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Integration of topic-specific pedagogical content knowledge components in secondary school science teachers' reflections on biology lessons

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Abstract
Teachers' reflections on their practice are a powerful tool for measuring and supporting their professional knowledge. Pedagogical content knowledge is one of the most influential domains of teacher professional knowledge. This multiple-case study investigated the topic-specific pedagogical content knowledge (TSPCK) components that Zambian secondary school science teachers integrate when reflecting on biology lessons. Three teachers from the same school were observed teaching a biology lesson and attended post-observation interviews. Data were mainly collected through lesson plans, lesson observation field notes and post-observation interviews. The data were analysed using in-depth analysis of explicit TSPCK, enumerative and constant comparative approaches. TSPCK maps were constructed to illustrate each teachers' integration of TSPCK components. The results revealed four features about the integration of TSPCK components: (a) None of the teachers depended solely on a single TSPCK component as they integrated other components (b) The components curricular saliency, students' prior knowledge and misconceptions, and conceptual teaching strategies were central in the TSPCK maps of all the teachers, while representations and analogies, and what make the topic easy/difficult to teach/learn were least integrated (c) All teachers had different pairs of reciprocal connections among TSPCK components, and (d) All teachers had different pairs of most integrated components. The implications of these findings for science and teacher education research were presented and discussed. It was concluded that teachers' reflections revealed the integration between TSPCK components and showed them differently. The study recommends investigating teachers' reflections over several lessons and tracking any changes in their TSPCK integration.

Keywords Topic-specific pedagogical content knowledge (TSPCK) · Integration of TSPCK components · Reflection on biology lessons · Secondary school science teachers

1 Introduction

Recent research on teacher knowledge has focused on Shulman's [1] seminal work on pedagogical content knowledge (PCK). Shulman [1] described PCK as a knowledge domain that is specific to teachers/educators—an amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding. Gess-Newsome [2] asserts that (personal) PCK is the knowledge of, reasoning behind, and planning for teaching

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a particular topic in a particular way for a particular purpose to particular students for enhanced student outcomes. This definition of PCK emphasises the person- and topic-specificity of PCK which has implications for this study. PCK is crucial because it determines how teachers teach, and therefore, students' achievement of learning outcomes. As such, understanding teachers' PCK is very critical to improving students' learning.

Because PCK is a blend of content and pedagogy, it is likely to be influenced by whether one is teaching in-field or out-of-field. Singh et al. [3] describe out-of-field (OOF) teaching as the mismatch between a teacher's area of expertise and teaching assignment. In this framing, an OOF teacher teaches a subject they were not trained to teach. On the other hand, an in-field teacher teaches a subject they trained to teach. In Zambia, many secondary school students are taught by teachers who are outside of their expertise in science—OOF teaching. Researchers have raised several issues about the effect of OOF teaching. For example, Du Plessis [4] asserts that OOF teaching may lead to dysfunctional learning environments as OOF teachers may lack the confidence to adequately engage students in challenging content. Furthermore, OOF teachers may avoid in-depth discussions due to a lack of adequate content knowledge. Research has also shown that in-field teachers tend to create productive learning environments. Given the prevalence of OOF teaching in Zambian secondary schools, it may be important to explore the PCK of in-field and OOF teachers of biology. As will be seen later, these types of teaching have implications for the present study.

In the revised consensus model (RCM) of PCK, reflection is considered one of the foundations for the development of teachers' pedagogical content knowledge [5]. Therefore, many PCK studies rely on teachers' reflections as a data source for examining teachers' PCK [6–9]. For example, Zeichner and Liston [7] assert that teachers' reflection-on-action makes them expert, capable and better teachers. Schön [10] explains reflection-on-action as the act of reflecting on the action and the knowledge informing the action. So, reflection-on-action occurs when teachers reflect on a pedagogical action after it occurs, e.g. after teaching. Through reflection, teachers demonstrate their pedagogical reasoning—the thinking underpinning their teaching [11]. Therefore, teachers articulate and explain the reasons underpinning their actions, making their PCK explicit. This way, teachers consider how their practice may be altered. According to Park and Oliver [12], teachers draw upon and expand their professional knowledge by reflecting on action. For Aydin et al. [13] reflection-on-action makes teachers aware of the need to augment or adjust their knowledge for teaching particular topics, leading to improvement of their professional knowledge. Therefore, information from teachers' reflections may inform teachers' future classroom actions and decisions on the needed professional learning to improve their knowledge and teaching. Reflections facilitate teachers' pedagogical reasoning, which allows access to the knowledge influencing the 'what-how-and-why' of teaching [11]. Conclusively, teachers' reflections may be considered a foundation for developing teachers' PCK and hence need to be considered when examining PCK.

Reflection-on-action is closely related to noticing, whereby teachers are prompted to reflect on teaching events that are either noticed by the teacher (teacher-noticing) or the researcher (researcher-noticing). Through noticing, effective teachers can identify and reflect on salient classroom interactions or activities within the visually complex classroom environment [14]. According to Koning et al. [15], noticing enables teachers to identify important and noteworthy classroom incidents, make connections between these incidents and broader principles of teaching and learning, and reasoning about classroom interactions. Noticing can be seen as a prerequisite to reflection on action. Because reflections are considered foundations for the development of PCK, many science education studies have used teachers' reflections as a source of data for assessing teachers' PCK, its development or component integration [8, 12, 16, 17]. These studies report that teachers' reflections assist in understanding the nature, development and/or interactions among PCK components. Furthermore, reflections help to readjust and strengthen the integration of components of PCK by exposing any weak connections among PCK components that may need improvement.

Researchers have expanded Shulman's [1] original conceptualisation of PCK by identifying and describing the components that constitute PCK. This has resulted in various models conceptualising PCK [12, 18–20]. The variations among these PCK models lie in the components' labels, descriptions, or arrangement. For example, the most cited PCK model proposed by Magnusson, Krajcik and Borko [18] conceptualises PCK in terms of five PCK components namely orientation towards science teaching, knowledge of student understanding, knowledge of instructional strategies, knowledge of assessment and knowledge of curriculum. Additionally, Mavhunga and Rollnick [19] describe a model for topic-specific PCK (TSPCK) comprising five components—students' prior knowledge including misconceptions, curricular saliency, what makes a topic easy or difficult to understand, representations including analogies, and conceptual teaching strategies. Recently, the revised consensus model (RCM) was proposed which describes PCK in terms of five components namely content knowledge, pedagogical content knowledge, knowledge of students, curricular knowledge and assessment knowledge. Although PCK has been conceptualised as a set of various components, researchers have focused their studies on establishing teachers' knowledge of the PCK components and their integration [9, 17, 20–27]. Researchers have attempted to understand how teachers link/connect/integrate the different knowledge domains during planning, teaching or reflecting. A literature review by Chan [28] found 22 studies that used the PCK map approach to investigate the integration of PCK components. Aydin et al. [13] note that researchers use terms like interaction, coherence, intersection, interrelationship, interrelatedness, and integration to refer to connections/links between the PCK components. In the present study, the terms integration, connection and interaction will be used interchangeably to refer to links between two or more PCK components.

Often, teachers do not use the PCK domains in isolation but integrate the different domains in a variety of ways. Expert teachers tend to connect the PCK domains in various complex ways while novice teachers tend to connect a few components. Researchers assert that the integrations among PCK components measure the coherence in teachers' pedagogical reasoning and indicate the quality of teachers' PCK [18, 20, 29, 30]. For instance, Park and Chen [20] argue that a developed PCK has all its components strongly integrated to each other such that the whole PCK structure can function to support student learning. Furthermore, Bayram-Jacobs et al. [30] aver that a teacher demonstrates developed PCK when s/he plans to use different teaching strategies by considering students' understanding of science or their difficulties, and plans to use appropriate methods/tools to assess learning. Furthermore, several researchers agree that high integration of PCK components indicates high or developed PCK, while low integration indicates limited PCK [12, 13, 20, 25, 31]. Therefore, revealing a more holistic picture of PCK by examining component integration may provide a deeper insight into PCK, and this may provide enriched knowledge of teachers' PCK.

Recently, integrating PCK components has been explored in various science topics. For example, Park and Chen [20] explored the nature of the integration of PCK components in the topics of photosynthesis and heredity. Results revealed that the integration was idiosyncratic and topic-specific. They also found that knowledge of student understanding and knowledge of instructional strategies and representations were central to the integration. They concluded that the quality of PCK depends on the coherence among the components and the strength of individual components. Akin et al. [27] examined the interactions among PCK components of novice and experienced chemistry teachers in teaching reaction rate and chemical equilibrium topics. They concluded that the teachers integrated the PCK components differently. Meanwhile, Gao et al. [9] examined how a middle school teacher integrated and reflected on PCK components during the teaching of natural selection. The study found that knowledge of instructional strategies and representation and knowledge of science content were most frequently connected with other PCK components. Sæleset and Friedrichsen [24] evaluated pre-service teachers' integration between knowledge of students' understanding and instructional strategies. The pre-service teachers taught various science topics such as nutrition, the eye, energy content in food, puberty, and sexual health. The authors found that participants frequently demonstrated the integration of knowledge of students and knowledge of instructional strategies in a topic-specific way. Focusing on cell division, Sen et al. [32] investigated how various PCK components informed each other in the PCK maps of a curriculum-led, content-expert, and content-novice teacher. They found that teachers integrated the PCK components differently. More recently, Mapulanga et al. [22] investigated the integration of planned TSPCK components among secondary school biology teachers. They concluded that the integration of TSPCK components was idiosyncratic and the more central components were conceptual teaching strategies, curricular salience and students' prior knowledge and misconceptions. To sum up, results on PCK component integration consistently show that PCK components are integrated in topic-specific, person-specific and context-specific ways. However, the apparent gap in many of these studies (except a few, e.g. [23, 24, 32]) is the lack of consideration of the direction of the interactions among PCK components [31]. Therefore, Sen [31] has called for more research that considers the direction of the integration. It seems that researchers' interest in the integration of PCK components has grown because researchers have reached a consensus that the frequency of integration among the PCK components is an indicator of the quality of teachers' PCK, and a well-developed PCK and an effective teaching should comprise all PCK components integrated.

The rationale of studies on PCK component integration is that the quality of teachers' PCK can be seen in their integration of the components and that complex integration of all components of teacher knowledge constitutes developed PCK. The findings of these studies give valuable insight into component interactions. For example, most studies report that integrating PCK is person- and topic-specific [9, 20, 22, 27, 32]. Furthermore, the integration of PCK components has been reported to be context-specific [20, 25]. The topic- and context-specificity of PCK makes it problematic to apply the results of PCK studies to all topics in a subject (e.g. biology). Hence, a need exists to evaluate the integration of topic-specific PCK (TSPCK) components in other challenging biology topics to widen and extend our understanding of component interactions. This understanding would help to improve the teaching of difficult biology topics. However, many of the previous studies on PCK component integration ignore the direction of integration. Therefore, a focus on the direction of the integration of the PCK components would expand our knowledge about the most influential components.

The dearth of literature on secondary school biology teachers' integration of PCK components in their reflections on taught biology lessons suggests that how secondary school biology teachers integrate their PCK components during reflection on teaching incidences remains unknown. In addition, there is much to be learned about how PCK is constructed for teaching different topics and how the integration of the components may differ for in-field and out-of-field science teachers. Although some studies on TSPCK component interaction have been conducted in sub-Saharan Africa [22, 23, 33, 36], none of these studies have explored the research question asked in the current study. Therefore, the current study investigates the integration of TSPCK components in science teachers' reflection-on-action on biology lessons. The findings would give insight into the nature of the integration of TSPCK components, which may be used to promote biology teaching in Zambia and other similar contexts. Furthermore, findings would extend knowledge in PCK research by showing how our sample (consisting of one in-field and two out-of-field teachers) integrates the topic-specific PCK components, considering the direction of integration. Therefore, this study sought to answer the following research question: *What is the nature of TSPCK component integration in science teachers' reflections on taught biology lessons?*

The study's novelty lies in determining the TSPCK components integrated into science teachers' reflections on taught lessons, with an emphasis on the direction of component interactions. This is consistent with the call to consider the direction of the interactions in component interactions [31]. Furthermore, there is a lack of research into PCK for excretion, holozoic nutrition and the nervous system although these topics are difficult to teach and learn [38]. Therefore, the study's findings highlight the TSPCK components integrated in teachers' reflections-on-action and the nature of the integration. The findings also highlight the participants' professional development requirements for improving their TSPCK in teaching excretion, holozoic nutrition and the nervous system. The study's outcomes may make teachers aware of pertinent issues in TSPCK component integration when reflecting on biology lessons, making them better teachers. Furthermore, the study contributes to the few biology education studies [8, 9] that report on teachers' integration of PCK components through reflections-on-action.

2 Theoretical background—pedagogical content knowledge (PCK)

Pedagogical content knowledge (PCK) is the teachers' knowledge and ability to arrange, represent and adapt content to the different learning needs of students [1, 5]. According to Park and Oliver [12], PCK comprises teachers' knowledge and its enactment. Chan et al. [34], assert that teachers draw upon PCK to plan and reflect on teaching. Thus, PCK underlies teachers' knowledge of, reasoning behind and planning for teaching particular topics in a particular way for a particular purpose to particular students. Therefore, it can be inferred that teachers draw from their PCK to plan particular lessons on specific topics and enact and reflect upon them afterwards. The present study is located within the revised consensus model (RCM) of PCK [35]. A simplified version of the RCM was adapted from Makchechane and Mavhunga [36] as illustrated in Fig. 1. The RCM emphasises the realms of PCK—(i) collective PCK (cPCK), which is the specialised knowledge shared by the community (ii) personal PCK (pPCK), which is the individual's personalised PCK. Personal PCK can be demonstrated through planning for teaching as planned PCK (plPCK) and classroom enactment as enacted PCK (ePCK). Furthermore, the RCM describes PCK in terms of three grain sizes, i.e. discipline-specific PCK, topic-specific PCK, and concept-specific PCK [35]. Discipline-specific PCK refers to the PCK needed to teach specific domains or subjects. For example, the PCK needed to teach biology would represent the discipline PCK in biology. As already mentioned, topic-specific PCK is the PCK needed to teach specific topics in a discipline [22, 23]. An example of topic-specific PCK is the PCK needed to teach respiration [22]. On the other hand, concept-specific PCK can be seen as the PCK needed to teach specific concepts in a topic such as cells [31].

The simplified version of the RCM connects well with the topic-specific pedagogical content knowledge (TSPCK) model of Mavhunga and Rollnick [19], shown on the right side of Fig. 1. The TSPCK model was selected for the current study because of the topic-specific nature of the study's focus. The model consists of five content-specific components described by Buma et al. [37] as follows: (a) *curricular saliency* (CS) refers to the capacity to choose and organise key concepts for teaching. (b) *students' prior knowledge and misconceptions* (SPK) refers to understanding what information students already possess, incorrect and alternate conceptions, from own experiences, previous learning or both. (c) *representations and analogies* (RP) is the knowledge of methods/ways (e.g., charts, demonstrations, metaphors, and models) for representing concepts in ways that support the conceptual development of ideas. (d) *what makes the topic easy or difficult to teach or learn* (WD) refers to the comprehension of topics which

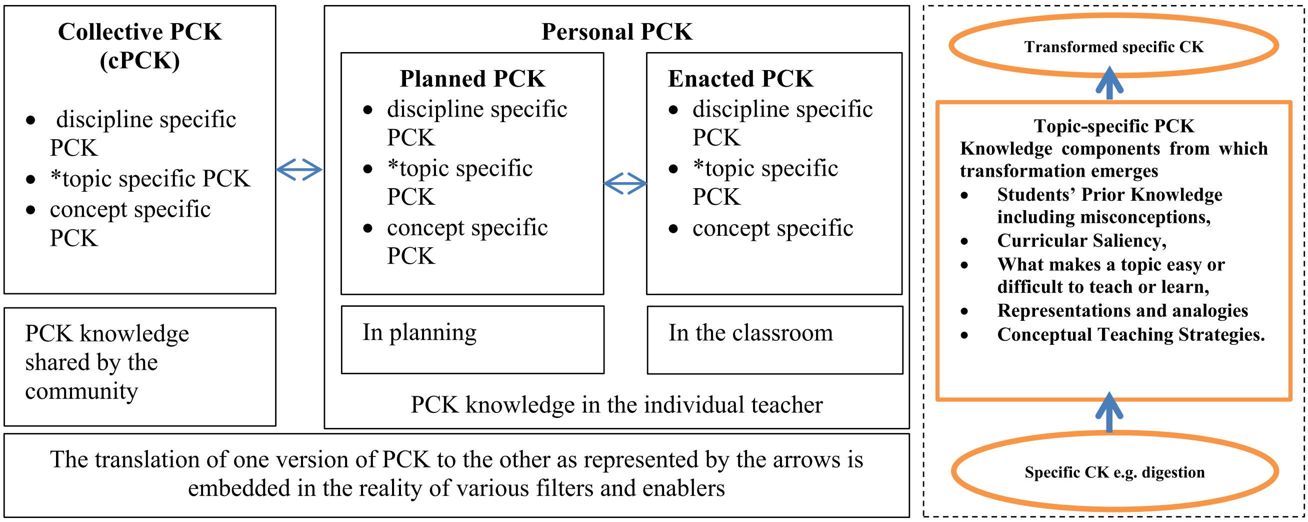

Fig. 1 Simplified positioning of topic-specific pedagogical content knowledge (TSPCK) in the refined consensus model of pedagogical content knowledge (PCK) (Adapted from Makchechane and Mavhunga [36])

demand extra care and time while teaching concepts that students usually find challenging, and (e) *conceptual teaching strategies* (CTS) refer to the understanding of the topic-specific teaching techniques that enable teachers to combine the other four components when explaining specific concepts.

The present study was located at the topic-specific grain size of PCK (TSPCK) as it aimed at exploring the teaching of several concepts from three biology topics—excretion, holozoic nutrition and the nervous system. In this framing, each topic has its own way of being taught, students' difficulties and misconceptions, objectives, effective teaching and assessment methods. Furthermore, these selected topics are considered difficult to teach and learn [38]. The study focuses on teachers' enacted TSPCK (eTSPCK) in the classroom i.e. during teaching (eTSPCKt) and reflection (eTSPCKr). The TSPCK model served as a conceptual and analytical framework to examine teachers' reflections and unpack the integration of the TSPCK components in teachers' reflections on taught lessons. The TSPCK components are complementary and facilitate insight into teachers' integration of TSPCK components in their post-lesson reflections. Therefore, the TSPCK model was used to map out the TSPCK component integration in teachers' reflections-on-action for the respective topics they taught.

3 Methodology

3.1 Research design

This study adopted the exploratory multiple-case study design, which is one of the qualitative research approaches [39]. The multiple-case study design allows the description of more than one case (situation and phenomenon) and comparison among the cases. Therefore, this design was used to describe and compare three science teachers' integration of TSPCK components in their reflection-on-action about biology lessons. In this study, the case referred to each of the three participants because the study sought to explore and give an in-depth description of their integration of TSPCK components for the taught topics.

3.2 Study context

The Zambian secondary school curriculum emphasises the need for teachers to have the right professional knowledge to teach at the secondary school level [40]. Therefore, teacher training universities and colleges have been charged with the responsibility of adequately training the teachers before their deployment. Studying for a bachelor's degree in science education takes four years, while a secondary teacher's diploma takes three years. Science teachers are mainly trained to teach one major subject and one or two other minor subjects. For example, teachers may be trained to teach biology (major subject) and chemistry (minor subject) and vice versa. However, owing to the shortage of science teachers in the country, it is very common to find teachers teaching subjects they were not trained to teach (i.e. out-of-field teaching). For example, two of the participants in the current study taught biology even though they were not specialised in teaching biology, one specialised in agricultural science, and the other in mathematics and physics education. The Zambian secondary school biology curriculum covers various topics that teachers must teach [41]. Among these topics are holozoic nutrition (nutrition in animals), excretion, and the nervous system. These topics have been reported to be challenging for some teachers and or students. The continued secondary school students' poor academic performance in biology in the Zambian national examinations suggests that biology teaching may be problematic [42]. Although it is believed to influence how teachers conduct their lessons and hence students' learning, the issue of the TSPCK that teachers use to teach biology topics remains under-exploited in Zambia [22, 42]. Hence, it is valuable to explore the teaching and learning of challenging biology topics in terms of the TSPCK components that teachers demonstrate or integrate when reflecting on taught lessons.

3.3 Sampling and sample characteristics

A purposive sample was selected from one school based on criterion sampling. Firstly, since PCK is context-specific, the participants were selected from the same public school. Therefore, they had similar teaching materials and were all teaching biology. Secondly, teachers had different levels of qualifications and teaching experience. At the time of the study, the selected school only had one qualified biology teacher (in-field teacher), and other biology teachers were not qualified biology teachers (out-of-field teachers) and had only taught biology for less than 5 years, as shown in Table 2. The teachers' experience in teaching biology ranged from less than one to three years, so they were considered novices [43]. Thirdly, the participants were easily accessible to obtain deep information on PCK in the specific topics taught. Finally, the lack of overlap in the teachers' schedules helped choose these teachers from the same context. Because integrating TSPCK is topic-, person-, and context-specific, examining the individual novice teachers' integration and reflection on TSPCK enabled the understanding of the complexity of their TSPCK [25]. Participants' characteristics, such as gender, qualification and teaching experience, are shown in Table 1. The participants volunteered to participate in the study and audio-recording their lesson and interview sessions. They were told about the aim of the study and that involvement in the study was voluntary. Furthermore, pseudonyms were given to participants, and the school's name was not reported to maintain confidentiality.

3.4 Instruments

The study mainly used the post-observation interview guide, which was adapted from Friedrichsen et al. [44] and Park et al. [45]. The interview guide comprised questions for the general information of respondents, open questions about teachers' observations/noticing, and five TSPCK components namely curricular saliency, what makes the subject easy or difficult to teach or learn, students' prior knowledge and misconceptions, representations and analogies, and conceptual teaching strategies. The open questions aimed at tapping into the teachers' noticing while the rest of the questions were mainly led by the researcher's noticing and aimed at probing participants' integration of the TSPCK components. Four university biology education lecturers and three secondary school biology teachers participated in validating the interview guide. Their observations and remarks were used to make the questions clear, concise and aligned with the TSPCK components (see sample questions in Table 2).

Table 1 Characteristics of participants

Name	Gender	Highest teaching qualifications	Teachers' category	Subject combination		Years of teaching	Years of teaching biology	School type
				Major	Minor			
Marie	F	Bachelor's degree	In-field	Biology	Chemistry	15	3	Public
Jemsa	F	Diploma	Out-of-field	Agriculture science	–	2	< 1	Public
Jeff	M	Diploma	Out-of-field	Mathematics	Physics	4	3	Public

Table 2 Sample leading questions for each TSPCK component

TSPCK component	Sample questions included in the questionnaire
Open questions	1. How do you feel about the lesson that I just observed today? What went well? What did not go well? 2. As you reflect on this lesson, did it proceed as you anticipated in your plan? If not, what caused the change (e.g., students/pupils knew more/less than expected, a student's behaviour caused a change in the way I introduced the lesson, etc.)? Please provide examples where necessary 3. What do you consider the most effective/successful teaching moment was in the lesson? Why? How did you achieve it? Why did it work? What signalled to you that the students/pupils were learning? How did you check their learning?
Curricular saliency	1. What important concepts did you intend your learners to learn? 2. Why is it important for students to know these concepts?
What makes the topic easy or difficult to teach/learn	1. Were there any difficulties you identified during the lesson? How did you address them? Did it work? Why do you think it worked/did not work? 2. Did you have any difficulties teaching this lesson today/ were there any concepts you were not comfortable to teach? How can they be overcome?
Students' prior knowledge, and misconceptions	1. What strategies did you use to check/confirm students' prior knowledge in the topic? 2. Were there any student misconceptions you identified during the class that you haven't known before? If yes, how did you respond to challenge them? Did it work? Why do you think it worked/did not work?
Representations and analogies	1. I noticed that you used/did not use any representation (e.g. chart/equation/diagram etc.), could you explain why? 2. How did the representation help students' learning?
Conceptual teaching strategies	1. Why did you use the question & answer/lecture/demonstration/discussion/experiment to teach this topic? How does it/do they promote learning? 2. What other method can be used?

3.5 Data collection procedures

Firstly, teachers were observed teaching one biology lesson each. The lessons were audio-recorded and transcribed verbatim. The teachers taught different biology topics, two taught grade eleven classes, and one taught a grade ten class (see Table 3). Secondly, each teacher was interviewed to probe the reasons for observed actions or decisions about selected incidents noticed in the lesson plans or observed lessons. The interviews enabled an understanding of the teachers' reflections on the taught lessons (reflection-on-action) and the integration of TSPCK components in the reflections. Interviews were conducted soon after the lesson observations so the teachers could easily remember the classroom/teaching events. Before recording the interviews on audio, the researcher (first author) explained the interview questions to the participants. Teachers revisited their lesson plans and justified their actions or choices during the interviews. It is worth noting that since the interviews were conducted concerning specific lesson plans and observed lessons, some questions were specific to each teacher. However, the first general questions were asked to all three teachers. The

Table 3 Description of the participants' lessons

Participant	Grade & Duration	Topic taught—(focus of the lesson)	Specific learning outcomes
1. Marie	Grade 11, 80 min	Nervous system—(parts of the brain)	a. Identify the parts of the brain b. Describe the functions of parts of the brain
2. Jemsa	Grade 10, 40 min	Holozoic nutrition—(parts of the alimentary canal)	a. Identify the parts of the alimentary canal b. Describe the stages of holozoic nutrition
3. Jeff	Grade 11, 80 min	Excretion—(parts of the human urinary system)	a. Identify the parts of the human urinary system b. Describe the functions of parts of the human urinary system

interviews were conducted to probe why teachers used certain activities in their lessons. The interviews lasted about 40 min. For easy analysis, the interviews were transcribed verbatim.

The primary data sources used in this study included lesson plans, field notes from lesson observations (including audio-recorded lessons, photographs of board work/teaching aids used), and transcripts of post-observation interviews. Table 4 shows the data sources and what the data were used for.

3.6 Data analysis

The researcher and an independent science education researcher separately coded and analysed the data by reading and rereading the lesson plans, lesson delivery transcripts/ and field notes (taken during lesson observation) [46]. The Krippendorff's alpha agreement level between the coders was found to be 0.78, which indicates a satisfactory level of agreement. Any disagreements that arose in the selection, coding and interpretations of TSPCK incidents were discussed until agreed on. The other authors verified the whole analysis process. The involvement of different parties in the analysis helped identify TSPCK/teaching incidents that indicated the enactment of TSPCK to probe teachers' reflections-on-action during interviews. TSPCK incidents included an integration of two or more PCK components in the TSPCK model i.e. a teaching incident represented the existence of two or more PCK components. For example, if a teacher decided to use a chart [in the lesson plan], this was followed up to see how it was used during the lesson (lesson observation), the researcher noted how the teacher used the chart (field notes). During interviews, the researcher asked why the teacher used the chart in the manner s/he did. The rest of the analysis sought evidence of integration among TSPCK components in the interview transcripts.

The analysis involved reading the interview transcripts several times and summarising the data into appropriate codes (TSPCK components) and categories (integrated/connected TSPCK components) [46]. There were 20 categories reflecting all possible reciprocal connections of PCK components used to analyse the data. The codes and categories were assigned to the appropriate sections/evidence in the reflection interview transcripts as described below. Table 5 shows some categories and their explanations.

The PCK mapping approach [20] was used to analyse the nature of interactions among the TSPCK components. The results were presented on TSPCK maps showing the components and frequency of component integration by each teacher in their reflections. The three main steps of the PCK mapping approach were followed to construct the TSPCK maps [28]: (1) In-depth analysis of explicit TSPCK, (2a) Enumerating and Mapping the TSPCK integration (2b) Visualisation in the form of a TSPCK map, and (3) Constant comparison. The three steps are briefly described below, and a summary of the steps is provided in Fig. 3.

3.6.1 Step 1. In-depth analysis of explicit TSPCK

This step involved the explicit identification of specific TSPCK incidents and TSPCK components for each teacher by analysing observation data (field notes) and interview transcripts. Lesson plans were used to probe the teachers if they deviated from the plan. We searched the data for component integration and evidence for the identified components. Table 6 illustrates the in-depth analysis process, evidence for the TSPCK components and the coding process of the integrated TSPCK components. During this step, we identified 18 incidents for Marie, 13 for Jemsa and 21 for Jeff, which were used in the enumerative process.

Table 4 Data sources and what the data were used for

Data sources	Purpose
Lesson plans	Comparing teachers' planned and enacted activities for further probing in the interviews
Lesson observation—field notes, transcripts of audio-recorded lessons, and photographs of the board work/teaching aids	Obtaining information on teachers' enactment of knowledge of TSPCK components in a real classroom situation
Post-observation interviews	Obtaining information on teachers' reflections-on-action, and integration of TSPCK components

Table 5 Example of categories for analysing data

Interaction among TSPCK components		Example
Categories[a]	Explanation	
RP → SPK	RP informed SPK	A teacher uses a specific representation to seek or reinforce students' prior knowledge or address a misconception
RP → WD	RP informed WD	Using a particular representation to remedy students' difficulties
RP → CS	RP informed CS	Using a particular representation to present the content
RP → CTS	RP informed CTS	Using a particular teaching strategy in consideration of the available/chosen representation
CTS → SPK	CTS informed SPK	Using a specific instructional strategy to handle a students' difficulty, misconception or pre-requisite knowledge
CTS → WD	CTS informed WD	Taking a learning difficulty, misconception, or pre-requisite knowledge into consideration while selecting or using a conceptual teaching strategy
CTS → CS	CTS informed CS	Using different teaching methods to present the content
CS → SPK	CS informed SPK	Using students' prior knowledge and misconceptions to structure the content or presenting the content in consideration of students' prior knowledge/misconception
CS → WD	CS informed WD	Using students' learning difficulties to structure the content or presenting the content in consideration of students' learning difficulties
WD → SPK	WD informed SPK	Identifying students' prior knowledge and misconceptions that make learning difficult

SPK students' prior knowledge including misconceptions, *CS* curricular saliency, *WD* what makes a topic easy or difficult to understand, *RP* representations including analogies, *CTS* conceptual teaching strategies

[a]Each of these categories had a reciprocal connection (e.g. the reciprocal connection RP→SPK is SPK→RP), thus making a total of 20 categories

Table 6 Example of in-depth analysis and coding of explicit TSPCK

Sample Incident in lesson plan/observation/or interview	Incident description	Codes and evidence of TSPCK components	Categories for integrated components
Incident name: use of chart of the human alimentary canal			
1. During the lesson, the teacher displayed a chart of the human alimentary canal [RP]. She then asked the students to go to the board and identify the different parts of the alimentary canal [CTS]	Teacher linked her knowledge of RP to CTS	**RP:** Displaying the chart of the human alimentary canal **CTS:** Asking the students to go to the board to identify the different parts of the alimentary canal	RP→CTS
2. During the interview, she was asked why she chose to use the chart as a teaching aid [RP]. While reflecting on RP, Jemsa said: "On the chart [RP], I wanted the learners to know the parts of the alimentary canal such as mouth, oesophagus, stomach, small intestine, large intestine, and anus [CS]. With a chart [RP], I will be pointing [CTS] at the parts of the alimentary canal and learners will be able to know the different parts that make up the alimentary canal….[CS],"	Teacher indicates that the chart [RP] would help students to know the different parts of the alimentary canal [CS] and that she would use the chart [CTS] to show the different parts of the alimentary canal. The excerpt also shows that she paid attention to central ideas such as mouth, oesophagus, stomach, small intestine, large intestine, and anus that she intended the students to learn	**RP:** Referring to the chart as a teaching aid **CS:** Mentioning the parts of the alimentary canal students were to identify **CTS:** Pointing at the parts of the alimentary canal	RP→CS RP→CTS **NB:** A frequency of one (1) was assigned to each of these pairs

CS curricular saliency, *RP* representations and analogies, *CTS* conceptual teaching strategies

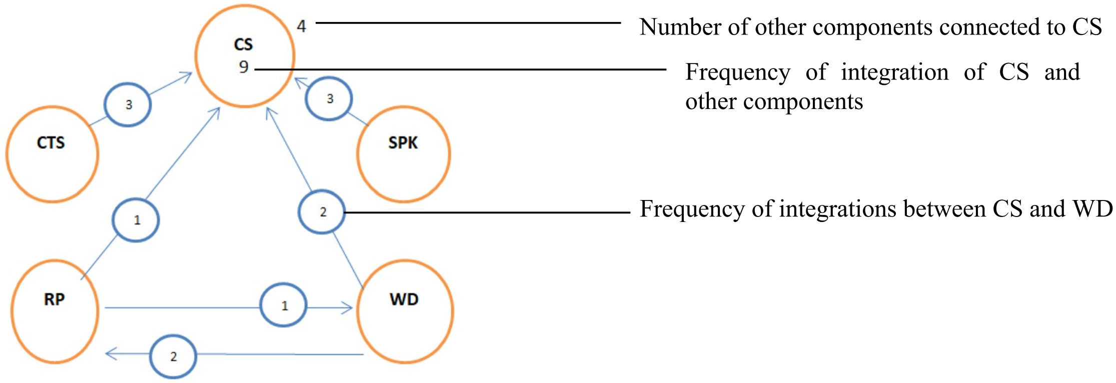

Fig. 2 Sample TSPCK Map. SPK: students' prior knowledge including misconceptions. *CS* curricular saliency, *WD* what makes a topic easy or difficult to teach or learn, *RP* representations and analogies, *CTS* conceptual teaching strategies

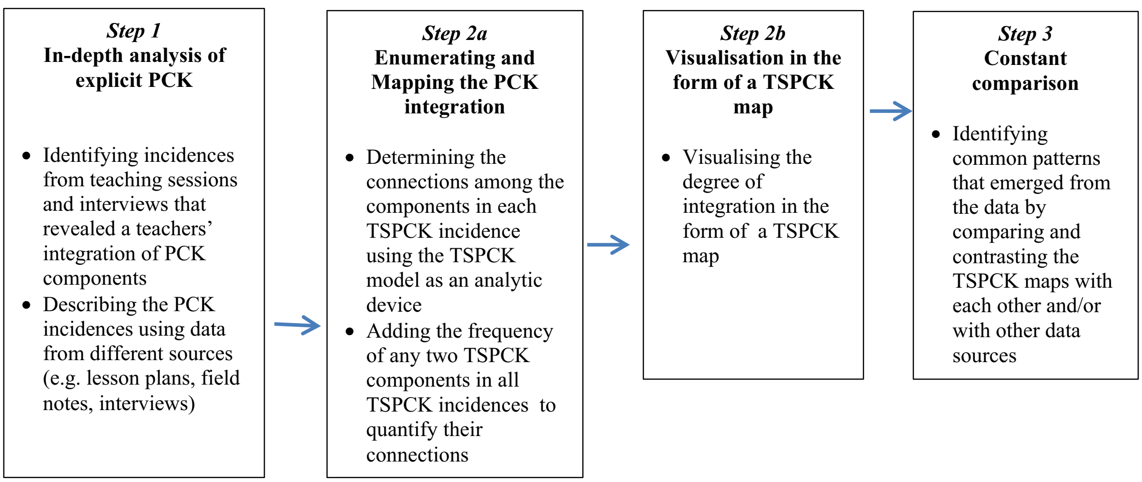

Fig. 3 Steps of the data analysis process (adapted from Chan [28])

3.6.2 Step 2. (a) Enumerating and mapping the PCK integration (b) Visualisation in the form of TSPCK maps

During step 2, we constructed a TSPCK map for each incident based on the integrated TSPCK components [25]. A headed arrow line (pointing to the integrated component) was used when a teacher connected one component when reflecting on the other. There were twenty possible integration types among the five TSPCK components (see Table 5 for an example of integration types). It was assumed that there was at least one connection between any identified pair of components and that the connections had equal strength [20]. Therefore, one frequency count was recorded for a connection between any two components. When three components were integrated in the same incident, each pair was coded separately. Next, we added all specific interactions and all the interactions that occurred in the analysis for each teacher to show how often components are interconnected to each other [25]. The frequency for specific pairs was indicated on the lines, while that of components was indicated in the circles along with the components. The number of other components connected to each component was indicated besides each component. For example, the TSPCK map in Fig. 2 shows that CTS was integrated to CS 3 times, 4 other components integrated CS, and CS was integrated 9 times i.e. (3 + 1 + 2 + 3). The total number of interactions in this map was 12, i.e. (3 + 1 + 2 + 3 + 1 + 2).

3.6.3 Step 3. Constant comparison

The constant comparative method was used to compare the findings within and between participants. This was done inductively by looking for similarities and differences in the specific and total component integrations in the teachers' TSPCK maps. The whole data analysis process is summarised in Fig. 3.

3.7 Trustworthiness of the study

The study's trustworthiness was established by meeting the criteria for credibility, confirmability, dependability, and transferability. Credibility was ascertained by the authors being immersed in the data analysis for a long period. Further, the first analyses by the first author and an independent researcher were regularly verified by the other authors. In addition, the Krippendorff's alpha agreement level between the coders was found to be 0.78. In-depth descriptions of the data collection and analysis procedures were given to meet the criteria for dependability and confirmability. The criteria for confirmability were met by using the TSPCK model as a framework for the study's framing, analysis and reporting. In addition, the verbatim reporting of teachers' integration of TSPCK components ensured the confirmability of the findings. Furthermore, triangulation was done by checking interview data with lesson plans and field notes of observed lessons. For transferability, the context of the study was described in detail for easy relation to other contexts.

4 Findings

This study explored the integration of TSPCK components in in-field and out-of-field science teachers' reflections of taught biology lessons. The in-depth analysis and enumerative approach enabled the construction of the TSPCK maps for each teacher participant (see Fig. 4). The number of connections in the TSPCK maps indicates the quality of teachers' TSPCK for teaching their respective topics [25, 31]. It follows that teachers with more connections in their TSPCK maps demonstrate more developed TSPCK in their respective topics. The study found that various TSPCK components were integrated in different ways when teachers reflected on each component (see Table 7). This is consistent with the context- and topic-specific nature of PCK given that teachers taught different topics and grades. The results (on teachers' TSPCK integration) are presented based on the salient features emerging from the analysis of the TSPCK maps. Four salient features emerged from the TSPCK maps (Fig. 4 and Table 7). First, the salient features are presented and then we present sample excerpts with examples. To help the readers follow the presentation of the results, examples from lesson plans/field notes and interviews are provided with codes for the integrated TSPCK components in square brackets.

4.1 First feature

None of the teachers depended solely on a single TSPCK component as they integrated other components. However, the results revealed that the teachers had different numbers of integrated components. For example, Jemsa and Jeff

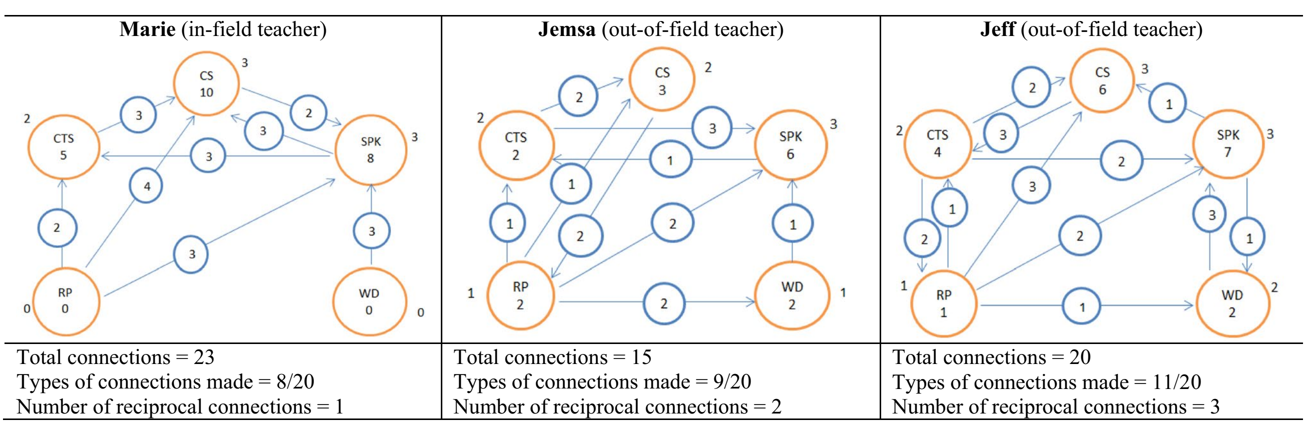

Fig. 4 TSPCK maps of the three teachers. *SPK* students' prior knowledge including misconceptions, *CS* curricular saliency, *WD* what makes a topic easy or difficult to teach or learn, *RP* representations and analogies, *CTS* conceptual teaching strategies

Table 7 Frequency of key patterns in teachers' TSPCK maps

	Teacher (frequency)		
	Marie	Jemsa	Jeff
Most connected components	CS (10) SPK (8),	SPK (6) CS (3)	SPK (7), CS (6)
Least/unconnected components	RP, WD (0)	RP (1) WD (1)	RP (1)
Reciprocal connection	CS-SPK (5)	CTS-SPK (4) CS-RP (3)	RP-CTS (3) CTS-CS (5) SPK-WD(4)
Most connected pairs	RP-CS (4)	CS-SPK (4) CS-RP (3)	CTS-CS (5) WD-SPK (4)
Least connected pairs	RP-CTS (2) WD-SPK (2)	RP-WD (1) RP-CTS (1) WD-SPK(1)	CS-SPK (1) RP-WD (1)
Missing/unconnected pairs	RP-WD CTS-WD CS-WD	CS-SPK CTS-WD CS-WD	CTS-WD CS-WD

SPK students' prior knowledge including misconceptions, *CS* curricular saliency, *WD* what makes a topic easy or difficult to teach or learn, *RP* representations and analogies, *CTS* conceptual teaching strategies

integrated all five components, while Marie only integrated three (CS, SPK, and CTS). Marie had 23 connections in total, Jeff had 20 connections, and Jemsa had 15 connections. The teachers also differed in the types of connections they made. Marie had eight different connections out of the 20 possible connections. Jemsa had nine types of connections, while Jeff had 11 types of connections. In terms of reciprocal connections, Marie had one (CS-SPK), while Jemsa had two (CTS-SPK, CS-RP) and Jeff had three (RP-CTS, CTS-CS, and SPK-WD). None of these connections were common among the participants. The results suggest that Jeff (an out-of-field teacher) had the most integrated TSPCK map, followed by Marie (an in-field-teacher) and lastly Jemsa (an out-of-field teacher) (see Fig. 4).

4.2 Second feature

The components CS, SPK and CTS were central in the TSPCK maps of all the teachers. However, the components RP and WD were least integrated in all the maps. The teachers' reflections were based on their knowledge of CS, SPK and CTS. However, the teachers differed in terms of the frequency with which they integrated these components. CS, SPK and CTS were most frequently integrated by Marie followed by Jeff and then Jemsa (see Fig. 4). To illustrate why RP was least enacted, it should be noted that all three participants only used charts or diagrams in their lessons. This may indicate that they had limited options of representations to use in their lessons. For instance, this was picked up in Jeff's interview, where he could not clearly state other representations he could have used in place of the charts.

4.3 Third feature

All teachers had different pairs of reciprocal connections. Jeff's reciprocal connections were RP-CTS, CTS-CS and SPK-WD. Jemsa's reciprocal connections were between CTS-SPK, and CS-RP, while Marie's reciprocal connection was CS-SPK.

The following example from Jemsa's interview illustrates teachers' reciprocal connections. First, when Jemsa was asked the important concepts she wanted the students to learn [CS], she said: "I wanted them to know the definition of holozoic nutrition, the five stages which are ingestion, digestion, absorption, assimilation and egestion [CS]. On the chart [RP], I wanted the learners to know the parts of the alimentary canal, there is the mouth, oesophagus, stomach, small intestine, large intestine and the anus". Later in the interview, she was asked why she used the chart [RP] to represent the concepts, she said: "On the chart, I wanted the students to know the parts of the alimentary canal such as mouth, oesophagus, stomach, small intestine, large intestine, and anus." In the first instance, Jemsa connected CS to RP, while in the second instance, she connected RP-CS.

4.4 Fourth feature

All teachers had different pairs of most integrated components. For example, Marie's most integrated pair was CS-RP (4 times), Jemsa's most integrated pair was CS-SPK (4 times) and Jeff's most integrated pair was CS-CTS (5 times).

The following section illustrates the findings (on teachers' TSPCK integration) in detail through examples from lesson plans/observation field notes and interviews. To help the readers follow the presentation of results, codes for the integrated TSPCK components were added in square brackets.

Marie was asked about the difficulties she identified in the lesson and how she addressed them [WD], in her response, Marie said: "A few students were not coming out to contribute effectively [SPK]. I noticed three or four students who were not participating in the lesson [SPK], I would engage them in the lesson [CTS] and ask more questions about why they were not participating [WD], and engage them in a group activity or to present in the next lesson [CTS]".

In this excerpt, Marie used her knowledge of students' learning difficulties [WD] to reveal her knowledge of SPK, and CTS. So, she linked WD to SPK, CTS. Specifically, Marie demonstrates that she can identify students who do not participate and those who provide inadequate answers [SPK]. She also shows that she makes efforts to find out why students do not participate in the lesson, allowing her to tap into their learning difficulties [WD], and she engages the students through general science teaching strategies e.g. group activities and presentations [CTS].

When she was asked why it is important for students to know the concepts she chose to teach [CS], she said: "Yes, that is now about skills and values, they should have awareness of how the brain works, how to take care of their bodies [CS], understand that different individuals have got different abilities and disabilities. They should be able to coexist with different individuals that have different challenges, maybe in vision, and mental abilities and to do different activities. They may be able to relate why some people they have met are more or less able to do certain activities [SPK]". Here, Marie linked CS to SPK by explaining that students would relate what they learn to their previous experiences [SPK].

Jemsa also revealed her knowledge of CS and CTS when reflecting on RP. For instance, during the lesson, Jemsa displayed a chart of the human alimentary canal [RP]. She then asked the students to go to the board and identify the different parts of the alimentary canal [CTS]. During the interview, she was asked why she chose to use the chart as a teaching aid [RP]. The excerpt below shows her response to the researcher:

> Researcher: I noticed that in your class, you used a chart of the human alimentary canal, could you explain why?
> Jemsa: On the chart [RP], I wanted the learners to know the parts of the alimentary canal such as mouth, oesophagus, stomach, small intestine, large intestine, and anus [CS]. I used the chart for the learners to see and know the parts of the alimentary canal. A chart is better because learners will be able to see, it is different whereby I just go and explain that the alimentary canal runs from the mouth to the anus. Learners may not be able to connect. I will just be talking more like I'm just preaching to them. With a chart [RP], I will be pointing [CTS] at the parts of the alimentary canal [CS], and learners will be able to know the different parts that make up the alimentary canal and if a diagram comes in the exam, learners will remember that they identify the parts in class. So it will be easy for learners to remember, to recall.
> Researcher: What other teaching aids/representations could be used in this lesson?
> Jemsa: Without a chart, it would be difficult to teach, for the mouth it can be easy but some parts are not even seen. Maybe using text books or maybe drawing the diagram on the board.

The above incidence and excerpt show that Jemsa linked her knowledge of RP to CS and CTS. She indicates that the chart [RP] would help students to know the different parts of the alimentary canal [CS] and that she would point on the chart [CTS] to show the different parts of the alimentary canal. The excerpt also shows that she paid attention to central ideas such as mouth, oesophagus, stomach, small intestine, large intestine, and anus that she intended the students to learn. In addition, Jemsa was able to justify why she used the chart and mentioned other teaching aids she could have used.

Jemsa's lesson predominantly used the question-and-answer approach. When asked why she used the question-and-answer approach in her lesson [CTS], she said: "The question and answer is a good method [CTS] since it involves learners participating in the lesson [SPK]. It helps learners to be active in class and even to think, when I ask questions [CTS], they should think….. Because when learners give answers, I have to explain [CTS] the main points to them for them to understand clearly [WD]." In this excerpt, she connected CTS to SPK and WD. She justified the use of the question-and-answer approach concerning how it would help students to learn [SPK]. She also indicated that she would use specific teaching strategies (explaining and asking questions) [CTS] to promote learning. However, this time she did not mention the main points (central ideas) she was referring to in the excerpt.

Jeff's reflection on CS showed that he integrated CTS. During the lesson, Jeff used several activities in which he asked learners [CTS] to describe excretion and to mention the excretory organs and products. Furthermore, this was evidenced in the interview as can be seen in the following interview excerpt:

> Researcher: What important concepts did you intend your learners to learn [CS]?
> Jeff: I asked learners [CTS] to describe the process of excretion [CS], and I also asked questions [CTS] based on examples of excretory products [CS]. In addition, I also asked learners [CTS] to state the organs that play a vital role in excretion [CS]".
> Researcher: Could you be specific about the concepts you planned to teach?
> Jeff: Oh yes, I wanted the students to describe excretion as the removal of metabolic waste products. As for examples of excretory products, there is carbon dioxide, urea, excess salts and water. The excretory organs include the kidney, lungs, liver, and skin specific [CS].
> The interview except shows an example of how Jeff integrated CS and CTS. It can be seen that in the first response, he only mentioned peripheral ideas he expected his students to learn. However, in the response to the follow-up question, he was able mentioned the central ideas that students were expected to learn.

Furthermore, reflecting on SPK, when asked about learners' misconceptions in the lesson, Jeff said: "….learners were confused between the definition of excretion and egestion [WD]. When we talk of egestion, it simply means the removal of undigested food substances from the body through the anus, but when we talk of excretion, it is the removal of toxic waste products of metabolism from the body [CS]" He connected SPK to WD and CS. It should be noted that he was able to refer to specific learning difficult students were having [WD], and the specific central ideas (distinction between excretion and egestion) [CS] that he intended the learners to comprehend.

In sum, the above results revealed some common and different features in the TSPCK maps. The following noteworthy revelations: (a) None of the teachers depended solely on a single TSPCK component as they integrated other components (b) The components CS, SPK and CTS were central in the TSPCK maps of all the teachers (c) All teachers had different pairs of reciprocal connections (d) All teachers had different pairs of most integrated components. The implications of these findings are discussed in the next section.

5 Discussion

The study's findings show evidence that participants integrated the TSPCK components in their reflections-on-action. The findings show that participants integrated some TSPCK components as they reflected on their lessons on specific biology topics. Further, results give insight into participants' pedagogical reasoning as a reflection of their professional knowledge (TSPCK) level for the taught topics [11]. Marie taught a lesson on the nervous system, Jeff on excretion, and Jemsa taught a lesson on the topic of holozoic nutrition. The findings revealed four salient features of teachers' integration of TSPCK components in their reflections. This section discusses each of these features.

The analysis of the data revealed that none of the teachers relied solely on one TSPCK component. This means that the teachers integrated the TSPCK components among others. However, in light of the nature of PCK, the teachers integrated the components differently, with Jeff (an out-of-filed teacher) showing the most integrated map compared to Marie (an in-field teacher). The fact that Marie is an in-field teacher could have influenced her integration of the components as she may have more content knowledge in the area compared to the other out-of-field teachers. This finding is in line with previous studies that show that teachers with high content knowledge usually focus on communicating that content and tend to have few integration among PCK components [32, 47]. However, differences were observed in the number and nature of TSPCK components integrated by the teachers. For instance, while Jemsa and Jeff integrated all five components, Marie only integrated three. There were also differences in the number and nature of pairs of integrated components. These results may be explained by the topic/context/person-specificity of TSPCK as the teachers taught different topics to different groups of students [25, 27]. However, it should be noted that it may not be possible for every teacher to integrate all the TSPCK components in a single lesson as some components may not be necessary. For example, more components were integrated in Jeff's and Jemsa's reflections than in Marie's.

The findings that different components were integrated in participants' reflections have implications for effective teaching. The integration of TSPCK components may facilitate the development of participants' topic-specific PCK [23], which may improve their teaching. Suh and Park [25] add that coherence in the component integration leads to high-quality PCK, which may translate into quality learning. Although Poti et al. [43] allude that novice teachers may not always integrate the TSPCK components in their classroom practices, the current study shows that the participants integrated some TSPCK components, although they were novice biology teachers. Furthermore, the teachers integrated TSPCK components regardless of being in-field or out-of-field.

The study's results concerning the central TSPCK components: curricular saliency (CS), students' prior knowledge (SPK), and conceptual teaching strategies (CTS) and the least integrated components: representations (RP) and what makes a topic easy or difficult to teach or learn (WD) supports previous studies (e.g. [9, 20, 22]). In line with Park and Chen [20], it may be concluded that participants were more confident in these components (SPK, CTS and CS) than RP and WD. It may imply that the participants presented the biology content (CS) according to their knowledge of students (SPK), hence students' needs. According to Alonzo et al. [48], knowledge and integration of SPK enable teachers to link content to students' experiences, making learning meaningful. Mapulanga et al. [22] also found that SPK, CTS and CS strongly influenced how teachers integrated the planned TSPCK components and that RP and WD were least integrated in planning respiration lessons. Similarly, Park and Chen [20] concluded that knowledge of student understanding (SPK) and knowledge of instructional strategies (CTS) were central to the integration of PCK components. However, the result that RP was least integrated contradicts the results of Park and Chen [20]. Furthermore, Mavhunga [23] found that CTS was least integrated in planning by the pre-service teachers. These variations in the findings on component integration may be explained by the topic- and context-specificity of PCK.

Although not adequately integrated by the participants in the current study, knowledge of representations (RP) and students' learning difficulties (WD) are critical for effective teaching. For example, RP would allow them (teachers) to connect science concepts with students' prior knowledge and misconceptions [49], thereby improving learning. Interestingly, all three participants only chose to use charts or diagrams in their lessons. This may indicate that they had limited knowledge or options of representations to use in their lessons. Also, despite being least integrated by the participants, knowing what makes topics easy or difficult to teach or learn (WD) is important. It lets teachers know which topics need dedicated time and attention during lessons. Aydin et al. [13] argue that teachers must know the difficulties their students present in learning various topics to deliver meaningful lessons.

In terms of the types of TSPCK component pairs integrated, the results reveal that the teachers differed in how they integrated the components. The participants often integrated different components when reflecting on the same components. For example, when reflecting on CS, Marie integrated SPK, Jemsa integrated RP, and Jeff integrated CTS and SPK. Furthermore, the results show differences in the number and nature of the overall integrations of TSPCK components across the lessons/topics taught. For instance, Marie only integrated CS, SPK, and CTS components. Jeff integrated all the components except RP. Both Marie and Jeff did not integrate RP in their reflections. However, Jemsa integrated all five components into her reflections. The results may imply that not all components may be necessary for every lesson. These results may also be explained by factors such as topics taught, teachers' beliefs and attitudes towards teaching, and the person and or context specificity of PCK. Furthermore, the results confirm the conclusion of earlier studies [13, 20, 22, 23] that integration of PCK is person-, topic- and context-specific. However, integration of the specific component pairs is critical for effective teaching. For instance, Mapulanga et al. [22] assert that by linking the TSPCK components (e.g. CTS to CS and CS to SPK), teachers can successfully impart knowledge to learners.

6 Limitations of the study

This study was limited by the small sample (three teachers), which hinders the generalisation of the findings of typical qualitative research [39]. However, a detailed description of the study's context was provided, allowing the findings to be applied to similar contexts. Although the findings were based on evidence from observed lessons, most of the data were generated through post-observation interviews. Thus, participants may have influenced the results by giving out expected responses. The other limitation was that only one lesson was observed per participant/topic so the findings on teachers' TSPCK were limited to the considered lessons as teachers may have different PCK in different contexts and topics. Another limitation relates to the lack of video recordings of lessons which might have caused us (researchers) to miss some TSPCK enactment. Also, the constructed TSPCK maps were not products of teachers' noticing, but the researchers'. Future studies may observe and video-record several lessons so that the teachers' TSPCK may be more accurately described in each topic over various lessons. Furthermore, teachers' TSPCK could be understood better if they teach the same topics. Another limitation was that the participants taught different topics, so the results were based on the description of their enactment of TSPCK in different topics.

7 Conclusions and recommendations

This study examined the TSPCK components science teachers integrated in their reflections on biology lessons. The study established the components participants drew from as they reflected on their enactment of TSPCK. More specifically, the study showed that reflections on action revealed participants' integration of the components: curricular saliency (CS), what makes a topic easy or difficult (WD), students' prior knowledge (SPK), representations and analogies (RP), and conceptual teaching strategies (CTS). However, the participants integrated these components in a person- and context-specific manner. The components SPK, CTS and CS were the most integrated regardless of the topic taught, while RP and WD were the least integrated. As discussed, these results follow a trend similar to previous studies. Given the significance of the interactions among TSPCK components in developing the overall PCK structure, it is advantageous to explore the TSPCK components teachers tend to integrate when reflecting on each component. The study highlights the need for more research on diagnosing PCK components that teachers mostly lack or have and the difficulty of integrating them with other components for specific topics. The study's findings suggest a need to focus on developing the teachers' TSPCK and interactions among the components in teaching specific topics. Based on the findings, the study made the following recommendations:

a. To investigate the TSPCK components teachers integrate as they reflect on several lessons in topics that students find challenging.
b. To support teachers in integrating the least enacted TSPCK components through PCK-based professional development programmes
c. To track any changes in teachers' TSPCK integration due to their reflection-on-action.

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Author contributions TM conceptualised the research conducted the material preparation, data collection, and formal analysis, and drafted the original manuscript. YA, GN and AB edited and critically reviewed the manuscript. All authors reviewed and approved the final version of the manuscript.

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Data availability All data supporting the findings has been reported within the article.

Code availability Not applicable.

Declarations

Competing interests The authors declare no competing interests.

References

1. Shulman LS. Those who understand: knowledge growth in teaching. Educ Res. 1986;15(2):4–14. https://doi.org/10.3102/0013189X015002004.
2. Gess-Newsome J. A model of teacher professional knowledge and skill including PCK: results of the thinking from the PCK summit. In: Berry A, Friedrichsen P, Loughran J, editors. Re-examining pedagogical content knowledge in science education. New York: Routledge; 2015. p. 28–42. https://doi.org/10.4324/9781315735665.
3. Singh H, Luft JA, Napier JB. The development of ePCK of newly hired in-field and out-of-field teachers during their first three years of teaching. Eur J Teach Educ. 2021. https://doi.org/10.1080/02619768.2021.1943660.
4. Du Plessis AE. Effective education: Conceptualising the meaning of out-of-field teaching practices for teachers, teacher quality and school leaders. Int J Educ Res. 2015;72:89–102. https://doi.org/10.1016/j.ijer.2015.05.005.
5. Gess-Newsome J, Taylor JA, Carlson J, Gardner AL, Wilson CD, Stuhlsatz MAM. Teacher pedagogical content knowledge, practice, and student achievement. Int J Sci Educ. 2019;41(7):944–63. https://doi.org/10.1080/09500693.2016.1265158.
6. Aydin S, Friedrichsen PM, Boz Y, Hanuscin DL. Examination of the topic-specific nature of pedagogical content knowledge in teaching electrochemical cells and nuclear reactions. Chem Educ Res Pract. 2014;15(4):658–74. https://doi.org/10.1039/C4RP00105B.
7. Zeichner KM, Liston DP. Reflective teaching: an introduction. 2nd ed. New York: Routledge; 2013. p. 1–144. https://doi.org/10.4324/9780203771136.
8. Sickel AJ, Friedrichsen P. Using multiple lenses to examine the development of beginning biology teachers' pedagogical content knowledge for teaching natural selection simulations. Res Sci Educ. 2017. https://doi.org/10.1007/s11165-016-9558-2.
9. Gao S, Damico N, Gelfuso A. Mapping and reflecting on integration of the components of pedagogical content knowledge (PCK) for teaching natural selection: a case study of an experienced middle-school science teacher. Teach Teach Educ. 2021;2021(107):1–14. https://doi.org/10.1016/j.tate.2021.103473.
10. Schön DA. The reflective practitioner: how professionals think in action. New York: Routledge; 2017. p. 1–384. https://doi.org/10.4324/9781315237473.
11. Loughran J. Pedagogical reasoning: The foundation of the professional knowledge of teaching. Teach Teach. 2019;25:1–13. https://doi.org/10.1080/13540602.2019.1633294.
12. Park S, Oliver JS. Revisiting the conceptualisation of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. Res Sci Educ. 2008;38(3):261–84. https://doi.org/10.1007/s11165-007-9049-6.
13. Aydin S, Demirdogen B, Nur Akin F, Uzuntiryaki-Kondakci E, Tarkin A. The nature and development of interaction among components of pedagogical content knowledge in practicum. Teach Teach Educ. 2015;46:37–50. https://doi.org/10.1016/j.tate.2014.10.008.
14. Chan KKH, Xu L, Cooper R, Berry A, van Driel JH. Teacher noticing in science education: do you see what I see ? Stud Sci Educ. 2021;57(1):1–44. https://doi.org/10.1080/03057267.2020.1755803.
15. Konig J, Santagata R, Scheiner T, Adleff A, Yang X, Kaiser G. Teacher noticing: a systematic literature review of conceptualizations, research designs, and findings on learning to notice. Educ Res Rev J. 2022;36:1–18. https://doi.org/10.1016/j.edurev.2022.100453.
16. Aydin S, Boz Y. Review of studies related to pedagogical content knowledge in the context of science teacher education: Turkish Case. Educ Sci Theory Pract. 2012;12(1):497–505. https://doi.org/10.1016/j.tate.2014.10.008.
17. Nilsson P, Karlsson G. Capturing student teachers' pedagogical content knowledge (PCK) using CoRes and digital technology. Int J Sci Educ. 2018. https://doi.org/10.1080/09500693.2018.1551642.
18. Magnusson S, Krajcik J, Borko H. Nature, sources, and development of pedagogical content knowledge for science teaching. In: Examining pedagogical content knowledge. Kluwer Academic Publishers; 1999. p. 95–132. https://doi.org/10.1007/0-306-47217-1_4.
19. Mavhunga E, Rollnick M. Improving PCK of chemical equilibrium in pre-service teachers. Afr J Res Math Sci Technol Educ. 2013;17(1–2):113–25. https://doi.org/10.1080/10288457.2013.828406.
20. Park S, Chen YC. Mapping out the integration of the components of pedagogical content knowledge (PCK): Examples from high school biology classrooms. J Res Sci Teach. 2012;49(7):922–41. https://doi.org/10.1002/tea.21022.
21. Lee E, Luft JA. Experienced secondary science teachers' representation of pedagogical content knowledge. Int J Sci Educ. 2008;30(10):1343–63. https://doi.org/10.1080/09500690802187058.
22. Mapulanga T, Nshogoza G, Ameyaw Y. Zambian secondary school biology teachers' profiles of planned topic-specific pedagogical content knowledge for teaching respiration. Afr J Res Math Sci Technol Educ. 2022;26(1):1–16. https://doi.org/10.1080/18117295.2022.2085402.
23. Mavhunga E. Revealing the structural complexity of component interactions of topic-specific PCK when planning to teach. Res Sci Educ. 2018;50(3):965–86. https://doi.org/10.1007/s11165-018-9719-6.
24. Sæleset J, Friedrichsen P. Pre-service science teachers' pedagogical content knowledge integration of students' understanding in science and instructional strategies. Eur J Math Sci Technol Educ. 2021;17(5):1–18. https://doi.org/10.29333/ejmste/10859.
25. Suh JK, Park S. Exploring the relationship between pedagogical content knowledge (PCK) and sustainability of an innovative science teaching approach. Teach Teach Educ. 2017. https://doi.org/10.1016/j.tate.2017.01.021.
26. Aydin-gunbatar S, Akin FN. Research and Practice to develop topic-specific pedagogical acid–base equilibrium. 2021;(2016). https://doi.org/10.1039/d1rp00106j
27. Akın FN, Uzuntiryaki-Kondakci E. The nature of the interplay among components of and chemical equilibrium topics of novice and experienced chemistry teachers. Chem Educ Res Pract. 2018;19:80–105. https://doi.org/10.1039/c7rp00165g.
28. Chan KKH. A critical review of studies using the pedagogical content knowledge map approach. Int J Sci Educ ISSN. 2022;44(3):487–513. https://doi.org/10.1080/09500693.2022.2035011.
29. Barendsen E, Henze I. Relating teacher PCK and teacher practice using classroom observation. Res Sci Educ. 2019;49(5):1141–75. https://doi.org/10.1007/s11165-017-9637-z.

30. Bayram-jacobs D, Henze I, Evagorou M, Shwartz Y, Aschim EL, Alcaraz-dominguez S, et al. Science teachers' pedagogical content knowledge development during enactment of socioscientific curriculum materials. J Res Sci Teach. 2019;56:1207–33. https://doi.org/10.1002/tea.21550.
31. Şen M. Suggestions for the analysis of science teachers' pedagogical content knowledge components and their interactions. Res Sci Educ. 2023. https://doi.org/10.1007/s11165-023-10124-7.
32. Şen M, Demirdöğen B, Öztekin C. Interactions among topic-specific pedagogical content knowledge components for science teachers: the impact of content knowledge. J Sci Teacher Educ. 2022. https://doi.org/10.1080/1046560X.2021.2012630.
33. Akinyemi OS, Mavhunga E. The place of learner views in examining pre-service teachers' enacted topic-specific pedagogical content knowledge. In: Book of Proceedings of the 30th Annual Conference of the Southern African Association for Research in Mathematics, Science, and Technology Education. Cape Town; 2022. p. 193–9. https://www.saarmste.org
34. Chan KKH, Rollnick M, Gess-Newsome J. A grand rubric for measuring science teachers' pedagogical content knowledge. In: Repositioning pedagogical content knowledge in teachers' knowledge for teaching science. Singapore: Springer; 2019. p. 253–71. https://doi.org/10.1007/978-981-13-5898-2_11.
35. Carlson J, Daehler KR, Alonzo AC, Barendsen E, Berry A, Borowski A, Carpendale J, Kam Ho Chan K, Cooper R, Friedrichsen P, Gess-Newsome J. The refined consensus model of pedagogical content knowledge in science education. In: Repositioning pedagogical content knowledge in teachers' knowledge for teaching science. Singapore: Springer; 2019. p. 77–94. https://doi.org/10.1007/978-981-13-5898-2_2.
36. Makhechane M, Mavhunga E. Developing topic-specific PCK in chemical equilibrium in a chemistry PGCE class: feasible or not? Afr J Res Math Sci Technol Educ. 2021. https://doi.org/10.1080/18117295.2021.1925486.
37. Buma MA, Doras S, Marissa R. Exploring the development of the quality of topic specific pedagogical content knowledge in planning: the case of grade 8 natural sciences teachers. Int J Sci Math Educ. 2023. https://doi.org/10.1007/s10763-023-10355-0.
38. Byukusenge C, Nsenganwimana F, Tarmo AP. Effectiveness of virtual laboratories in teaching and learning biology: a review of literature. Int J Learn Teach Educ Res. 2022;21(6):1–17. https://doi.org/10.26803/ijlter.21.6.1.
39. Creswell JW. Research design: qualitative, quantitative, and mixed methods approaches. 4th ed. SAGE; 2014.
40. Curriculum Development Centre. Zambia education curriculum framework 2013. Lusaka: Curriculum Development Centre; 2013.
41. Curriculum Development Centre. Biology syllabus grades 10–12. Lusaka: Zambia Educational Publishing House; 2013. p. 1–61.
42. Mapulanga T, Ameyaw Y, Nshogoza G. Improving secondary school biology teachers' topic-specific pedagogical content knowledge: evidence from lesson studies. J Balt Sci Educ. 2023;22(1):20–36. https://doi.org/10.33225/jbse/23.22.20.
43. Poti JG, Dudu WT, Sebatana MJ. A South African beginner natural sciences teacher's articulated PCK-in-practice with respect to electric circuits: a case study. Eur J Math Sci Technol Educ. 2022;18(10):1–16. https://doi.org/10.29333/ejmste/12426.
44. Friedrichsen PJ, Abell SK, Pareja EM, Brown PL, Lankford DM, Volkmann MJ. Does teaching experience matter? Examining biology teachers' prior knowledge for teaching in an alternative certification program. J Res Sci Teach. 2009;46(4):357–83. https://doi.org/10.1002/tea.20283.
45. Park S, Jang J-Y, Chen Y-C, Jung J. Is pedagogical content knowledge (PCK) necessary for reformed science teaching?: Evidence from an empirical study. Res Sci Educ. 2010;41(2):245–60. https://doi.org/10.1007/s11165-009-9163-8.
46. Braun V, Clarke V. Using thematic analysis in psychology. Qual Res Psychol. 2006;3(2):77–101. https://doi.org/10.1191/1478088706qp063oa.
47. Käpylä M, Heikkinen JP, Asunta T. Influence of content knowledge on pedagogical content knowledge: the case of teaching photosynthesis and plant growth. Int J Sci Educ. 2009;31(10):1395–415. https://doi.org/10.1080/09500690802082168.
48. Alonzo AC, Kobarg M, Seidel T. Pedagogical content knowledge as reflected in teacher-student interactions: analysis of two video cases. J Res Sci Teach. 2012;49(10):1211–2139. https://doi.org/10.1002/tea.21055.
49. Soysal Y. An exploration of the interactions among the components of an experienced elementary science teacher's pedagogical content knowledge. Educ Stud. 2017;44(1):1–25. https://doi.org/10.1080/03055698.2017.1331839.