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9. IMPLEMENTING PCK TOPIC BY TOPIC IN METHODOLOGY COURSES

A Case Study in South Africa

INTRODUCTION

The history of South Africa presents a story of a divided education system with policies deliberately designed for disparity in the quality of provision. Prior to 1994, education policy in the country was used to constrain political, social, and economic development of people of colour, who are in the majority. Twenty years on, the widespread after-effects of this segregated education policy continue to trouble the present society from all quarters. For science education, the effect manifests as under-performance evidenced in both international studies and local research. Spaull (2013) points particularly to a weakness in South African teachers in relation to content knowledge. His findings are no surprise, as the majority route for the training of black high school science teachers in the apartheid era was through primarily rural teacher training colleges with few resources. These colleges offered three-year post-school diplomas delivered primarily through transmission teaching. Science and mathematics education researchers argue that improvement in education lies at the heart of teacher development, and furthermore with the teacher education system that produced new teachers (Taylor, 2015). As part of the post-democracy reforms in education, the teacher education system was radically re-organized, entailing the closing of most teacher training colleges. The remainder were merged with higher education institutions (HEIs), thereby making initial teacher education (ITE) the responsibility of HEIs only and turning teaching into an all-graduate profession.

Today, three pathways are possible routes to access for initial teaching that leads to a qualified teacher status: (i) a four-year Bachelor of Education degree (BEd), (ii) a three-year undergraduate Bachelor degree capped by a one year professionally-focused Post Graduate Certificate in Education (PGCE) and (iii) A technical Diploma capped by a professionally focused Advanced Diploma in Teaching which exits at a slightly lower level to graduate status, being that of a diploma. This third option is limited to vocational based programmes. The BEd degree and the PGCE are most appropriately located at a degree level. According to the national policy on Minimum Requirements for Teacher Education Qualifications (MRTEQ) (Department of Higher Education and Training, 2015), the primary purpose of all ITE

A. J. Sickel & S. B. Witzig (Eds.), Designing and Teaching the Secondary Science Methods Course, 149–170.

qualifications is to certify that the holder has specialised knowledge as a beginning teacher in a specific phase (grade level) and/or subject. This specialisation can take one or more of a variety of forms, all of which are associated with competence in subject matter knowledge. Specialisation can be linked to a phase (for example, the Foundation Phase – grades 1–3), a subject (for example, Mathematics or English), or a combination thereof. The BEd is designed to include 480 credits, usually studied over 4 years of full-time study. The PGCE is usually studied over one year of full time study and follows a general degree that includes the study of subjects that provide sufficient disciplinary learning.

As mentioned above, the national policy (Department of Higher Education and Training, 2015) calls for the development of teachers in areas of specialization. To this end, students at institutions of Higher Education, nationally, are thus registered according to their desired school phase or combinations of specialization. A school phase refers to a level in our school system hierarchy that is comprised of three successive school grades/academic years. The options available are: (i) BEd in Foundation Phase Teaching (this refers to the first four Grades of the South African schooling system, which are Grades R[1], 1, 2, and 3); (ii) BEd in Senior Primary Phase Teaching (school Grades 4-6). The Senior Primary Phase is also referred to as *Intermediate Phase* and this is the phrase used in the discussion below; (iii) BEd in Senior Phase (school Grades 7–9); and (iv) Further Education Training (FET) Teaching (school Grades 10–12). In the South African context, largely, a primary school offers Grades in the Foundation and Intermediate phases and a Secondary school offers Grades in the Senior and FET Phases. Variation from this norm occurs with schools called Intermediate schools which may offer Grades in the Intermediate phase only.

Within each phase, pre-service teachers are encouraged to take a major course in a discipline of specialization and a second sub-major course which may be in a different or same discipline of specialization. According to the national policy, the delivery of learning within each phase is to contain a knowledge mix in three categories: the first category is *disciplinary learning*, which refers to the study of education and its foundations, and the development of specialised subject matter knowledge. For FET and Senior Phase teaching this must be in the disciplines that underpin the school subject to be taught. The second category is the *Pedagogical Learning*, which includes general pedagogical knowledge and the bulk being allocated to Pedagogical Content Knowledge (PCK) for the specific subject of specialisation(s). The third category is *Practical Learning* or school-based work, which is supervised and assessed as a teaching practice. Pre-service teachers within a phase are required to be exposed to school-based supervised experience for a minimum of 16 weeks and a maximum of 24 weeks over the four years of the degree. In any given year, a maximum of 10 weeks should be spent in schools and at least three of these should be consecutive. In practice this translates to two 3-week periods spent in school in every semester.

Methodology Courses in Secondary School Science Education

Our institution offers two streams of science education courses for the BEd degree for teaching in Secondary Schools. These are: the life science and the physical science education options. The physical science education stream combines the chemistry and physics domains of the science discipline as these domains appear as a joint subject in the South African secondary school curriculum, where the two components are given equal weight and thus are taught as such in schools. Pre-service teachers are able to choose either stream at the third year of their study and continue to graduate in the chosen subject as a major in the fourth and the final year of the degree. They are also required to choose a second school subject as a sub-major. A major subject would be a subject taken to the fourth year of study and a sub-major a subject taken to a maximum of third year of study. Our institution offers options to take the sub-major in a different discipline, such as mathematics, or in the same discipline, such as life or physical science, by running two versions of third year courses in each of these subjects, respectively. For example, a student may have life science or a physical science as a major combined with mathematics as a sub-major; alternatively, a pre-service teacher may have life science or physical science each as both a major and sub-major.

All students who register for the BEd degree for teaching in Secondary Schools take a course called *Natural Science* in their first two years of the degree. This course reflects the content of its namesake in the Senior Phase school curriculum, as it comprises content in chemistry, physics, life science and earth science in equal proportions. The course is geared to prepare pre-service teachers to also teach the three school Grades of the Senior Phase, a Phase that precedes the three Grades in the final FET phase. Thus, a graduate teacher from the life or physical science stream, when employed in a Secondary school, will be able to teach classes in both the Senior and the FET Phases.

The delivery of the degree is such that the subject content knowledge and the pedagogy/methodology courses run in parallel. There is a methodology course for each academic year. Overall, a pre-service teacher would be exposed to a total of five methodology courses over the four years of study: two Natural Science methodology courses in the first two years of study, two methodology courses in the major subject across years three and four and one methodology course in the sub-major subject in year three. Each of the methodology courses has two semesters in a year. A semester is made out of 36 hours of teaching spread over 12 weeks. Each week has three periods of just under one hour each for teaching. Integration across the content and the methodology courses is achieved by deliberate planning such that the discussion in the methodology courses is simultaneously based on topics that are taught in the content course. This alignment is sometimes not possible; in such cases, a topic that was previously taught, in the previous academic year, may be chosen. The school-based practical experience is an integral component of the BEd degree allocated

6 weeks in each academic year. Three consecutive weeks are allocated in the first semester, while the second set of consecutive weeks is used in the second semester.

PLANNING: DISCUSSION OF COURSE DESIGN

The importance of preparing preservice teachers to teach effectively is shared worldwide (Osman, 2010). However, for a country like South Africa, where the education system is adversely affected by the policies of the past, there is a moral obligation to continually scrutinize the nature of the curriculum offered to Initial Teacher Education (ITE); firstly to guard against a repeat of the past and also to seize the opportunity rendered by the present curriculum to offer quality ITE as a potential means of addressing the historical crisis (Osman, 2010; Rusznyak, 2015). Given the concerns about subject matter knowledge highlighted above, the consideration of the value of Pedagogical Content Knowledge (PCK) for science education as the knowledge that ought to be taught to pre-service teachers was most attractive as a starting point for our courses. PCK has been the subject of discussion by many science education scholars since Shulman's (1986) introduction of the theoretical construct (e.g. Aydin et al., 2015; van Driel, Verloop, & de Vos, 1998). From a learning to teach perspective, the understanding of Pedagogical Content Knowledge as topic-specific (Rollnick & Mavhunga, 2015) has provided a framework from which we have designed our methodology courses. In addition, the recognition of the construct as part of Pedagogical Learning, cited in our newly revised national policy on teacher development – the MRTEQ, has given a much appreciated renewed emphasis on what is to be learned by prospective teachers with an improved alignment to the science education research literature.

Purpose and Outcomes

The purpose of our science methodology courses is to develop a specific depth and specialisation of knowledge, together with practical skills that comprise a professional teacher competence for teaching core topics in a specified science discipline, (Life Science, Physical Science or Natural Science). Given the time constraint in the methodology courses, it is not possible to use all topics in a discipline as examples when developing the competence to teach. Thus, we have adopted a strategy where two to three core topics in a discipline are selected. By core topics we mean those topics that encompass several sub-concepts that link to other topics more explicitly. For example, in chemistry, stoichiometry is fundamental to the successful understanding of many different types of chemical reactions such as redox. Also, the core topics are contained as school topics in the school curriculum. Linked to this purpose are three major outcomes, producing graduate science teachers who have:

- Specialized PCK knowledge in core topics in the discipline of Natural Science and that of their major stream.
- An understanding that teaching is about transformation of their comprehension of concepts and a belief that learners are central in their planning and choice of pedagogical approaches.
- Knowledge of how to pedagogically transform comprehended knowledge when engaged in planning and teaching a new topic.

Our methodology courses are heavily based on PCK. Central to the theoretical framework of PCK used in our courses is the idea of transformation of content knowledge in specific topics (Geddis, Onslow, Beynon, & Oesch, 1993). We have conceptualized PCK at a topic level as the knowledge to transform topic concepts into versions that are accessible for understanding by a learner. This pedagogical transformation of content emerges from thinking about the topic from the perspective of (i) Learner prior knowledge, including misconceptions, (ii) Curricular saliency, (iii) Knowledge of what is potentially difficult to learners, (iv) Representations and (v) Knowledge of topic-specific conceptual teaching strategies. These five content-specific components are regarded as a framework that could be applied to any topic to achieve pedagogical transformation of its concepts. Unpacking the construct of PCK in this manner has offered us a tool that has been used to assist pre-service teachers with understanding the construct one topic at a time, and also learn a framework to apply to new topics that may not have been covered explicitly in ITE or that may also be a result of curriculum changes once in practice. PCK acquired through the use of this framework has been termed Topic Specific Pedagogical Content Knowledge (TSPCK); more specifically referred to as espoused TSPCK at a planning level and then enacted TSPCK when pre-service teachers are afforded teaching opportunities in schools as part of the ITE. The implementation of the construct of TSPCK in our methodology course enables pre-service teachers' development of discipline specialization (referred to at a national policy level by the MRTEQ as *Disciplinary Learning*) which includes the study of specific specialised subject matter relevant to academic disciplines underpinning teaching subjects.

Implementation of TSPCK in the Early Stages of the BEd Degree in Natural Sciences

While the value of the implementation of PCK, particularly TSPCK, in science ITE has been received positively by the science education community (Rollnick & Mavhunga, 2015), implementation of the construct with pre-service teachers, particularly in the early stages of their study, remains a challenge for a number of reasons. First, as mentioned previously, pre-service teachers come to the methods courses with disparate backgrounds in terms of their content knowledge, which is largely poor given the South African context. Second, teacher educators generally do

not have time to model lessons related to every core curriculum topic in which they could demonstrate best practices (Grossman, 2011).

In the first year methodology course, PCK is introduced in a very broad way. What is emphasized at this level is the fact that PCK is the knowledge that bridges content knowledge and ways of teaching it. Also introduced at this level is the pedagogical reasoning process as suggested by Shulman (1987). In the second year, the pre-service teachers start to look at their development of the construct in selected Natural Science topics. Two topics are used; chemical bonding and cell structure and function. Both topics are included in the school curriculum for Natural Science.

In order to bring the topic-specific nature of PCK to the fore, only three of the five content specific components of the TSPCK framework are used (Mavhunga & Rollnick, 2013). These are (i) Learner prior knowledge, (ii) Curricular saliency and (iii) Representations that are specific to the topic. These three content-specific components were chosen as they are reported to reveal the topic-specific nature of PCK more visibly than others in studies that have a focus on science teachers' topic-specific PCK (e.g. Aydin et al., 2015; Aydin, Friedrichsen, Bozc, & Hanuscin, 2014). The components are discussed one at a time. For an example, the discussion on the component of Learner Prior Knowledge in Chemical Bonding focusses on common misconceptions of the topic, such as the adoption of a molecular framework for explaning ionic bonding. Beginning pre-service teachers are provided with research articles explicitly discussing misconceptions in the topic (e.g. Tan & Treagust, 1999). In this approach, content found lacking is explicitly discussed as the opportunity arises.

To sum up, in the first year of the BEd degree, PCK is first introduced as a broad concept relying mostly on the definition from Shulman (1986), and the process of pedagogical reasoning and action (Shulman, 1987). In the second year, the topic-specific nature of PCK is introduced. Pre-service teachers begin to develop PCK in core topics by explicitly developing their understanding of the topic from a perspective of three selected content specific components and how considerations from these components interact in formulating teaching plans. In the both the first and the second year methodology courses, discussion on PCK takes up 80% of the course content. The importance of observation and reflection as well as class management are also discussed in the first and second year of study, respectively. These topics are introduced to start preparing pre-service teachers for school teaching experience where they observe teaching by expert teachers in the first year and start to handle actual teaching in the second year.

Implementation of TSPCK in the Science Major Streams in the last two years of the BEd Degree

The science education methodology courses in the last two years of the BEd degree are geared at preparing students for specialization in either the Life Science or the Physical Science stream and relate to the FET curriculum (grades 10–12) in Secondary schools. They are characterized by a strong focus on developing TSPCK

in core topics of the Secondary school curriculum. At the beginning of the year, the understanding that PCK is topic specific is re-visited and the definition of TSPCK as a construct defining the topic specific nature of PCK is made explicit. All five components of TSPCK are emphasized at this stage of the programme. Clarity is also given that the aim is not only to think about a topic from the perspective of the components but equally important is recognition on how the components interact with each other. Pre-service teachers must develop the capability to demonstrate such interactions in lesson planning and eventually in classroom practice during school teaching experience. The topics used in the third and fourth year methodology courses are determined largely by two factors. Firstly, that they should have been covered in the separate, parallel content course or they are covered at about the same time as they are discussed in the methodology course. Secondly, that they are in the secondary school curriculum. Often, a discussion will ensue between the educators of the content and the methodology courses, or in other cases the same educator is teaching both the content and the corresponding methodology course. Typical content topics used to develop TSPCK include: Meiosis, Mitosis, Embryology and Circulatory systems (life science stream); and Chemical Equilibrium, Electrochemistry, Organic Chemistry, Stoichiometry, Kinematics, Electric Circuits and Electrostatics (physical science stream). In each of the senior academic years (3rd and 4th year), pre-service teachers would experience a discussion of TSPCK at least in two topics in a given domain (i.e. two topics in Chemistry, in Physics, and in Life Science) according to the major they have chosen. One of the topics would have been discussed explicitly in detail over a long time (six weeks), and the second topic used for summative assessment. Additional topics related to other pedagogical knowledge aspects of education such as inquiry in science, assessment in science, practical work, and class management are discussed over the last six weeks of a semester following a detailed discussion on TSPCK. Discussion of general pedagogy occurs at the end of the semester because pre-service teachers are being prepared for a school teaching experience just before the semester ends.

In summary, the science education methodology courses in the 3rd and 4th years of the BEd degree programme have an explict foucs on developing specialized professional knowledge in teaching core topics. Furthermore, the exposure to discussions on TSPCK in several topics using the same framework, provides pre-service teachers with an opportunity to develop awareness of the consistency of the framework and yet also the variety and difference in the knowledge generated. It is intended within the constraints of time in the methodology courses, that pre-service teachers would appreciate the TSPCK framework as a reference to fall back on when faced with planning and teaching for a new topic.

Strategy Behind the Assessment Used

Assessment is based on continuous, formative and summative types of assessment. As one of the outcomes of the course is to promote appreciation of TSPCK as a

possible framework to use when faced with planning and teaching a topic, assessment serves two purposes in the methodology courses. The first is to assess the extent of acquisition of TSPCK in the topic of the intervention. This is the topic that the TSPCK content specific components would have been discussed explicitly and in detail. The second purpose is to assess the extent to which pre-service teachers are able to transfer their learnt knowledge of the TSPCK framework and how the components could be used interactively to transform content of a novel topic, thus developing their TSPCK in the new topic. The tools used in each case could be a combination of specially designed instruments that measure the quality of TSPCK in the topic and/or the development of Content Representations (CoRe) (Loughran, Berry, & Mulhall, 2004) in the topic of intervention. The specially designed tool for TSPCK is a pencil and paper based instrument, which consists of tasks that would make explicit teachers' tacit TSPCK. The TSPCK test consists of five sections that correspond to the five components of TSPCK (Mavhunga & Rollnick, 2013), namely learners' prior knowledge, curricular saliency, what makes a topic easy or difficult to teach, representations and conceptual teaching strategies. Each section is considered as a test item with two to three sub-questions. The understanding of each TSPCK component and its interactions with other components are considered as windows into the quality of TSPCK. The tasks in the tool require responses from teachers that demonstrate both understanding of a component and the interaction of one or more other components. For an example, Figure 1 presents a sample test item.

The CoRe used in the course is modified from Loughran et al. (2004) to reflect explicit prompts on the five content specific components of TSPCK, as shown in Table 1.

CATEGORY D:

Le Châtelier's' Principle

Below is a student's written response in a class test designed to assess prior knowledge of students about Le Châtelier's' Principle.

Question:

What is the effect of adding more water to the reaction given below at equilibrium?

$$CH_3CO_2H(aq) + H_2O(l) \rightleftharpoons CH_3CO_2^-(aq) + H_3O^+(aq)$$

A student responded:

'More $CH_3CO_2^-$ (aq) and H_3O^+ (aq) will be formed, to counter act the effect of adding more water to the reactants. This will happen until a new equilibrium is reached'.

Following the student's response, how will you teach a lesson on predicting the effect of factors disturbing the equilibrium?

Figure 1. A sample test item from the TSPCK tool on the component of conceptual teaching strategies

Table 1. An adapted CoRe highlighting the five components of TSPCK

Curricular saliency	What do you intend the learners to know about this idea? *(original CoRe item – geared to capture subordinate concepts)*
	Why is it important for learners to know this big idea? *(original CoRe item – a potential window to observe any consideration of the other TSPCK components in the provided reasons)*
	What concepts need to be taught before teaching this big idea? *(original CoRe item – captures pre-concepts)*
	What else do you know about this idea (that you do not intend learners to know yet)? *(original CoRE item – captures what is considered peripheral)*
What is difficult to understand	What do you consider easy or difficult in teaching this big idea? Explain. *(new question added)*
Learner Prior Knowledge	What are the typical learners' misconceptions on this big idea? *(new question added)*
Representations	What representations will you use in your teaching? *(new question added)*
Conceptual teaching strategies	What conceptual strategies would you use in teaching this big idea? *(new question added)* What questions would you consider important to ask in your teaching strategy? (*adapted from original: captures teaching procedures)*
Reflections	What ways would you ascertain students' understanding *(adapted from original: captures specific ways to ascertain students' understanding*)
	What aspects of planning and teaching this big idea would you like to reflect on *(original CoRe item)?*

Table 1 shows what was added or modified to the CoRe in comparison to the original instrument. Windschitl, Thompson, and Braaten (2011) support the argument for the importance of providing novice teachers with support for effective teaching using "praxis tools". According to the authors, praxis tools embed theory about effective teaching into material resources or strategies that guide the planning and teaching process. The value of the CoRe in capturing and guiding the thinking of pre-service teachers has been demonstrated through a number of studies (e.g. Bertram & Loughran, 2014; Hume & Berry, 2010). On the other hand, the specially designed TSPCK tools for specific topics has been useful in developing insights into how pre-service teachers reason about a topic from an angle of the individual content components of TSPCK and in their interactive use. This has been an area of

our research interest; providing an opportunity to explore the nature of TSPCK and its acquisition in ITE.

CLASSROOM PRACTICE: VIGNETTE OF A SIGNATURE TEACHER EDUCATION LESSON

A Lesson on TSPCK in a Second Year Methodology Class: The Component of Learner Prior Knowledge

As mentioned above, the discussions on TSPCK in a topic at this level are based on explicit discussion of three components of TSPCK. Each of the components are delivered over 2 weeks, where each week is comprised of a single period of 1 hour traditional lecture and a double period of 2 hours interactive tutorial time. The structure allows time for pre-service teachers to try out activities and receive valuable feedback. The traditional lecture is a combination of the lecturer providing information and some whole-group discussion, although the lecture is not as interactive as the tutorial sessions. Prior to the discussion, the theoretical construct of TSPCK is introduced. Reference is made to how it differs from the broader PCK construct at a discipline level, thus the importance of working within a specific topic (chemical bonding in this case) is noted. TSPCK is defined as having five content specific components, and these are named. Pre-service teachers are then made aware that only three of the components will be discussed explicitly while the other two are discussed implicity. The first component, *Learner Prior Knowledge,* is introduced. The component is explained as referring to knowledge about the topic that learners carry, including common misconceptions. A few examples of common misconceptions about chemical and bonding are discussed. These include, for example, the adoption of a molecular framework for explaning ionic bonding, and the misconception that atoms form bonds to satisfy the octet rule. In this approach, content found lacking is included and discussed as the opportunity arises, including suggestions for improving both pre-service teachers' and learners' understandings. This arena for discussing pre-service teachers' own misconceptions has proved to be a powerful mechanism for addressing challenges in pre-service teachers' content knowledge in the context of pedagogy (Friedrichsen, Van Driel, & Abell, 2011). The value of understanding a topic from the perspective of common misconceptions as a future teacher is discussed. We then discuss with pre-service teachers how they can learn about common misconceptions of a topic, since they have not necessarily been exposed to classroom practice. Pre-service teachers are pointed to research articles and discussion with expert teachers. Pre-service teachers are then provided with research articles explicitly addressing misconceptions in the topic (e.g. Tan & Treagust, 1999), and a set of tutorial questions that require them to identify a few more common misconceptions and suggestions for overcoming them, which is then discussed in a tutorial session.

The second component, *Curricular Saliency*, is introduced as knowedge that assists in developing a structural overview of a topic. This component has three features that are used to unpack and re-pack the structure of a topic. These are: (i) Identification of the most important meaning that, without it, learners would not develop adequate understanding of the content matter of the topic (Geddis et al., 1993). The concept of 'big ideas' is introduced as a way to identify and formulate the most important understandings. (ii) Understanding the pre-concepts needed prior to the teaching of a big idea and lastly, (iii) the sequencing of the identified big ideas. Analysing a topic from these three aspects develops pre-service teachers' understanding of curricular saliency about the topic. Pre-service teachers generally struggle with the formulation of big ideas. To help them in developing a mental picture of the topic, concept maps are introduced as a visual representation of the major and sub-major concepts of a topic. The major concepts in the topic are then used as anchors in formulating statements that express the most important understandings to be esablished about each one. Pre-concepts are identified from asking a question such as, "What concepts need to be first understood prior to teaching this big idea?" In order to establish a logical sequence for teaching big ideas, the following question is presented: "which big idea is needed in order to understand the next big idea?"

The last component, *Representation,* is introduced from the perspective of the value derived in using representations to simultaneously address different levels – macroscopic, symbolic and sub-microscopic levels in order to explain a concept (Davidowitz & Chittleborough, 2009). The pre-service teachers work in permanent tutorial groups throughout the six week period. The value of the tutorial lies in the actual struggle, the trial and error opportunity (Nilsson, 2008) afforded to pre-service teachers to plan for possible strategies to correct a particular misconception, and to formulate a big idea statement and use representations in a meaningful way. It is in the struggle and the presence of input from peers that the understanding of the topic from the perspective of learner prior knowledge is endorsed, and possible interaction of the TSPCK components emerges in the suggested correction strategies. Pre-service teachers are then required to present to the entire class how they would address a particular learner misconception in the topic. Feedback on both strong and weak aspects of the presentation from the entire class is encouraged. Due to time constraints, not all groups are able to present. Often, two to three presentations of 5 minutes each are allowed, and the session ends with a closing discusson. During this discussion, the educator explicitly provides examples of common areas of learning difficulty, which often draw interactively on considerations made from the three components of TSPCK in planning for teaching. The emphasis in the closing argument is in the explicit identification of possible component interactions emerging from the suggested strategies by pre-service teachers, and provinding more examples. Pointing out explictly the component interactions in pre-service teachers'

suggested strategies always captures the interst of the entire class. The discussion on these three components as described lasts over a period of six weeks, with three hours per week.

A Lesson with all Five Components of TSPCK in 3rd and 4th Year Methodology Classes

The structure of the methodology courses in a week is similar to that described above for the second year classes. However, unlike in the second year classes, the discussion on TSPCK in a specific topic entails the explicit discussion of all five components of TSPCK in a sequence given in Table 2 below. Thus, each component of TSPCK is allocated only a single week for discussions, with the sixth and last week used for synthesizing all the discussions and capturing them into a CoRe. Table 2 presents a lesson series for the development of TSPCK in the topic, particulate nature of matter.

Pre-service teachers are assisted to relate each component of TSPCK to the topic of particulate nature of matter. Starting with the component of learner prior knowledge, focus is placed on common learner misconceptions in the topic. These are drawn mainly from the literature. Examples discussed include the thinking that the size of atoms increases when substances are heated (Ayas, Özmen, & Çalik, 2010). The discussion of strategies to counteract this misconception include, among others, reminding learners about the properties of atoms of specific elements as classified in the Periodic Table. Thus, if atoms were to change size, it would be impossible to classify them, as they may change identity and lose their location on the Periodic Table. The component of curricular saliency, like in the second year class, is explained as referring to three aspects. These are: the most important understandings to be established in the topic expressed as big ideas; the knowledge of pre-concepts needed prior to teaching a particular big idea and the sequencing of the teaching of the identified big ideas. For example, some of the statements that could be regarded as big ideas in the topic of particulate nature of matter include: “Substances are made up of tiny particles called atoms”; “There are empty spaces between the atoms.” In order to generate big ideas, pre-service teachers were advised to first draw a concept map for the topic, where the major concepts of the map are turned into statements that demonstrate their most important meaning in the topic. For the component of ‘What is difficult to understand,’ the discussion identifies those concepts that are not necessarily misconceptions but create difficulty in understanding because of other prior knowledge. For example, learners may experience difficulty in understanding compression and expansion of air because of the empty spaces between the particles of air. The reason of this issue is because it is difficult to imagine empty spaces that are not filled by anything. The component of representations entails discussions on how representations at the macroscopic, symbolic and sub-microscopic levels are used interchangeably to support understanding of concepts in a topic. For the topic of particulate nature of matter, the use of representations showing the three

Table 2. Description of the TSPCK in particulate nature of matter intervention by component

Component	*Intervention*	*Specific examples used*
Learners' prior knowledge	Discussion on widely researched common misconceptions of the topic found in the literature. These are provided to pre-service teachers as drawn mainly from the literature. There are cases where pre-service teachers may share an experience encountered in a school-based experience.	• The misconception that the size of particles increases with increasing heat. • Phase change.
Curricular saliency	Discussion geared toward identifying the 'big ideas' and the corresponding subordinate concepts in a topic; sequencing big ideas; awareness of the foregrounding concepts, and knowing what is most important to understand in a big idea.	Big ideas: • All substances are made of tiny particles. • Particles are in constant motion. • Molecules have forces between each other. Prior knowledge needed: • Knowledge of the periodic table.
What is difficult to teach	Exploration of concepts considered difficult to learn, and pin-pointing the actual issues that make understanding difficult.	• There is an empty space between particles of matter. • There are different types of small bits of substances.
Knowledge of representations	Introduction of the three levels of explanations in chemistry at macroscopic, symbolic and sub-microscopic levels. Emphasis is placed on the power of using all three representations simultaneously in explaining a phenomenon.	• Use of a diagram simultaneously showing macro and sub-micro levels of representation of matter (see Figure 2).
Conceptual Teaching strategies	Discuss conceptual teaching strategies and how they are developed with consideration for the other four components.	• Strategically using the combination of macro, symbolic and sub-microscopic representations to illustrate different phases of matter. Paying particular attention to size of particles used to illustrate different phases ensuring they are of the same size.
Pulling it together	Introduction of Content Representations (CoRe) as a tool to capture thoughts as one thinks about content knowledge of a topic through the knowledge components of TSPCK.	• Construction of a CoRe using the big ideas listed above in the component of curricular saliency.

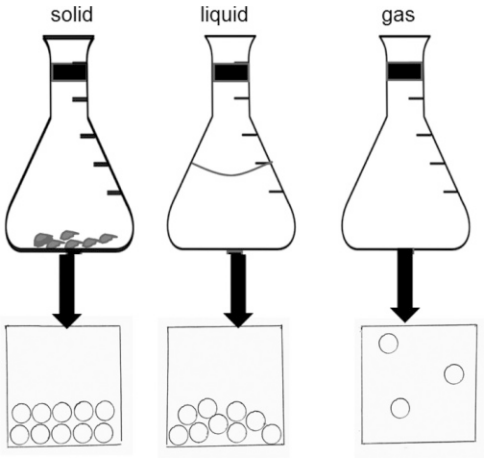

Figure 2. Representation for teaching particulate nature of matter (Rollnick & Mavhunga, 2017)

phases of matter was selected as an example on which to base the discussions (see Figure 2).

During discussions, it was shared that a common challenge in using these representations in a topic lies in how teachers tend to move from one form to another without making learners aware of the difference. Another issue is that educators need to be knowledgeable on different types of representations in a topic in order to choose those that would be most suitable for supporting the learning of the concept under discussion (Shulman, 1986). The discussion on conceptual teaching focused on the interaction of the different components by drawing on the considerations made above to generate a teaching plan. For example, pre-service teachers think about how the use of representations at different levels may be used to teach an aspect of a big idea that has been identified as difficult to understand – particular empty spaces between atoms. It should be noted that the discussion of a topic from this approach enables repeated opportunities to provide accurate content knowledge on the topic as it is needed, while emphasis is on the use of representations to support formulation of explanations when teaching. At the end of the discussion, pre-service teachers begin to develop an improved insight into the topic in a manner that distinguishes their content knowledge and aspects of their special PCK in the specific topic.

As with the second year methodology courses, the two tutorial periods per week offer pre-service teachers the opportunity to struggle practically through each of the TSPCK components discussed in that week. The unique feature in the class of 4th years is that they are encouraged to consider their school-based practical component of the degree as an opportunity to conduct a mini-research evaluating their use of the TSPCK framework in planning and in the actual delivery. The first school-based practical in an academic year often happens after the completion

of the six weeks where TSPCK was introduced and worked through in detail in a given topic (particulate nature of matter in this case). During the school-based experience, pre-service teachers are required to teach various topics which may not include the topic in which they learnt TSPCK. Thus, their classroom teaching offers opportunities to evaluate how they apply their learnt ways of transforming content knowledge. In schools, they are under the mentorship of a practicing teacher whom may not necessarily have been briefed on the content to which the pre-service teachers have been taught. Before the pre-service teachers leave for their school-based experience, they are provided with a template for planning a lesson that uses the five components of TSPCK as prompts. They are required to use the template in planning their lessons and audio-record their own lessons. All ethical requirements such as asking permissions from the school, the teacher, learners and their parents for audio-recording the lessons are observed. On returning, the pre-service teachers are assisted in analysing and writing up research reports on the quality of TSPCK in their teaching.

ASSESSMENT: VIGNETTE OF A SIGNATURE ASSESSMENT

The signature assessment in the series of lessons on developing TSPCK in a given topic occurs in the sixth week in both the 2nd and the 4th year class, where the CoRe is introduced as a tool for capturing pre-service teachers' reasoning on each of the five components of the TSPCK in a topic. The CoRe used in the methodology courses is the modified CoRe as discussed earlier and shown in Table 1 above. Pre-service teachers first work in the permanent groups to identify the big ideas and then work individually to complete the rest of the CoRe. The activity to identify big ideas is a difficult activity, often achieved through group input by practicing teachers (Loughran et al., 2004). Pre-service teachers formulate their big ideas, as explained earlier, by accessing their content knowledge of the topic through drawing concept maps. The concept map activity assists in identifying major concepts from which the struggle to write statements about the most important understandings of a major concept ensues. The subordinate concepts that are linked to the identified major concepts become the reservoir from which the questions of the CoRe, such as "What do you intend the learners to know about this idea?" and "What concepts need to be taught before teaching this big idea?" can be answered. The CoRe serves in both the second and higher academic level courses as a tool to assess the development of TSPCK in the topic discussed explicitly in the intervention. It should be noticed that all five components of the TSPCK construct are included in the CoRe, thus providing us with insight on how pre-service teachers in the second year level courses develop understanding of the non-discussed components of TSPCK, namely, knowledge of what is potentially difficult to understand and conceptual teaching strategies. As discussed earlier, the methodology courses are the hub of our research activities due to the strong focus on developing TSPCK in core topics of science. In addition to developing a modified CoRe, the research team has also designed special tools

that measure the quality of TSPCK in specific topics. Some of the topics used in the course have corresponding TSPCK tools available. These are mostly in the chemistry discipline, and include the following topics: chemical bonding, chemical equilibrium, organic chemistry, particulate nature of matter, stoichiometry and electrochemistry (Rollnick & Mavhunga, 2014). Two tools also exist for the physics discipline; electric circuits and kinematics. Such topics, where tools exist, allow us to assess the second outcome of the methodology courses, which is the transfer of the learnt knowledge about how to transform content knowledge using the components of TSPCK to engage with a new topic not discussed in class, and therefore develop TSPCK in the new topic. The mini-research reports from the 4th year class also serve as a major assessment, evaluating both the transfer of the competence to transform pedagogical knowledge in a new topic and the recognition of TSPCK in action by pre-service teachers.

We have also developed a five-point scale rubric of TSPCK to use in marking the completed TSPCK tools (see Table 3 below). The rubric is criterion based, developed to have four different categories that reflect the degree to which a response engages with the test question. The categories are 'Limited' assigned a score of 1, 'Basic' a score of 2, 'Developing' a score of 3 and 'Exemplary' having a score of 4, similar in structure to the rubric for measuring the quality of PCK by Park, Chen and Jung (2011). The category *Limited* reflects poor TSPCK, where none of the five components of TSPCK are adequately recognized in the pre-service teacher's responses to teacher tasks. The category *Basic* reflects limited recognition of individual components in pre-service teachers' responses, with no evident interaction with other components. The category *Developing* reflects recognition of the five components in ways that reflect interaction of at least three components. The *Exemplary* category has criteria calling for rich interaction of more than three components in the responses. The recorded audio classroom teaching are often analysed through the identification of TSPCK Episodes using the definition established by Park and Chen (2012, p. 928), where an episode is identified as a "teaching segment that indicated the presence of two or more components" of TSPCK are used in an interactive manner.

CONCLUSION: STRENGTHS AND AREAS FOR IMPROVEMENT

We started the discussion in this chapter by outlining the role that ITE is expected to play in restoring and re-building the state of science education in South Africa. We are encouraged by the revised national policy of minimum requirements for teacher education (MRTEQ). This policy now embraces subject specialization and the learning of pedagogies that recognizes the value of PCK as unique knowledge that assists teachers to build the understanding of difficult concepts for student understanding. We are also aware that PCK is highly valued in the science education community as one of the professional knowledge bases to be developed in ITE, although its implementation is still ongoing. Ball and

Table 3. A rubric to assess the completed TSPCK tools

	(1) Limited	*(2) Basic*	*(3) Developing*	*(4) Exemplary*
Learner Prior Knowledge	• No identification/No acknowledgement/ No consideration of student prior knowledge or misconceptions. • No attempt to address the misconception.	• Identifies misconception or prior knowledge. • Provides standardized definition as a means to counteract the misconception. • No drawing on other components.	• Identifies misconception or prior knowledge. • Provides standardized knowledge as definition. • Expands and re-phrase explanation using one other component of TSPCK interactively.	• Identifies misconception or prior knowledge. • Provides standardized knowledge as definition. • Expands and re-phrases explanation correctly. • Confronts misconceptions/ confirms accurate understanding drawing on two or more other component of TSPCK interactively.
Curriculum Saliency	• Identified concepts are a mix of Big Ideas and subordinate ideas. • Identified pre-concepts are far from topic. • Sequencing no value due to mixed concepts. • Reasons given are generic – benefit of education.	• Identifies at least 3 Big Ideas. • Not all 3 Big ideas subordinate concepts identified. • Suggested sequencing has one or two illogical placing of Big Ideas. • Identified pre-concepts are far from the current topic. • Reasons exclude conceptual considerations and show no evidence of drawing on other components.	• Identifies at least 3 Big Ideas. • Subordinate concepts correctly identified for all Big Ideas. • Provides logical sequence. • Identifies pre-concepts relevant to the topic. • Reasons given for importance of topic include reference to conceptual scaffolding/ sequential development draw on one other TSPCK components e.g. what makes topic difficult.	• Identifies at least 3 Big Ideas. • Subordinate concepts correctly identified for all Big Ideas with explanatory notes. • Provides logical sequence of all three Big Ideas and with logical reasons. • Identifies pre-concepts relevant to the current topic and explanatory notes given. • Reasons include conceptual scaffolding with reference to other TSPCK components.

(Continued)

Figure 3. (Continued)

	(1) Limited	*(2) Basic*	*(3) Developing*	*(4) Exemplary*
What makes topic difficult	• Identifies broad topics without reasons and specifying the actual sub-concepts that are problematic.	• Identifies specific concepts but provides broad generic reasons such as 'abstract'.	• Identifies specific concepts leading to learner difficulty. • Reasons given relate to one other TSPCK components.	• Identifies specific concepts with reasons linking to specific gate-keeping concepts and to TSPCK components such as prior knowledge and aspects of curricular saliency.
Represen-tations	• Limited to use of only macroscopic (analogies, demos, etc.) representation with no explanation of specific links to the concepts represented.	• 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.	• Use of macroscopic representation and use of scientific symbolic representation with explanatory notes linking the two representations to the aspect(s) of the concept being explained. • Use of above representations combined with reference to one other TSPCK components e.g. learner prior knowledge.	• 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.
Teaching Strategies	• No evidence of acknowledgement of student prior knowledge and misconceptions. • Lacks aspects of curriculum saliency. • Use of representa-tions limited to mac-roscopic or symbolic representation.	• Acknowledges student misconceptions verbally with no corresponding confrontation strategy. • Lacks aspects of curriculum saliency. • Use of macroscopic and symbolic representations with no linking explanatory notes.	• Considers student prior knowledge and/or misconceptions. • Considers at least one aspect related to curriculum saliency e.g. sequencing or what not to discuss yet or emphasis on important concepts. • Uses at least two different levels of representations to enforce understanding.	• Considers student prior knowledge and evidence of confrontation of misconceptions. • Considers at least two aspects related to curriculum saliency: sequencing, what not to discuss yet, emphasis of important aspects. • Uses either the macroscopic or symbolic representation with sub-microscopic representation to enforce understanding.

Forzani (2009) remind us that the practice of teaching is not a natural process, but a purposefully constructed process. The strong focus on PCK found in our methodology courses, particularly PCK in specific topics (TSPCK) is a strength in two major ways. Firstly, from an educator perspective, it has provided a vehicle for fulfilling both the requirements for national imperatives as a well as a hub to explore models for implementation of the construct in ITE, an aspect of interest to the PCK literature. Secondly, pre-service teachers are being granted an opportunity to develop both their content knowledge and the knowledge of teaching (Mavhunga, 2014) in core topics, which in turn makes their learning of the teacher professional knowledge explicit to them. Van Driel and Berry (2012) argue for the importance of awareness by pre-service teachers of the knowledge they need in developing their practice. Analysis of the end-of-year general course reviews, not discussed in this chapter, indicate appreciation by the pre-service teachers of the language they have developed in talking about and describing their professional knowledge.

As most of the work being done with TSPCK in the courses is at the level of planning, the kind of TSPCK being developed is espoused or planned TSPCK. This means the pre-service teachers develop the skills of planning lessons that have sound big ideas, are pedagogically sequenced, and formulate explanations of concepts that draw interactively on multiple components of TSPCK to ensure accessibility by learners. However, for various reasons, including time constraints within the methodology courses, pre-service teachers have limited exposure to real classroom practice and would benefit from more enhanced in-school teaching during the course of their study. Hence, the extent to which the planned TSPCK in the various core topics is translated to enacted TSPCK is unknown. This is an area to focus on for improvement in our programmes.

In an effort to address this challenge, at the final year of study (the fourth year), pre-service teachers are exposed to a minimum level of research. They are asked to regard their allocated teaching during the school experience as a research project. In their final year, pre-service teachers are allocated 3 weeks of school exposure in the subject of their major choice. During this time, they are allocated a school where they will work under the academic mentorship of a practicing teacher in the school. They may be assigned by their allocated school to teach one or several classes in the last three grades of school, and they are likely to teach topics that may not have been covered in the methodology class for the final year. For the research element, they need to demonstrate evidence of planning and teaching that has considered transformation of content in the topic they are teaching. Therefore, the research element encourages them to return to the TSPCK framework and try to plan and enact their newly constructed TSPCK. Pre-service teachers are encouraged to formulate research questions of their choice as long as it is linked to their own teaching and has a TSPCK element in it. They are directed to consider lesson plans and audio recordings of their teaching as data.

Back on campus, after completion of the school teaching experience, they analyse their collected data for TSPCK episodes. Eventually, they develop research reports and a poster for presentation in a school of education undergraduate symposium where all other pre-service teachers from different disciplines present their projects. While detailed analysis of this approach is still under way, preliminary results based on pre-service teachers' self-analysis indicate an encouraging level of awareness of strengths and weaknesses in their own teaching. Also, pre-service teachers have developed the skill of articulating challenges generally encountered in classroom practice.

While we are encouraged by the findings and the potential demonstrated in developing pre-service teachers who have TSPCK in selected core topics and an understanding of the pedagogical transformation process, we encourage open discourse in the literature on what should be regarded as knowledge for teaching science and the models for implementation at different stages of the teacher qualification degree. Towards this end we offer our approaches as a stimulus for further exploration of the implementation of PCK in the form of TSPCK.

NOTE

[1] R is used to refer to "reception year", derived from practice in the United Kingdom. In the USA it is referred to as Kindergarten.

REFERENCES

Ayas, A., Özmen, H., & Çalik, M. (2010). Students' conceptions of the particulate nature of matter at secondary and tertiary level. *International Journal of Science and Mathematics Education*, *8*(1), 165–184.

Aydin, S., Demirdöğen, B., Atkin, F. N., Uzuntiryaki-Kondakci, E., & Tarkin, A. (2015). The nature and development of interaction among components of pedagogical content knowledge in practicum. *Teaching and Teacher Education, 46,* 37–50.

Aydin, S., Friedrichsen, P., Bozc, Y., & Hanuscin, D. (2014). Examination of the topic-specific nature of pedagogical content knowledge in teaching electrochemical cells and nuclear reactions. *Chemistry Education Research and Practice, 15*(4), 658–674.

Ball, D. L., & Forzani, F. M. (2009). The work of teaching and the challenge for teacher education. *Journal of Teacher Education, 60*(5), 497–511.

Bertram, A., & Loughran, J. (2014). Planting the seed: Scaffolding the PCK development of pre-service science teachers. In H. Venkat, M. Rollnick, J. Loughran, & M. Askew (Eds.), *Exploring content knowledge for teaching science and mathematics: Windows into teacher thinking*. London: Routledge.

Davidowitz, B., & Chittleborough, G. (2009). Linking the macroscopic and sub-microscopic levels: Diagrams. In J. K. Gilbert & D. Treagust (Eds.), *Multiple representations in chemical education* (pp. 169–191). Dordrecht: Springer.

Department of Higher Education and Training. (2015). *Policy on the minimum requirements for teacher education qualifications, as revised 2014*. Pretoria: Government Gazette.

Friedrichsen, P. J., Van Driel, J. H., & Abell, S. K. (2011). Taking a closer look at science teaching orientations. *Science Education, 95*, 358–376.

Geddis, A. N., Onslow, B., Beynon, C., & Oesch, J. (1993). Transforming content knowledge: Learning to teach about isotopes. *Science Education, 77*, 575–591.

Grossman, P. (2011). Framework for teaching practice: A brief history of an idea. *Teachers College Record, 113*(12), 2836–2843.

Hume, A., & Berry, A. (2010). Constructing cores—a strategy for building PCK in pre-service science teacher education. *Research in Science Education, 41*(3), 341–355.

Loughran, J. J., Berry, A., & Mulhall, P. (2004). In search of pedagogical content knowledge in science: Developing ways of articulating and documenting professional practice. *Journal of Research in Science Teaching, 41*(4), 370–391.

Mavhunga, E. (2014). Improving PCK and CK in chemistry pre-service teachers. In M. Askew, M. Venkat, M. Rollnick, & J. Loughran (Eds.), *Exploring content knowledge for teaching science and mathematics: Windows into teacher thinking* (pp. 29–49). Abington, UK: Routledge.

Mavhunga, E., & Rollnick, M. (2013). Improving PCK of chemical equilibrium in pre-service teachers. *African Journal of Research in Mathematics, Science and Technology Education, 17*(1–2), 113–125.

Nilsson, P. (2008). Recognizing the needs – student teachers´ learning to teach from teaching. *Nordina, 4*(1), 284–299.

Osman, R. (2010). The challenge and promise of university-based teacher education. *Focus 56: On Teaching and Learning, 56*, 21–25.

Park, S., & Chen, Y. (2012). Mapping out the integration of the components of pedagogical content knowledge (PCK): Examples from high school biology classrooms. *Journal of Research in Science Teaching, 49*(7), 922–941

Park, S., Jang, J.-Y., Chen, Y.-C., & Jung, J. (2011). Is pedagogical content knowledge (PCK) necessary for reformed science teaching? Evidence from an empirical study. *Research in Science Education, 41*, 245–260.

Rollnick, M., & Mavhunga, E. (2014). PCK of teaching electrochemistry in chemistry teachers: A case in Johannesburg, Gauteng province, South Africa. *Educacion Quimica, 25*(3), 354–336.

Rollnick, M., & Mavhunga, E. (2015). The PCK summit and its effect on work in South Africa. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education* (pp. 135–146). London: Routledge.

Rollnick, M. & Mavhunga, E. (2017). Pedagogical content knowledge. In K. S. Taber & B. Akpan (Eds.), *Science education: An international course companion* (pp 507–522). Rotterdam: Sense Publishers.

Rusznyak, L. (2015). Knowledge selection in initial teacher education programmes and its implications for curricular coherence. *Journal of Education, 60*, 8–29.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1–22.

Silberberg, M. S. (2009). *Chemistry: The molecular nature of matter and change, 2006* (5th ed.). New York, NY: McGraw-Hill.

Spaull, N. (2013). South Africa's education crisis: The quality of education in South Africa 1994–2011. *Centre for Development and Enterprise*, 1–65. Retrieved from http://www.section27.org.za/wp-content/uploads/2013/10/Spaull-2013-CDE-report-South-Africas-Education-Crisis

Tan, K. C. D., & Treagust, D. F. (1999). Evaluating students' understanding of chemical bonding. *School Science Review, 81*(294), 75–83.

Taylor, N. (2015). How can teaching become more professional? *JET Bulletin*, 1–6. Retrieved from http://www.jet.org.za

Van Driel, J. H., & Berry, A. (2012). Teacher professional development focusing on pedagogical content knowledge. *Educational Researcher, 41*(1), 26–28.

Van Driel, J. H., Verloop, N., & de Vos, W. (1998). Developing science teachers's pedagogical content knowledge. *Journal of Research in Science Teaching, 35*, 673–695.

Windschitl, M., Thompson, J., & Braaten, M. (2011). Fostering ambitious pedagogy in novice teachers: The new role of tool-supported analyses of student work. *Teachers College Record, 113*(7), 1311–1360.

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