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Exploring the Development of the Quality of Topic Specific Pedagogical Content Knowledge in Planning: the Case of Grade 8 Natural Sciences Teachers

Anastasia Malong Buma[1] · **Doras Sibanda**[2] · **Marissa Rollnick**[1]

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Abstract

The intervention programmes have a direct influence on teachers' knowledge of teaching different topics. This paper focuses on how Grade 8 natural science teachers' knowledge developed during an intervention programme. Eight schools were selected to participate, and 25 Grade 8 Natural Sciences teachers from Gauteng province participated. Data were collected during the intervention sessions, and participants completed a written TSPCK test and content representation tool. Quantitative data were analysed using the Rasch analysis model, and qualitative data were analysed using content analysis of TSPCK episodes using the TSPCK rubric. The episode was a response segment, where TSPCK components were used to transform the topic content. The findings showed that teachers' pedagogical content knowledge improved significantly in different components of TSPCK. The teachers' PCK development was revealed through extensive use of knowledge of representation including demonstrations using diagrams aimed at transforming the concept in planning. Besides, during the intervention, teachers were able to collaborate, have explicit discussions on specific topics, and provide explanations on the use of the five TSPCK components. The study implies that the development of PCK in fundamental topics in a discipline can be implemented through a TSPCK-based intervention.

Keywords Teacher development · Intervention programme · In-service teachers · Topic specific · Pedagogical content knowledge in planning

✉ Anastasia Malong Buma
Anastasia.buma@wits.ac.za; abuma626@gmail.com

Doras Sibanda
Sibandad@ukzn.ac.za

Marissa Rollnick
marissa.rollnick@wits.ac.za

1 School of Education, University of the Witwatersrand, 27 St Andrew's Rd Parktown , Johannesburg, South Africa

2 University of KwaZulu Natal, Edgewood Campus Pinetown, Durban, South Africa

Introduction

Over the years, since the mid-1980s, research on teacher knowledge has gained momentum until to date (Mehiso & Mavhunga, 2020; Shulman, 1986). A substantial body of studies stems from the seminal work of Shulman (1986) on pedagogical content knowledge (PCK). According to Shulman (1986), subject matter knowledge for teaching consists of different knowledge components that are used to transform lesson content into forms that are comprehensible to learners. An understanding of PCK acquisition and growth is of value in contexts where teachers are grappling with the task of teaching difficult topics like the particulate nature of the matter in chemistry. The teaching of the particulate nature of matter, which has been identified as a challenging topic for over 30 years (Driver, 1985; Treagust et al., 2010), remains so today, especially in South Africa, the site of this study.

Shreds of evidence from recent studies in PCK development highlight the use of different PCK components in transforming the lesson content, and the focus has been on preparing pre-service teachers to teach at senior high school level (Mavhunga, 2016; Pitjeng-Mosabala, & Rollnick, 2018). As such, there is a need to explore how in-service teachers in junior secondary school progressively develop their teacher knowledge of teaching a particular topic through an intervention programme. The intervention programme utilises TSPCK components as pedagogical resources to transform teachers' PCK on the particulate nature of matter to facilitate student learning of science. The topic of particulate nature of matter in junior school curriculum is one of the basic topics that prerequires for future understanding of other chemistry topics, such as stoichiometry, chemical bonding, acids and bases, and rates of reactions at higher levels of education. This study seeks to understand the nature of the development of the quality of TSPCK in planning to teach particulate nature of matter among practising Grade 8 natural sciences teachers following their participation in an intervention. The teacher's knowledge of planning is linked to pedagogical reasoning.

Loughran (2019) views pedagogical reasoning as a way of thinking that informs professional practice. Horn (2010) defines episodes of pedagogical reasoning as 'moments in teachers' interaction when they describe issues and questions about teaching practice, and these descriptions are accompanied by some elaboration of reasons, explanations, or justifications (237).

According to Shulman (1986), reasoning in planning to teach is as important as the actual act of teaching, and it inevitably influences the thinking that teachers draw upon in justifying their actions in teaching. More so, planning is known to initiate the operationlisation of PCK and has been considered one of the promising ways to promote PCK acquisition and development (Carlson et al., 2019; Mavhunga, 2016). We believe that getting in-service teachers to participate in a TSPCK-based intervention that affords practical opportunities for applying an understanding of using TSPCK components in transforming concepts as taught in the intervention is an important driver for PCK growth. Therefore, it is from this stance that we explored the question:

> To what extent does the explicit teaching of transformation of concepts in the particulate nature of matter, through the set of five components, influence the quality of PCK in planning in natural sciences?

Theoretical Background

Our conceptualisation of TSPCK in planning, how it is gained and developed during an intervention, was informed by three existing frameworks: Warford's model of Zone of Proximal Teacher Development (ZPTD) (Warford, 2011), Mavhunga's 2019 simplified version of the Refined Consensus Model (RCM) of PCK (Carlson et al., 2019), and the five-component TSPCK construct (Author). Here, the premise for Warford's model of ZPTD stemmed from aspects of Vygotsky's theory on the social construction of knowledge (Vygotsky, 1978), particularly the notion of 'the Zone of Proximal Development' (ZPD). This ZPD has been defined as the difference between what learners can do without help and what they can do with help (Vygotsky, 1978). In considering the ZPD in the context of a teacher, Warford (2011) adapted it to the ZPTD. In light of this notion, to reduce the situation of teachers needing help and increase competence to work effectively, the teachers in the current study worked together with seasoned academics as facilitators and more knowledgeable peers, who collaborated and shared pertinent insights into the topic of the intervention to enable learning and developing their TSPCK.

Based on the RCM model, PCK has been reconceptualised to include three realms: collective (cPCK), personal (pPCK), and enacted PCK (ePCK) within the grain size of a specific discipline, topic, or concept (Carlson et al., 2019) (see the model on the right-hand side of Fig. 1). The cPCK is described as common specialised professional knowledge generated collectively from an expert group of science teachers. In this study, cPCK on the topic of the intervention was presented to the teachers as learning resources, which they drew from to inform their pPCK during the training workshops. pPCK is considered a private expert knowledge possessed by an individual teacher, accrued from engaging with cPCK, own teaching, and learning experiences. In the case of ePCK, also known as PCK in action, it includes the unique subset of knowledge and skills revealed when a teacher draws from the pPCK in transforming a lesson content during planning, delivery, and post-teaching reflection for a specific group of students in a particular context. In this study, the focus is on ePCK in planning, such that the transformation of relevant concepts about the particulate nature of matter is manifested via the operationalisation of pPCK through the five TSPCK components.

The five TSPCK components (see the model on the left-hand side of Fig. 1) are explained next. The first one is *curricular saliency* (CS), which includes teachers' knowledge of important concepts and their sequencing. The second one is *learner prior knowledge* (LPK), which is the teachers' understanding of ideas that learners have about a topic, which could be alternative or misconceptions on scientific content, for example, some learners think that atoms expand in size when heated. The third one is *the representations* (REP) component, which includes ways of representing content, such as analogies, real-life examples. The fourth component addresses the teacher's knowledge of *what makes a topic difficult to teach and learn (*WDT). The final component addresses *conceptual teaching strategies* (CTS), which refer to the teacher's knowledge of how to combine the other four components when explaining a specific concept.

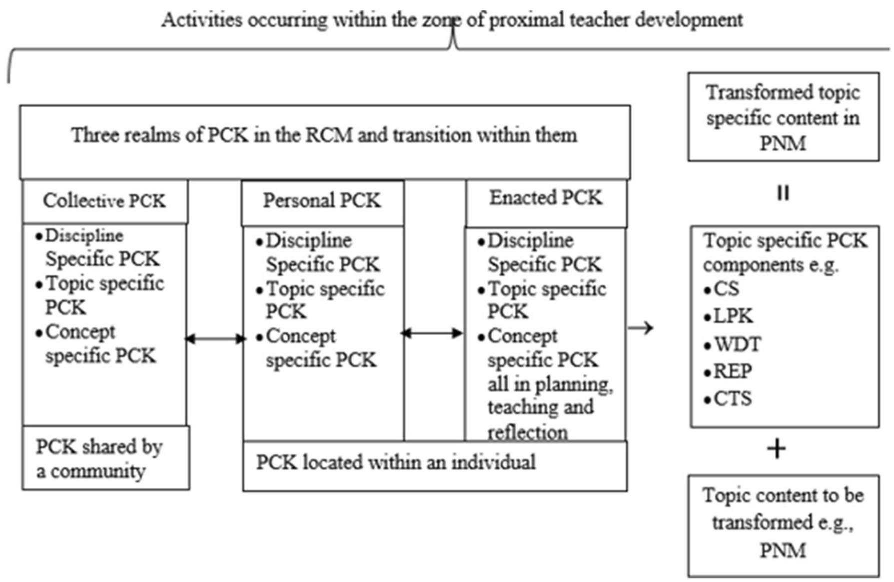


Fig. 1 Developmental pathway and five components through which transformation occurs

Literature Review

Teaching Particulate Nature of Matter as a Foundational Topic in the Curriculum

Particulate nature of matter is an integral part of basic chemistry school curricula worldwide. In the country where this study is conducted, it is known as the particle model of matter and is taught in junior school as a natural science topic. The natural sciences subject taught in junior high school includes disciplines like chemistry, physics, biology, and earth sciences. When taught from Grades 7 to 9 (Junior high school levels), as in this study, it is presented as one of the topics in the matter and materials strand. Equally important is the notion that the topic is considered a foundational topic for understanding other chemistry topics, such as stoichiometry, chemical bonding, and solution chemistry in senior high school (Department of Basic Education, 2011). Furthermore, the prescribed content sequence in Grades 7–9 curriculum policy document consists of descriptors, such as *all matter is made up of tiny bits called particles* and *the particles have different arrangements in solid, liquid, and gases* (Department of Basic Education, 2011:45). It is believed that the particulate nature of matter is abstract and difficult to teach and learn (Kellner et al., 2011). Accordingly, different scholars have reported evidence of learner misconceptions about this scientific content and the adversity to teaching and learning. For example, Boz (2006) investigated Turkish learners' conceptions of the particulate nature of matter and found that they experienced difficulties in understanding the concept of *constant movement of particles,* especially in a solid phase of matter. In another study, Özalp and Kahveci (2015) reported that learners have misconceptions that individual atoms can heat up and melt and their volume increases. This further confirms Boz's (2006) argument that learners have difficulties in understanding the relationship between the molecular and macroscopic nature of matter. Equally reported is the idea that teachers have difficulties in understanding the relationship between the macroscopic and molecular representations of particles of matter. This affects their ability to provide explanations that connect the different levels of representation of matter, which is a fundamental element of TSPCK competence (Diezmann & Watters, 2015; Treagust et al., 2010). Thus, to develop the relevant TSPCK to effectively teach these concepts so as to attain conceptual change and address learning difficulties, teachers need to have a deeper understanding as well as knowledge to use the different TSPCK components related to the topic in question (Kellner et al., 2011; Özalp & Kahveci, 2015). Therefore, there is a need to strengthen science teachers' understanding of the particulate nature of matter by involving them in an intervention.

Characteristics of Effective Teacher Professional Development Interventions

Professional development has been defined as learning opportunities purposely created to assist teachers develop competencies germane to their practice (Hallman-Thrasher et al., 2019; Msimanga et al., 2019). Research has shown that professional development may take different forms, such as in-service teacher training workshops, mentoring, and lesson study (Akerson et al., 2017). Some authors have identified different elements of successful professional development programmes:

- The programme is long term (at least a year). However, moderate duration like a day or two-day workshop can be effective if focused on narrowly specified aspects of teaching that facilitators work with teachers as equals and encouraging participants to take over the leadership of the pedagogical development (Cordingley et al., 2015). In this study, the specific need was to develop teachers' TSPCK in the particulate nature of matt*e*r.
- Instructions and activities should be well planned to create more learning opportunities for the teachers to practise the intervention and to reflect individually and/or collectively upon applying their newly acquired knowledge (Hallman-Thrasher et al., 2019).

Furthermore, Author reported on a study where an effective two-day workshop that focused on improving teachers' PCK to transform science content in ways that are relevant to learners was initially taken up with much enthusiasm by the participating teachers. However, Author acknowledged that sustaining such excitement and ensuring integration of the learnt competence into their future lesson was challenging and citing time constraints among other school-related challenges. This study involved the latter and examined the TSPCK development of in-service teachers. It has been argued that student outcomes are one way of determining the success of a teaching and learning encounter (Carlson et al., 2019). In our study, considering that the teachers will be learning to integrate TSPCK components in the topic of the intervention, we, therefore, explore various ways in which the learnt competence is portrayed.

Research Methodology

The study employed a mixed methods research design that allowed for quantitative and qualitative analysis of the TSPCK portrayed by the teachers. According to the Creswell (2014b), a mixed methods design has potential to draw from both strengths and weakness of quantitative and qualitative research approaches. The qualitative analysis adopted a case study approach that afforded in-depth analysis of the data (Creswell, 2014a).

The Context and the Participants

An intervention programme targeting an understanding of how teachers transform the particulate nature of matter concepts through the use of five TSPCK components was implemented in two phases. These phases were carried out in term one and phase two in term four of the academic school calendar. In total, 25 in-service teachers attended both 2-day workshops during terms one and four. The workshops focused on the five components, as the topic of the particulate nature of matter was introduced, taught, and discussed explicitly by the facilitators and the participant teachers. Both interventions were accommodated at the same university venue.

The participants were purposively selected from a population of science teachers teaching at eight public high schools in the North and South of Johannesburg. They were invited to participate voluntarily in the intervention, and they consented and were free to leave at any time during the project. All the 25 teachers worked in groups of five, and among each of the group of five members, five group leaders were selected purposefully and conveniently as case study participants. Their selection was based on their high level of interaction during the workshops and appeared knowledgeable about the topic under investigation. Thus, they were considered potential sources of rich qualitative data. The participants range in age between 25 and 35 years. They were regarded as representative of the larger group, since they participated in both workshops and completed the TSPCK test, as well as the CoRe. Like most high school teachers in other parts of the continent, they teach one or more classes at both junior (Grades 8 and 9) and senior high school (Grades 10, 11, and 12) levels. In terms of qualifications, they had first degrees in science and postgraduate science qualifications and had done chemistry for a minimum of 1 year during studying for their qualifications.

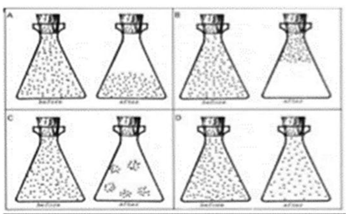
The TSPCK-Based Training

Two TSPCK-based training workshops were structured into different activity sessions, ranging from 60 to 120 min of specific tasks set by the facilitators, who were four science education experts, including the co-authors. During the initial workshop, the teachers were purposively arranged into 5 groups of five members per group. This arrangement was maintained in the second training to enable sustained collaboration of expert insights of their experiences in teaching. They were provided with learning resources as cPCK (Carlson et al., 2019). In both workshops, the five components of TSPCK, as described above in the framework for the study, were addressed one at a time using appropriate sub-topics and concepts on the topic of the intervention. The discussion was typically followed by explicit explanations of one of the knowledge components using central concepts in particulate of matter. For example, the discussion of the *representation* commenced with an introduction of the three distinct levels of representation of the three states of particles of matter, including macroscopic, symbolic, and sub-microscopic levels. Emphasis was also placed on the benefit derived from using all the three levels of representation at about the same time when explaining a concept for better understanding.

Data Collection

Data were collected using the previously validated TSPCK test and CoRe (see Figs. 2 and 3 for extracts from the test and CoRe respectively). The test was administered and completed for an hour in the beginning of the first and second training workshops, as pre-test and post-test respectively. The test was structured into five categories that correspond with the five TSPCK components, and each section had a few sub-questions that were presented as teacher tasks, formulated to allow open-ended responses about concepts in the topic of the intervention. In addition, what the in-service teachers knew (pPCK) at the end of both workshops was captured through a comprehensive paper-and-pencil task in the form of an adapted CoRe, a tool that captures PCK in planning (Author). It was administered as pre-CoRe and post-CoRe at the end of the 1st and 2nd workshops respectively. When constructing the CoRes which required an hour, with the guidance of the facilitators, the participants were asked to select key ideas from Grade 8 particulate nature of matter content and present these ideas in a particular teaching sequence. Following this, the teachers applied their knowledge framed in the TSPCK components to transform the key ideas as taught in the intervention by providing explicit responses to the prompts in the CoRe, an action that could lead to PCK development.

The diagram below shows four learners' responses, A, B, C and D



Following these four leaners' responses, how will you teach a lesson on particle nature of matter in the gaseous phase? Explain fully showing any analogies or representations you would use and how you would deal with their response.

Fig. 2 Excerpt on CTS item from TSPCK test on particulate nature of matter

Content area	Big idea A	Big Idea B	Big idea C	Big Idea D
Curricular Saliency				
What do you intend students to learn about this idea?				
Learner prior knowledge				
What are typical students' misconceptions when teaching this idea				
What makes the topic difficult or easy to understand				
What do you consider easy or difficult about teaching this idea?				
Representations				
What representations would you use in your teaching ?				
Conceptual teaching strategies				
What effective strategies would you use in teaching this big idea?				

Fig. 3 CoRe template extract adapted from Loughran et al. (2004)

Data Analysis

A transcript of the written responses in both pre- and post-tests was first coded using a previously validated four-point criteria TSPCK rubric (Vokwana, 2021) (see Fig. 4 for a rubric extract). The key strength of the rubric lies in the progressive nature of the criteria from one to four quality levels reflecting the degree to which a response engages interactively in-depth with the TSPCK components. These levels are as follows: 'limited', 'basic', 'developing', and 'exemplary', and the assigned scores were 1, 2, 3, and 4 respectively (Vokwana, 2021). Such a measure is a kind of an interval scale that preserves the equality of intervals. Specifically, a quantitative measurement scale where variables have an order, the difference between two variables is equal and used to measure variables that exist along a common scale in equal intervals (Ferrante et al., 2020). Before the analysis, transcripts of 5 completed pre- and post-tests were independently coded by a chemistry expert and the co-authors using constant comparison. The various scores were discussed for peer validation for the accuracy of the content and confirmed the consistency of codes. In cases where there were large differences, we discussed and reached an agreement using the rubric. The scores were then used to determine the interrater reliability, and the agreements were calculated at a Cohen's kappa value of 0.85 and 0.80 for the pre-/post-tests respectively, which is considerably acceptable. The remaining tests were then coded.

The numerical value of the coded responses to the test was subjected to Rasch analysis to establish the validity and reliability of the tools in measuring test performance. The calculation of validity in Rasch is based on the idea that the recorded performances are reflections of a single underlying construct, which is made explicit by the relationship of items to the human ability in the measured sample (Boone & Rogan, 2005).

TSPCK Components	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)
Conceptual teaching strategies	No awareness and confronting misconceptions	Recognize and does not address misconception	Considers and confronts prior knowledge	Considers and address learner misconceptions
	Lacks aspects of curriculum saliency	Considers an aspect of curriculum	Considers at least one aspect related to curriculum	Considers at least two aspects of curriculum
	No representations	No use of representations	Uses at least two levels of representations	Considers what is difficult to teach
				Uses all three levels of representations

Fig. 4 Extract from rubric showing categories for coding responses to CTS (Vokwana, 2021)

A *T*-test was conducted to determine if there exists any statistically significant difference in terms of understanding the integration of TSPCK components. It is important to note that the Rasch places persons' ability measures on the same interval scale as the measures for items' difficulty (Boone & Rogan, 2005). This assists in determining internal coherency and in establishing rank order of persons' ability and item difficulty measures. Typically, item difficulty and person ability measures that fall within the fit statistic range of – 2 to + 2 are considered a good match, that is coherent and measuring a single construct, which therefore constitutes a valid measure. The names of the topic-specific PCK components are abbreviated for ease of reference as CS (curricular saliency), LPK (learner prior knowledge), WDT (what is difficult to teach), REP (representations) and and CTS (conceptual teaching strategies).

In addition, evidence of rich TSPCK episodes from the transcript of the teachers' responses to the CTS item from the pre- and post-CoRes tests that were subjected to in-depth qualitative analyses were used to illustrate PCK development. These components are reported to be common in most other qualitative PCK tools. The use of these components in transforming the content at the topic level logically demands extensive explanations from the participants that should possibly reveal the integration of the other TSPCK components and a richer TSPCK. For example, the use of representations at multiple levels works together with at least two of the other components in an explanation of a concept to provide depth and support meaning. A first step involved the identification of planning segments that demonstrate the presence of TSPCK episodes. This was done such that the identified TSPCK episodes were first extracted, analysed for the number of TSPCK components interacting and complementing one another in the formulated response and then coded using the TSPCK rubric (Vokwana, 2021) (see Fig. 4 for an excerpt of the rubric) in conjunction with expert CoRes (Loughran et al., 2004) (see Fig. 5 for an excerpt of expert CoRe). A definition of the TSPCK episode was adapted from Park and Chen (2012)

Content area: Particulate nature of matter	Big idea A Matter is made up of small bits that are called particles.	Big Idea B There is empty space between particles.	Big idea C Particles are in constant motion	Big Idea D Particles of different substances are different
What are typical learners' misconceptions which influence your teaching of this idea.	Many learner's thing that matter is continuous	learners think that particles get bigger during expansion.	It is difficult to imagine particles in a solid moving	Learners think that all particles are the same.
What effective teaching strategies would you use to teach this big idea?	Probs learners understanding, use analogies e.g. Ask them to draw a flask containing air, then redraw the same flask with some of the air removed	Activities to predict, observe and explain e.g. squashing syringe of air and predict the outcome based on the air particles	Demonstration e.g., a jar of marbles as model: packed tight to show a solid; remove 1 & shake to show movement in a liquid.	Concept Map using the terms: solid; liquid; gas; particles; air; nothing

Fig. 5 Extract of expert CoRe on learner misconceptions and teaching procedures (Loughran et al., 2004)

	Extracted transcript episode	Coding category	Explanation of coding
Pre-TSPCK test from CTS item	I will explain that gas particles have irregular arrangement and move rapidly in all direction in a container (CS)	Basic TSPCK	Here the teacher provides a generally simple explanation with limited use of one TSPCK component (CS)
Post- TSPCK test from CTS item	I will use *diagrams* (REP) to show learners and ask question how the particles in the gaseous phase are arranged (LPK). I will emphasis that gas particles have *irregular arrangement and move in every direction* and fill up the whole container (CS)	Developing TSPCK	Teacher planning with three components REP, LPK and CS used interactively, enriching the explanation for possible learning.

Fig. 6 Example of an extract showing in-depth qualitative codding of a TSPCK episode

as a segment of a response that displays the interaction of two or more components of TSPCK in planning. The identification and analysis of the TSPCK episodes were performed independently by two of the three raters mentioned above, and discrepancies were discussed for consensus. An example of the preceding process is shown below (see Fig. 6).

Findings

The results that are organised by data analysis for clarity indicated some development in the quality of the teachers' TSPCK in planning. We describe details of our results in the following sections.

Quantitative Extent of Improvement in the Quality of TSPCK

After subjecting the test scores to the Rasch model to establish the validity and reliability of the tool, the Rasch measures generated produced acceptable person and item reliability indices in both tests. In the case of the pre-test, the item reliability was 0.59 and the person reliability of 0.64. For the post-test, the item reliability was 0.70 and person reliability of 0.81 (the nearer the scores are to 1, the greater the reliability) (Boone & Rogan, 2005). In terms of validity, the measured item and person scores reflected error estimates well inside the conventionally acceptable fit statistics range of – 2 and + 2, indicating good validity in both cases. The fact that these reliability and validity indices are within the acceptable fit statistic range is further evidence of validation of TSPCK as a construct. Hence, the tool is a reliable and valid instrument to measure a single construct, which is the quality of the teachers' TSPCK for planning to teach the particulate nature of matter.

About the *t*-test, it came out highly significant with a value $t = 5.54 \times 10^{-12}$ Indicating a statistically significant difference between the pre- and post-TSPCK test scores. The results revealed that the teachers performed significantly better in the post-TSPCK test than in the pre-test, thus signalling that the in-service teachers experienced an improvement in their TSPCK quality (Fig. 7).

Qualitative Perspective of Growth of the Teachers' TSPCK

It is useful to get an overview of how the quality of the combined TSPCK episodes changed for the test and the CoRe over the two training workshops before looking at the level at which the 5 case study teachers performed over the intervention. When comparing the overall numbers of TSPCK episodes per quality level for the pre-test and post-test, it was observed that the teachers experienced an improvement in the quality of their TSPCK. The trend in the quality of their TSPCK shifted from more 'limited' and 'basic' in the pre-test/CoRe, to more 'developing' and 'exemplary' levels in the post-test/CoRe (see Fig. 8 above). This indicates that prior to the intervention, the teachers mostly used one or two TSPCK components in transforming the

TSPCK quality levels	Limited (1 component)	Basic (2 components)	Developing 3 (components)	Exemplary (4 - 5 components)
No of identified episodes from pre- test	8	15	2	0
No of identified episodes from post- test	3	4	14	5
No of identified episodes from pre-CoRe	3	7	11	4
No of identified episodes from post-CoRe	0	4	7	14
Total	14	31	37	23

Fig. 7 Summary of the number of TSPCK episodes per quality level

content. This poor-quality teacher knowledge glaringly improved with prolonged participation in the intervention with more episodes of developing (14) and exemplary (14) PCK quality levels in the post-test and post-CoRe respectively that were completed in the beginning (post-TSPCK test) and end (post-CoRe) of the second training workshop, signalling that the teachers experienced growth in the quality of their TSPCK over the two workshops. Each episode was initiated by a teacher making a statement or asking a question about issues linked to a concept in the topic of the intervention that often generated into TSPCK component-rich discussions and explanations. The extract in Fig. 9 is an example from one such episode. Furthermore, evidence in the form of excerpts from the responses to the CTS item for the pre- and post-test and CoRe of the five case study teachers (Paul, Silase, Peter, Esther, and Jameis pseudonym) is provided in the findings that follow. The episodes are presented in pairs to enable comparison of responses to illustrate growth in understanding.

Case Study 1: Paul—TSPCK Episodes Showing Growth Among the Quality Levels

Paul attended both training workshops. He has been teaching for 9 years and teaches science in Grades 8 and 9 and physical science in Grades 10 and 11 in an under-resourced high school. He completed the test and CoRe. Evidence of growth in his PCK quality from basic to developing in the pre-and post-test episodes is presented below.

Both episodes present a scenario from the pre-and post-tests. This test item required Paul to apply his teacher's knowledge about the concept of *rapid random movement of a gas particle* in order to address the learner misconception that when gas particles are removed from a container, the remaining particles group up. Paul's response from the pre-test episode was more of a simple explanation that restated the instruction using two components (LPK and CS), which resulted in his TSPCK here being labelled basic quality. To be more specific, his knowledge of CS applies to his use of the correct understanding of the key concept that *when some gas particles are removed from*

Pre-TSPCK test response with basic TSPCK	Post-TSPCK test response with developing TSPCK
I can use the four responses to show understanding that 1) the particles of air will not sink to the bottom of the flask as shown in A. 2) The particles will not float at the top of the flask as shown in B. 3) They will not form clumps in the container as shown in C. 4) They will spread evenly with more empty spaces between them.	I will first use the diagrams for learners to see before asking them to explain what they think is happening. Thereafter, I will explain that when some air particles are pumped out of a container, the remaining particles fill up the whole space evenly to correct the misconception that air particles can occupy only a certain area in a container. I will, for example, use a balloon for learners to blow
	air into it before explaining with emphasis that particles in the gaseous state move in all directions to take up space in the whole balloon because of the large spaces and weak forces between them.

Fig. 8 Two TSPCK episodes from the pre-and post-tests showing growth from basic to developing

Pre-test episode with basic TSPCK quality	Post-test episode with exemplary TSPCK
I will explain to learners that if some of the particles are removed from the flask, by a pump, the remaining particles will fill up all the container. While explaining, I will ask questions to test learners' understanding	I will start by explaining that gas particles always move quickly and randomly to occupy the entire container using a video or computer simulation supported by corresponding diagrams and get learners to see the random movement of gas particles. As they watch, I will pause the video at certain points to show what is happening in relation to the diagrams and between the explanation. I will ask questions to establish learners' understanding. I will then explain and emphasise that air particles have no fixed pattern of arrangement and so move randomly to fill up the space that is available in the container.

Fig. 9 TSPCK episodes from pre-and post-tests showing growth in quality from basic to exemplary

a container, the remaining particles spread out evenly to fill the whole container with more space between particles. In addition, Paul used his knowledge of LPK to identify and confront the misconception in the provided instruction by stating that the particles will not form clumps but will spread out evenly in the entire space available in the container. On the other hand, the episode from the post-test presents evidence that Paul's explanation of the post intervention was starting to improve as it displayed an interactive use of three components (REP, CS, and LPK), which were working together to enrich the explanation of the same concept. Although the applied knowledge of CS and LPK in the post-test was similar to that in the pre-test, there was evidence of depth in the quality of Paul's TSPCK revealed in his use of two levels of macroscopic and sub-microscopic representations (REP) in the post-test. This was shown in the use of diagrams and the practical demonstration with a balloon in explaining an idea of the topic content that the air particles blown into a balloon *move quickly in all directions to fill up the whole space*. Therefore, in comparison to the pre-test episode, the post-test episode showed the use of more TSPCK components (REP, CS, LPK). As a result, the PCK quality in the pre- and post-tests episodes was scored as basic and developing respectively, indicating growth in his understanding of the topic. This confirmed the evidence of growth in the quality of Paul's TSPCK in the topic of the intervention, which can be linked to the effectiveness of the intervention.

Case Study 2: Silase—TSPCK Episodes Showing Growth Among the Quality Levels

Teacher Silas has been teaching in an under-resourced urban school for 6 years at the time of the study. She teaches natural sciences to Grades 8 and 9 and biology to Grades 10 and 11. Two TSPCK episodes from pre- and post-tests showing evidence of growth in her TSPCK quality are presented below.

From the above pre-test episode, it can be seen that teacher Silase simultaneously used two TSPCK components in transforming the concept. To be more specific, she drew from her understanding of using questions to tap into what learners know (LPK) about the concept as she explained that *gas particles always fill up the entire space of its container* (CS). Based on her use of two components (LPK and CS), this episode was categorised as basic quality. In the case of the post-test episode, teacher Silase used knowledge of curricular saliency (CS) to explain the concept of *rapid random movement of gas particles to fill up the entire container*. This knowledge was applied interactively with knowledge of representation in her use of diagrams and animations (REP) to show the movement of air particles. Yet still, Silase drew from her understanding of knowledge of learner prior knowledge (LPK) to ask questions while explaining and emphasising that *air particles do not group up in a container but rather fill up the entire space,* which is an aspect of the content that is difficult to learn (WDT). Here, her response in the post-test showed evidence of coherent use of four components (CS, REP, LPK, and WDT). As such, we valued her TSPCK quality as exemplary, an indication of growth in her teacher knowledge when compared to the basic quality in the pre-test.

Furthermore, it can be argued that in developing their TSPCK, teachers are more likely to have drawn from their pPCK accrued from constructive engagements with the cPCK presented as learning resources throughout the intervention (Carlson et al., 2019), coupled with rich insights gained from collaborating with the more knowledgeable peers and the veteran facilitators (Warford, 2011). Hence, the gains in TSPCK quality could be understood in terms of the ZPTD. It could be inferred that the teachers now have a better understanding of knowledge to transform the content due to the effective learning experienced during the intervention (Warford, 2011). It is shown from these episodes that the teacher knowledge used in the post-CoRe episode was similar to the expert CoRe on the topic of the intervention developed by Loughran et al. (2004) and presented to the teachers as reference materials during the intervention. Interestingly, even the incorporated representations in their responses were similar to those discussed during the training. Therefore, the merit to reason that the collaborative experience of thinking, sharing, and explaining the use of the TSPCK components in the context of the intervention could have afforded the teachers the opportunity for their TSPCK to develop.

Case Study 3: Peter—TSPCK Episodes Showing Growth Among the Quality Levels

Teacher Peter has been teaching in an under-resourced urban school for 11 years at the time of the study. Two TSPCK episodes from pre- and post-tests showing evidence of growth in his TSPCK quality are presented below (Fig. 10).

From the above pre-test episode, it can be seen that teacher Peter drew from his understanding of using diagrams (REP) and the meaning of the concept of constant random movement of gas particles in order to explain to learners that *gas particles move in all directions to fill up the whole space of the container* (CS). Based on his use of two components (REP and CS), this episode was categorised as basic quality. In the case of the post-test episode, he used knowledge of representation

Pre-test episode with basic TSPCK quality	Post-test episode of exemplary TSPCK quality
I will use one of the diagrams and explain that gas particles are always moving, and I will explain and help learners to learn that gas particles move in all directions to fill up the whole space of the container.	I will use the right diagrams to explain to the learners that particles in gases move in all directions to fill up the whole container and that gas particles do not form clumps. I will use pictures so that learners can see the random movement of gas particles and ask them to explain what they can see happening in the picture. I will ask learners to draw a diagram on the board and explain the movement of particles.

Fig. 10 TSPCK episodes from pre-and post-tests showing growth from basic to developing

in mentioning the use of diagrams and pictures (REP) to show the movement of air *particles in all directions to fill up the whole container* (CS). In addition, Peter drew from his understanding of learner prior knowledge (LPK) to ask questions while explaining and to get learners to draw a diagram and explain it. Here, his response in the post-test showed evidence of coherent use of three components (REP, CS, LPK). As such, we valued his TSPCK quality as developing, an indication of growth in his teacher knowledge when compared to the basic quality in the pre-test.

Case Study 4: Esther—TSPCK Episodes Showing Growth Among the Quality Levels

Teacher Esther has been teaching in a fairly resourced public high school for 5 years at the time of the study. She teaches natural sciences to Grades 8 and 9 and biology to Grades 10 and 11. Two TSPCK episodes from pre- and post-tests showing evidence of growth in her TSPCK quality when explaining the concept of random movement in gas particles are presented below (Fig. 11).

From the above pre-test episode, it can be seen that teacher Esther drew from her understanding of using questions to tap into what learners know (LPK) and the use of *diagrams* (REP) to show the movement of air particles in *all directions to occupy its entire container* (CS). Based on her use of three components (LPK, REP, and CS), this episode was categorised as developing quality. In the case of the post-test episode, she used knowledge of curricular saliency to explain the concept of *rapid random movement of gas particles to fill up the entire container* (CS). This knowledge was applied interactively as she drew from her understanding of knowledge of learner prior knowledge (LPK) to ask questions while explaining and using diagrams (REP) and emphasising that *air particles do not group up in a container but move randomly in all directions to fill up the entire space*, which is an aspect of the content that is difficult to learn (WDT). Here, her response in the post-test showed evidence of coherent use of four components (CS, REP, LPK, and WDT). As such, we valued her TSPCK quality as exemplary, an indication of growth in her teacher knowledge when compared to the developing PCK quality in the pre-test.

Case Study 5: Jameis—TSPCK episodes showing growth among the quality levels

Teacher Jameis has been teaching in a fairly resourced public high school for 12 years at the time of the study. She teaches natural sciences to Grades 8 and 9 and biology to Grades 10 and 11. Two TSPCK episodes from pre- and post-tests showing evidence of growth in her TSPCK quality when explaining the concept of random movement in gas particles are presented below (Fig. 12).

Both episodes present a scenario from the pre-and post-tests where Jameis applied her teacher's knowledge about the concept of *rapid random movement of gas particles* in order to address the learner misconception that when gas particles are removed from a container, the remaining particles group up. Jameis's response from the pre-test episode was an explanation that showed the use of diagrams (REP) and understanding of the key concept that *when some gas particles are removed from a container, the remaining particles spread out evenly to fill the whole container with more space between particles (CS)*. In addition, Jameis used her knowledge of LPK to ask questions to engage learners and confront the misconception (LPK). Based on the use of three components, her TSPCK in this instance was labelled as developing quality. On the other hand, the episode from the post-test presents evidence that in addition to the three components used in the pre-test response, she used knowledge of what is difficult to learn by explaining that "when some gas particles are pumped out of the container; the remaining particles do not mass up but still spread out to fill up the entire container because the particles are always moving and spreading out through the entire space they occupy" (WDL). This indicates that Jameis's explanation post intervention was starting to improve as it displayed an interactive use of four components (REP, CS, LPK, and WDL), which were working together to enrich the explanation of the same concept. As a result, the PCK quality in the pre- and post-tests episodes was scored as developing and exemplary respectively, indicating growth in the quality of his TSPCK.

Discussion and Conclusion

Literature on science teaching has argued that teachers are grappling with the task of teaching abstract topics, such as the particulate nature of matter (Treagust et al., 2010). In this study, we aimed at examining how a TSPCK-based intervention supported the development of in-service teachers' PCK in planning. A key finding of this study lies in the observed significant improvement in the quality of teachers' PCK in the particulate nature of matter, the topic of intervention. The improvement indicates growth in understanding of the topic of the intervention from the perspective of planning that relates to formulating responses that draw upon multiple components of TSPCK. Pedagogically, this will transform the content, thus demonstrating improved quality of TSPCK. The result in this study confirms the findings of previous studies, which reported a deeper understanding of applying the TSPCK among teachers who participate in an intervention online; the current studies were based on the transformation of concepts in different topics in sciences (Mavhunga, 2016; Özalp & Kahveci, 2015). Studies have reported an increase in teachers' understanding of their

Pre-test excerpt with developing TSPCK quality	Post-test with exemplary TSPCK quality
I will prompt learners' prior knowledge by using diagrams on the chalkboard to show the movement of air particles in all directions to occupy the entire container. I will then ask learners to explain what they can see happening to the gas particles in the diagrams	I will explain that pas particles move randomly to fill up all the space they occupy. I will prompt learners' prior knowledge by using diagrams on the chalkboard to show the movement of air particles. I will emphasise that gas particles do not group up in a container but move randomly in all directions to fill up the entire space. I always like to engage my learners with questions. I will then ask learners to explain what they can see happening to the gas particles in the diagrams to make sure that they have a sound understanding as they move.

Fig. 11 TSPCK episodes from pre-and post-tests showing growth from developing to exemplary

practices, following their participation in an effective intervention. For example, studies conducted by researchers (Miheso & Mavhunga, 2020; Msimanga et al., 2019) have reported improvements in teacher knowledge among in-service teachers who participated in training workshops that were narrowly focused on a specific aspect of teaching, where the teachers worked collaboratively, and engaged with instructions and activities that were well planned to create more learning opportunities for the teachers to practice the intervention. With this in mind, we used a TSPCK-based intervention to enrich the quality of TSPCK for in-service science teachers.

In the current study, the intervention exposed the teachers to discussions that explicitly interrogated the use of TSPCK components interactively and brought depth to their understanding and application thereof as observed. As far as the new knowledge learnt from the intervention was concerned, there were many incidents

Pre-test excerpt with developing TSPCK quality	Post-test excerpt with exemplary TSPCK quality
I will use diagram D to engage the learners to see as I explain that when gas particles are pumped out from a container, the remaining particles spread evenly in all directions with more space between the particles. I will then ask questions for learners to explain their understanding after my explanation	I will explain that gas particles are constantly moving rapidly to fill up the whole space they occupy. I will then use draw diagrams on the board and ask learners to explain and I will emphasise that when some gas particles are pumped out of the container, the remaining particles do not mass up but still spread out to fill up the entire container because the particles are
	always moving and spreading out through the entire space they occupy.

Fig. 12 TSPCK episodes from pre-and post- tests showing growth from developing to exemplary

of high-quality TSPCK episodes in the post-test and post-CoRe. As expected, the trend in the quality of the in-service teacher's TSPCK shifted from more *limited* and *basic* in the pre-test and pre-CoRe to more *developing* and *exemplary* levels in the post-test and post-CoRe (see the figures above). This means that before the intervention, the number of components used coherently was limited to one or two components that increased as the teachers attended more sessions at the training workshops. The episodes of teacher Paul and Silase presented evidence of such improvements through extensive use of knowledge of representation, including demonstrations in combination with diagrams to transform concepts in ways that support conceptual understanding. These findings concur with those of Coetzee et al. (2020), who reported evidence of rich application of knowledge about representations where the participants were able to combine different representations, such as a demonstration or a video supported by a corresponding diagram after their experience in a training.

In another example, teacher Silase also displayed evidence of growth in the post-CoRe episode in relation to knowledge of what is difficult to understand. It was used to explain the concept that even in the most solid materials at the molecular level, the particles are still moving by vibrating in place. Another evidence of growth in the quality of TSPCK was revealed in teacher Paul's rich application of knowledge of representation, which involved two levels of representation (macroscopic and sub-microscopic(REP) in the post-CoRe episode. This was evident in his application of knowledge of diagrams and demonstration with a balloon to explain that air particles blown into a balloon move quickly in all directions to fill up the whole space. These findings resonate with those of some researchers (Aydin & Boz, 2013; Park & Chen, 2012), who reported that in-service teachers can develop PCK in terms of increased TSPCK component interaction when supported.

Our results revealed that, when relevant support is provided, in-service teachers can develop their understanding and application of knowledge about TSPCK in terms of the interplay among its components to some extent. In light of the results, it can be stated that the intervention was effective and very useful for the in-service teachers. It enabled them to work collaboratively within their groups, learning from each other and from rich insights from the facilitators to improve their teacher knowledge on understanding and applying TSPCK components for planning and teaching. This idea may be explained in terms of Warford's (2011) ZPTD, where veteran facilitators and resourceful peer teachers supported the less knowledgeable in developing their teacher knowledge in the context of the intervention. The success of the intervention could be associated with the collaborative sessions where the in-service teachers learnt how to use the TSPCK components effectively. In our study, Paul, Silase, Esther, Jameis, and Pater were the five group leaders with sound content knowledge and depth in pedagogical content knowledge that was established in a pre-intervention planning session attended by the group leaders but purposely excluded in the current report. These valuable learning experiences have the potential to address Özalp and Kahveci (2015) call for improving science teaching. Regarding the effectiveness of the intervention, it can also be inferred that during the discussion sessions at the intervention, the in-service teachers could have drawn from the collective TSPCK that was presented to them through the learning materials (Loughran et al., 2004) and also from their PCK, thus improving their enacted TSPCK in planning as suggested in the RCM of PCK (Carlson et al., 2019).The study has a limitation which is pinned to the inability to generalise the findings due to the nature of research participants who were a few groups of teachers described as small samples (< 50 teachers). Another limitation stems from the fact that the study focused only on capturing improved teacher knowledge in planning to teach a specific topic, thereby excluding experiences in actual teaching and reflection. However, Shulman (1986) notion that pedagogical reasoning is as important as the actual enactment of the lesson upholds the merit of the study. The study does, however, complement the work of researchers, such as Aydin and Boz (2013) and Park and Chen (2012), and contributes to the theory about the continuous development of PCK of in-service teachers in teaching abstract topics. Therefore, it is recommended that PCK teaching should be about implementation support through continuous teacher development intervention programmes, which should be defined, structured, and packaged at a topic level as shown in this study.

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