the study was limited in the sense that no measurements were taken for understanding of content knowledge in electric circuits and in the various transfer topics, the findings suggest that a topic of choice facilitated the transfer of the learned competence. This could be because of good understanding of content knowledge in the topic, or simply because of liking the topic. Exemplary cases are the individual performances of pre-service teachers Sam and Duma, who scored poorly across all the TSPCK components in the topic of the intervention but demonstrated an improvement in all components for the topic of choice. However, the observed counterproductive performance of Angela and Phala, who experience a decrease in score in the component of what is difficult to understand, in the topic of their choice is an indicator revealing that their knowledge of the topic content, or even their liking of the topic of choice, was not enough to transfer their ability to develop TSPCK. Thus it is unlikely that the improved performance in TSPCK in the topic of choice is solely due to participants’ strong content knowledge, nor to the participants’ pre-existing quality of TSPCK, as they have had little opportunity or need to consider developing TSPCK for any of the topics chosen. Therefore, it is most likely that the superior TSPCK is a result of their learning from the intervention, and the increased familiarity with the CoRe instrument which has been applied to the chosen topic.

Conclusion

The present study has shown how the intervention assisted pre-service teachers to transfer the competence to transform content knowledge learned in electric circuits to an extent of developing TSPCK in another chemistry or physics topic. The findings, however, should be interpreted mindful of the limitations of this study which include the absence of a completed CoRe in the topic of transfer before the intervention. However, distinct features of the intervention like the use of some form of a classification map as a step towards formulating Big Ideas and the emphasis of the simultaneous use of representations at different levels were shown to be explicitly applied with the topic of transfer. These strategies are tools pre-service teachers fell back on whilst navigating their thinking through a new topic. By focusing the attention of pre-service teachers on the competence to transform content knowledge, which according to Shulman (1987) is the essence of sound reasoning about teaching, pre-service
teachers demonstrated transfer of this competence into reasoning through other topics. This transfer has implications in offering a possible route to empower pre-service teachers to continuously development their TSPCK across various topics without the dependence on explicit topic-specific teaching within their teacher development programme.

Note

1. Physical Science is a term used in South African schools to refer to a school subject that incorporates chemistry and physics as two equal components.

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References


## Appendix: Topic-specific Pedagogical Content Knowledge (TSPCK) Rubric

<table>
<thead>
<tr>
<th>Learner Prior Knowledge</th>
<th>Limited (1)</th>
<th>(2) Basic</th>
<th>(3) Developing</th>
<th>Exemplary (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No identification/No acknowledgement/No consideration of student prior knowledge or misconceptions</td>
<td>• Identifies misconception or prior knowledge</td>
<td>• Identifies misconception or prior knowledge</td>
<td>• Identifies misconception or prior knowledge</td>
<td>• Identifies misconception or prior knowledge</td>
</tr>
<tr>
<td>No attempt to address the misconception.</td>
<td>• Provides standardized definition as a means to counteract the misconception</td>
<td>• Provides standardized knowledge as definition</td>
<td>• Provides standardized knowledge as definition</td>
<td>• Provides standardized knowledge as definition</td>
</tr>
<tr>
<td></td>
<td>• No evidence of drawing on other TSPCK components.</td>
<td>• Expands and re-phrase explanation using one other component of TSPCK interactively.</td>
<td>• Expands and re-phrase explanation correctly</td>
<td>• Expands and re-phrase explanation correctly</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Curriculum Saliency</th>
<th>Limited (1)</th>
<th>(2) Basic</th>
<th>(3) Developing</th>
<th>Exemplary (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identified concepts are a mix of Big Ideas and subordinate ideas</td>
<td>• Identifies at least 3 Big Ideas</td>
<td>• Identifies at least 3 Big Ideas</td>
<td>• Identifies at least 3 Big Ideas</td>
<td>• Identifies at least 3 Big Ideas</td>
</tr>
<tr>
<td>Identified pre-concepts are far from topic</td>
<td>• Not all 3 Big ideas subordinate concepts identified</td>
<td>• Subordinate concepts correctly identified for all Big Ideas</td>
<td>• Subordinate concepts correctly identified for all Big Ideas</td>
<td>• Subordinate concepts correctly identified for all Big Ideas</td>
</tr>
<tr>
<td>Sequencing no value due to mixed concepts</td>
<td>• Suggested sequencing has one or two illogical placing of Big Ideas.</td>
<td>• Provides logical sequence</td>
<td>• Provides logical sequence</td>
<td>• Provides logical sequence</td>
</tr>
<tr>
<td>Reasons given are generic - benefit of education.</td>
<td>• Identified pre-concepts are far from the current topic</td>
<td>• Identifies pre-concepts relevant to the topic</td>
<td>• Identifies pre-concepts relevant to the current topic and with logical reasons</td>
<td>• Identifies pre-concepts relevant to the current topic and with logical reasons</td>
</tr>
<tr>
<td></td>
<td>• Reasons exclude conceptual considerations and show no evidence of drawing on other TSPCK components.</td>
<td>• Reasons given for importance of topic include reference to conceptual scaffolding/sequential development drawn on one other TSPCK components e.g. what makes topic difficult.</td>
<td>• Reasons include conceptual scaffolding with reference to other TSPCK components</td>
<td>• Reasons include conceptual scaffolding with reference to other TSPCK components</td>
</tr>
<tr>
<td>What makes topic difficult</td>
<td>Identifies broad topics without reasons and specifying the actual sub-concepts that are problematic.</td>
<td>Identifies specific concepts but provides broad generic reasons such as ‘abstract’.</td>
<td>Identifies specific concepts leading to learner difficulty. Reasons given relate to one other TSPCK components.</td>
<td>Identifies specific concepts with reasons linking to specific gatekeeping concepts and to TSPCK components such as prior knowledge and aspects of curricular saliency.</td>
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<tr>
<td>Representations</td>
<td>Limited to use of only macroscopic analogies, demos, etc.) representation with no explanation of specific links to the concepts represented</td>
<td>Use of macroscopic representation (analogies, demos, etc.) and use of scientific symbolic representation without explanatory notes to make the links to the aspects of the concept being explained.</td>
<td>Use of macroscopic representation and use of scientific symbolic representation with explanatory notes linking the two representation to the aspect(s) of the concept being explained.</td>
<td>Use of macroscopic representation or symbolic representation with sub-microscopic representation to enforce a specific aspect. Explicit link to other components of TSPCK e.g. emphasis of core aspect of CK demonstrated in the representations and learner prior knowledge.</td>
</tr>
<tr>
<td>Teaching Strategies</td>
<td>No evidence of acknowledgement of student prior knowledge and misconceptions.</td>
<td>Acknowledges student misconceptions verbally with no corresponding confrontation strategy.</td>
<td>Considers confirmation/confrontation of student prior knowledge and/or misconceptions.</td>
<td>Considers student prior knowledge and evidence of confrontation of misconceptions.</td>
</tr>
<tr>
<td></td>
<td>Lacks aspects of curriculum saliency.</td>
<td>Lacks aspects of curriculum saliency.</td>
<td>Considers at least one aspect related to curriculum saliency e.g. sequencing, what not to discuss yet or emphasis of important concepts.</td>
<td>Considers at least two aspects related to curriculum saliency: sequencing, what not to discuss yet, emphasis of important conceptual aspects, etc.</td>
</tr>
<tr>
<td></td>
<td>Use of representations limited to macroscopic or symbolic scientific symbolic representation.</td>
<td>Use of macroscopic and symbolic representations with no linking explanatory notes.</td>
<td>Uses at least two different levels of representations to enforce understanding.</td>
<td>Uses either the macroscopic or symbolic representation with sub-microscopic representation to enforce understanding.</td>
</tr>
</tbody>
</table>