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IMPROVING SECONDARY SCHOOL BIOLOGY TEACHERS' TOPIC-SPECIFIC PEDAGOGICAL CONTENT KNOWLEDGE: EVIDENCE FROM LESSON STUDIES

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Abstract. *Since pedagogical content knowledge (PCK) influences the teaching-learning process, it has dominated research on teacher effectiveness. This case study explored teachers' enacted topic-specific PCK (TSPCK) during the biology lesson study stages: planning, teaching, and reflecting. The enacted TSPCK in two video-recorded research lessons was analysed qualitatively. The results showed that the teacher enacted both high-order and low-order pedagogical actions in the enactment of the TSPCK on eight themes, namely: teaching strategies, classroom interactions, representations, curricular saliency, conceptual teaching strategies, students' prior knowledge and misconceptions, and what makes teaching or learning difficult. The results also show that the teachers' collective planned TSPCK was more developed than their personal TSPCK, indicating that participation in the lesson study improved the teachers' TSPCK. The study is important as it shows how teachers enact their personal and collective TSPCK in respiration. It also demonstrates the potential of lesson study to improve teachers' PCK through collaborative planning and reflection on taught lessons. The study recommends using lesson study to improve teachers' enacted TSPCK in respiration, and biology as a whole.*

Keywords: *enacted pedagogical content knowledge (ePCK), topic-specific pedagogical content knowledge (TSPCK), respiration, secondary school, lesson study*

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Introduction

Pedagogical content knowledge (PCK) is among the factors influencing students' comprehension of taught content. According to Shulman (1986), PCK refers to teachers' professional knowledge through which they transform content knowledge in ways that make it easily understood by students. Therefore, teachers draw on their PCK to transform content knowledge so students can easily comprehend it. According to Gess-Newsome et al. (2019), there are three realms: collective (cPCK), personal (pPCK), and enacted (ePCK). Collective PCK is the PCK held by the community of teachers and researchers in a given domain, while personal PCK lies in individual teachers. On the other hand, enacted PCK is the PCK that teachers apply in a teaching-learning situation (Behling et al., 2022). Because PCK has a high potential to affect science learning, it has become a favourite area of research in science education (Park & Chen, 2012). Some researchers have described teachers' PCK (Marake et al., 2022; Mazibe et al., 2018), while others have supported the development of teachers' PCK (Barendsen & Henze, 2019; Ndlovu & Malcolm, 2022).

There is a growing interest in science education research focused on the topic-specific grain size of PCK. Mavhunga and Rollnick (2013) called this level of PCK as topic-specific PCK (TSPCK). They describe it as the knowledge that allows teachers to transform content knowledge, in a particular topic, into forms that students can comprehend. It follows then that teachers draw on different forms of TSPCK to teach particular topics in their subjects. In line with this, many studies on teachers' professional knowledge have been located at the topic level of PCK, with some referring to it as PCK (Nilsson & Karlsson, 2018) while others as TSPCK (Mavhunga and van der Merwe ,2020; Ndlovu and Malcolm, 2022). In the current study, the professional knowledge for teaching a specific topic is referred to as TSPCK. Having said that, the concept TSPCK is used in place of PCK related to teaching specific topics in a subject while PCK is used in reference to teaching specific subjects.

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In sub-Saharan Africa, studies on TSPCK have been conducted in science subjects, mainly in South Africa. For example, Mazibe et al. (2018) explored physical science teachers' TSPCK in graphs of motion. They concluded that teachers' enacted TSPCK was either equal to or less than their reported TSPCK. A study by Mavhunga and van der Merwe (2020) focused on the TSPCK of pre-service teachers in electrostatics, light, and stoichiometry. The results revealed structural changes in teachers' TSPCK from the planning to teaching contexts. Recently, Ndlovu and Malcolm (2022) investigated the planned TSPCK of pre-service teachers in stoichiometry. They reported improvement in teachers' TSPCK after attending the practicum. Khan and Nyamupengundengu (2022) explored the integration of content and pedagogy when teaching pre-service teachers at a South African university in the context of genetics (meiosis) lessons. They found that the instructor integrated methodology (knowledge of teaching) and meiosis severally. In Swaziland, Mthethwa-Khunene et al. (2015) explored the TSPCK in genetics among experienced teachers. They found that the teachers utilized some topic-specific teaching strategies but did not use experiments and physical models. They also found that teachers had inadequate knowledge of students' preconceptions in genetics.

Researchers have not fully explored the status of biology teachers' TSPCK in Zambia, and a literature search showed a lack of research in this area. For example, Mapulanga et al. (2022a) investigated biology teachers' planned TSPCK for teaching respiration. They found that the teachers integrated the planned TSPCK components in a person-specific way, and that students' prior knowledge, curricular saliency, and conceptual teaching strategies influenced the teachers' planned TSPCK profiles. Furthermore, they also reported that the least integrated components were what makes the topic easy or difficult and representations. In another related study, Mapulanga et al. (2022b) explored the Zambian teachers' perceptions of PCK enactment in biology. They concluded that the teachers' perception of their enacted PCK components was high except for the component - what makes the subject easy or difficult.

The teaching and learning of secondary school biology in Zambia have been problematic, as evidenced by the poor academic performance of students in the national examinations. The Examinations Council of Zambia has attributed this to how biology is taught (Examinations Council of Zambia, 2017). Since the way teachers teach is influenced by the level of their pedagogical content knowledge, and hence topic-specific PCK, there is a need to investigate biology teachers' TSPCK in Zambia. In line with this, the current study investigated biology teachers' TSPCK in respiration. The topic of respiration was selected because it is taught from primary school to university levels in biological sciences, and there is evidence that students present some learning difficulties and misconceptions about some respiratory concepts (Dam et al., 2019). For example, some students think that all sub-processes of respiration need oxygen to happen (Dam et al., 2019). These authors point out the following reasons why respiration is challenging to teachers and students; (i) respiration is very abstract and cannot be made visible to the unaided eye, (ii) inability to connect among the sub-processes, and relate them to real life, (iii) it is too detailed and needs learning new vocabulary. In the Zambian secondary school biology syllabus, respiration features in grade ten under the topic of the respiratory system. Although teachers find the topic to be very abstract, they are expected to assist the students to learn about gaseous exchange and types of respiration (Curriculum Development Centre, 2013). It may be of value to investigate the pedagogical content knowledge components teachers use to deliver respiration concepts to secondary school students.

Theoretical Perspective

The framing of this study was guided by the theory of pedagogical content knowledge (PCK). Since its conceptualisation by Shulman (1986), researchers have used PCK to explore teachers' professional knowledge (Park & Chen 2012; Usak & Duran, 2022). PCK describes the teachers' professional knowledge domain used to transform content knowledge in ways that are easy for students to understand (Mientus et al., 2022). In the revised consensus modelį (RCM), PCK occurs as collective, personal, and enacted PCK. Collective PCK (cPCK) is the PCK shared by several teachers and researchers in a particular field. Personal PCK (pPCK) is the PCK held by teachers as individuals. The PCK that teachers enact during the teaching process, that is, - planning, teaching, and reflecting, is called enacted PCK (Behling et al., 2022). The current study explored personal and collective PCK enacted during a lesson study on a biology topic - respiration.

Conceptual Framework

Mientus et al. (2022) assert that pPCK can be transformed into enacted PCK (ePCK) during the teaching cycle, i.e. when planning as ePCKp, when teaching as ePCKt, and when reflecting as ePCKr. This study conceptualised

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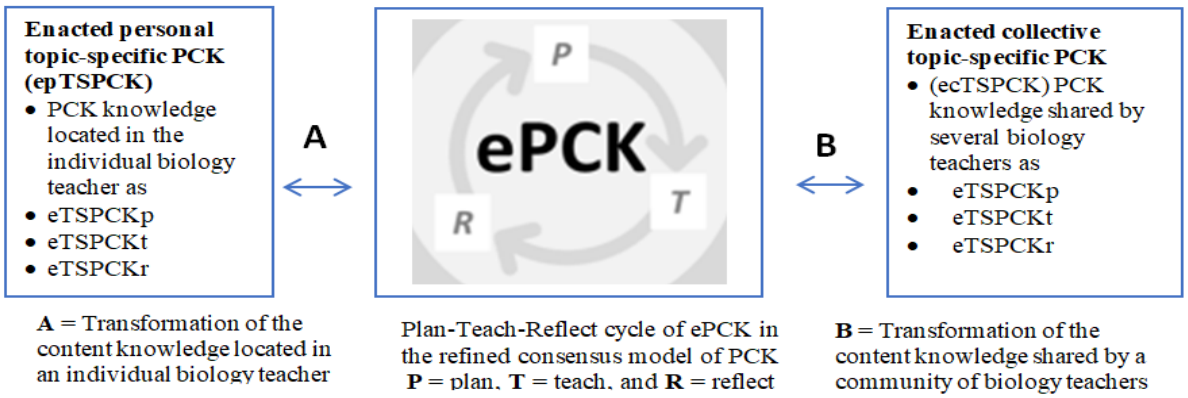
cPCK as the PCK shared by the biology teachers at the selected secondary school. Because PCK is topic-specific, this study investigated the teachers' enacted topic-specific PCK (eTSPCK) in respiration at the planning, teaching, and reflection stages. The underlying assumption was that eTSPCK is transformed at the personal (pPCK) and community (cPCK) levels during the planning, teaching, and reflecting stages. The study used the revised consensus model as the conceptual framework to investigate the enactment of topic-specific PCK at the planning, teaching, and reflection stages. The study assumed that teachers enact their personal and collective PCK during the planning-teaching-reflecting stages, as illustrated in Figure 1.

Figure 1
Enactment of Personal and Collective TSPCK during the Plan-Teach-Reflect Cycle



Use of the Lesson Study Approach to Improve Teachers' Professional Knowledge

One approach adopted to support the improvement of teachers' TSPCK is lesson study - a process of collaborative planning, teaching, and reflecting on the teaching (Dudley et al., 2019). Lesson study has its roots in Japan, where it has been practiced for over a hundred years (Khokhotva, 2018). Researchers have articulated the importance of participating in lesson study including enabling teachers to learn from planning, observation, feedback, and reflection sessions (Coenders & Verhoef, 2019); improving teachers' professional knowledge (Dudley et al., 2019); learning from collaborating with others in team planning, teaching, and discussion in communities of practice (Adler & Alshwaikh, 2019). The stages of the lesson study fit well with the plan-teach-reflect cycle in the centre of the RCM, allowing for the investigation of ePCKp, ePCKt, and ePCKr respectively (Mientus et al., 2022).

Research has reported using lesson study in teacher professional development. For example, Agricola et al. (2020) employed the lesson study to develop supervisors' PCK related to instructional strategies and students' understanding. The supervisors' PCK was developed by reflecting on their practice and knowledge of students. Akerson et al. (2015) investigated the impact of lesson study on the ability of pre-service elementary teachers to conduct science lessons based on the nature of science. They revealed that the pre-service teachers failed to integrate the nature of science in their lessons. In another study, Thi et al. (2019) conducted a study to enhance the pre-service biology teachers' ability to prepare lesson plans. They concluded that the lesson study improved teachers' content knowledge and planning ability. Also, the participants appreciated the benefits of collaborating to plan lessons that meet learners' needs. These studies demonstrate that lesson study has the potential to improve teachers' TSPCK.

Research Problem

Although there is abundant research on biology teachers' TSPCK (Bravo & Cofré, 2016; Mthethwa-Khunene, 2015; Nilsson & Karlsson, 2018: Park & Chen, 2012), fewer studies are investigating biology teachers' TSPCK in respiration (Mapulanga et al., 2022a; 2022b). This is despite research showing that students face challenges and misconceptions about respiratory concepts (Dam et al., 2019). This study was motivated by the need to investigate the TSPCK that teachers use to teach respiration. There is a dearth of research on biology teachers' TSPCK, in Zambia and attempts, if any, to improve their TSPCK have not been documented. Therefore, the current study explored

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the improvement of biology teachers' TSPCK in respiration. The study responds to calls to enhance teachers' TSPCK in science topics considered challenging to teach or learn. It contributes knowledge about improving biology teachers' TSPCK using the lesson study model. In addition, the study contributes information about the teachers' enactment of TSPCK in respiration. Furthermore, it was necessary to conduct this study in the Zambian context because TSPCK is topic and context-specific.

Research Aim and Research Questions

This study aimed at exploring the secondary school biology teachers' enacted TSPCK in respiration during a lesson study. The following research questions guided the study:

1. What respiration-TSPCK components do biology teachers enact during a lesson study?
2. What improvements occur to teachers' enacted respiration-TSPCKp components during a lesson study?

Research Methodology

General Background

Using the case study design, the study adopted the qualitative research approach (Creswell, 2014). The study examined the secondary school teachers' enacted personal and collective TSPCK in respiration by analysing teachers' personal and collective content representations – CoRes, transcripts of planning, teaching, and reflection sessions. Respiration was selected as the topic of investigation because it is considered difficult for some teachers and students (Dam et al., 2019).

Ethical Considerations

After getting ethical clearance from the University of Rwanda, permits were obtained from the Zambian Ministry of Education and the selected school. The teachers voluntarily consented to participate in the study. The head teacher gave consent on behalf of the students. To ensure participant protection, the name of the school was not disclosed and pseudonyms were used to identify the teachers and students.

Sample Selection

The participants comprised two novice and four experienced biology teachers purposively selected from one secondary school in Lusaka district. The school was purposively selected due to the availability of teachers to attend all the lesson study sessions. Also, the students' academic performance in biology at this school was poor. The teachers were selected because they taught biology and agreed to participate in the study. Table 1 shows the teachers' demographic information. For students, two grade 11 classes were purposively selected based on their academic performance. Therefore, one high performing and one low-performing class were selected and all the students in the two classes formed the sample.

Table 1
Teachers' Demographic Information

Participant ID	Gender	Academic qualification	Teaching experience (years)	Level
T1	Female	Science teachers' diploma	3	Novice
T2	Male	BSc. Education	5	Experienced
T3	Male	Science teachers' diploma	15	Experienced
T4	Female	Science teachers' diploma	14	Experienced
T5	Male	BSc. Education	3	Novice
T6	Female	BSc. Education	18	Experienced

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Instruments and Data Collection Procedures

The study used content representations (CoRes) to collect data regarding the teachers' planned TSPCK in respiration. The CoRe is valid and reliable and has been used to capture and portray the PCK of teachers (Coetzee et al., 2020; Loughran et al., 2004). A CoRe consists of key ideas across the top row and prompts to be answered for each key idea on the left-hand column. Key ideas represent the main ideas and concepts in a topic that a teacher intends to teach. An example of a key idea in respiration is 'types of tissue respiration'. CoRes ask teachers to consider the most effective ways to teach topics to encourage student learning through prompts in Table 2.

The CoRe aided teachers in conceptualising their TSPCK and articulating the different components and connections between content knowledge, teaching, and learning about respiration.

Table 2
The Content Representation (CoRe) Template used in this Study

Prompts/Questions	Key Idea 1	Key Idea 2
1. What do you intend the learners to know about this idea?		
2. Why is it important for students to know this?		
3. What concepts need to be taught before teaching this idea?		
4. What else do you know about this idea (that you do not intend learners to know yet)?		
5. What do you consider difficult about teaching this idea?		
6. What are typical learners' misconceptions when teaching/learning this idea?		
7. What effective teaching strategies will you use to teach this idea?		
8. How will the strategies help students understand the concept or idea?		
9. What representations (teaching aids, diagrams, equations, models, etc.) will you use in your teaching strategies?		
10. How will the representations help learners' understanding of the idea?		

The data collection was done for six weeks between May and June 2022. Data were collected in three stages, as described below.

Stage 1: Individual Teachers' Lesson Planning

This stage was conducted three weeks before the lesson study started. Each teacher was requested to complete the lesson planning questionnaire (content representation – CoRe). The teachers used the same template to ensure they were given equal opportunity to express their planned TSPCK (eTSPCKp). Therefore, six individual teachers' CoRes were collected from the teachers to measure their personal eTSPCKp in respiration.

Stage 2: Research Lesson One - Cycle one

This stage involved the implementation of the first cycle of the lesson study, consisting of planning, teaching, and reflecting on the taught lesson. Firstly, the teachers collectively planned a lesson and completed a collective CoRe. Two two-hour planning sessions were conducted on two separate days. During planning, the teachers drew on the ideas and contributions of all lesson study team members. Each teacher demonstrated his or her personal TSPCK and the feedback from other team members helped refine their personal TSPCK, leading to the improvement of their TSPCK (Dudley et al., 2019). The teachers were supported by the researcher (first author) by discussing the prompts in the CoRe (TSPCK components) one at a time through a lecture-discussion. The roles of the teachers and researcher are summarised in Table 4. The planning sessions were used to measure the teachers' collective eTSPCKp in respiration. The planned lesson was delivered to a grade 11E class by one of the teachers (a demonstrator) while the other teachers observed the lesson, which lasted for 82 minutes. The observers noted the actions of

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the teacher and students. The lesson study team then reflected on the lesson, focusing on the teachers' actions, students' learning, and areas of the lesson that needed improvement. The reflection session lasted 60 minutes.

Stage 3: Improving Research Lesson One - Cycle Two

This stage involved the planning stage of cycle two in which research lesson one was improved before being retaught. The focus of improvement was on the delivery of the lesson such as timing and delivery of the group activity. The improvements made are shown in Table 3. The reasons forwarded for the proposed changes contributed to improving the teachers' eTSPCK and would maximise the students' acquisition of taught concepts. The lesson was then delivered to a grade 11C class by the same teacher who taught the first research lesson, and the other teachers observed the lesson which lasted for 86 minutes. The observers noted the actions of the teacher and students. The lesson study team then reflected on the lesson, focusing on the teachers' actions, students' learning, and areas of the lesson that needed improvement or change.

Table 3
Some Improvements made to the Research Lessons

Aspect	Observations made in research lesson one	Improvements made in research lesson two
Group activity	In the group activity, two groups were asked to construct each type of word equation. However, there was no time left for the groups to construct the chemical equations. Therefore, the lesson only covered word equations of the types of tissue respiration in plants and animals.	In the group activity, some groups were asked to construct word equations while others were asked to construct chemical equations. Therefore, the lesson covered both word and chemical equations of the types of tissue respiration in plants and animals.

Researchers' Roles

The researcher was an active participant during the lesson study, some roles of the teachers and the researcher are summarised in Table 4.

Table 4
Roles of Teachers and the Researcher

Teachers' roles	Researcher's roles
Choose the teaching/ learning problem	Provide feedback on how the teaching-learning problem fits in the topic of respiration
Choose pedagogical approaches	Provide feedback on whether/how the pedagogical choices are backed by research
Design key activities	Provide feedback on the implications of the selected key activities
Setup a realistic timeline for the lesson	Provide feedback on the set timeline
Choose case students and predict behaviour	Choose categories for case students that are related to 21st century skills, give feedback on predicted behaviour
Teach the lesson and observe case students' learning	Observe teaching and learning
Evaluate the lesson within the lesson study team and adapt the lesson	Evaluate the lesson within the lesson study team and provide feedback on possible adaptations for the lesson
Teach/observe the research lesson and instruct	Observe case students, interview students, gather data from the written exercise
Evaluate the lesson within the lesson study team and formulate possible adaptations	Evaluate the lesson within the lesson study team and provide feedback on possible adaptations for the lesson

The aspects of TSPCK investigated, sources of data, and methods of analysis employed in the study are shown in Table 5.

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Table 5
Summary of the Stages, Data Sources, and Analysis Methods

Stage	Enacted TSPCK investigated	Data sources	Analysis methods
Planning -Before LS (personal planning)	eTSPCKp	Content representations (CoRes)	Scoring using a rubric
-During LS (collective planning)	eTSPCKp	Content representations (CoRes), Research lesson plans, Transcript of planning sessions	Scoring using a rubric Thematic analysis
Teaching	eTSPCKt	Transcripts of video-recorded research lessons	Thematic analysis
Reflecting	eTSPCKr	Transcripts of reflection sessions	Thematic analysis

Data Analysis

The transcripts of the planning, teaching, and reflecting sessions were analysed following Braun and Clarke (2006), by (i) reading and rereading transcripts (ii) coding extracts of transcripts (iii) formulating themes and collecting data for each theme (iv) comparing the themes with coded extracts (v) Refining and defining the specifics of the themes (iv) choosing examples of extracts for reporting the analysis.

The analysis of the transcripts involved identifying themes that described the teachers' enacted TSPCK components in teaching sessions. The units of analysis included segments in lesson plans and moments in the taught lessons where the teacher's explanations or responses contained one or more enacted TSPCK components. The evidence identified in planning, teaching, and reflecting sessions were analysed in depth by identifying the TSPCK components at play, and describing the nature of the interplay, if two or more components were employed. The findings from the different stages were constantly triangulated for emerging patterns in the teachers' TSPCK. The evidence from the transcripts for the planning, teaching, and reflecting segments were analysed in detail to answer the first research question. The responses in the personal and collective CoRes were analysed by the first and fourth authors using the same rubric. Any variances in the scores were discussed so that a consensus was reached and a final score assigned. The second and third authors constantly checked the analysis and conclusions drawn from them. The findings were used to answer the second research question. The rubric was developed through a literature search (Mazibe et al., 2018; Ndlovu & Malcolm, 2022) and validated by two science education lecturers and a science teacher. Part of the rubric is shown in Table 6.

Table 6
Rubric Showing Criteria for Scoring the First Four Prompts

Prompt	Level of TSPCK Enactment				
	Very limited (0)	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)
1.	Not answered	Identified concepts are key ideas or a mix of key ideas and subordinate ideas	At least one identified concept indicates the science content to be learned	Two or more identified concepts indicate the science content to be learned	All identified concepts indicate the science content to be learned
2.	Not answered	Reason(s) given are generic benefits of education	Reasons given for the importance of the topic exclude conceptual considerations and show no evidence of integrating other TSPCK components	Reasons given for the importance of the topic include reference to conceptual consideration and show evidence of integrating other TSPCK components e.g., what makes the topic difficult	Reasons given for the importance of the topic include reference to conceptual consideration and show evidence of integrating other TSPCK components e.g., what makes the topic difficult

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Prompt	Level of TSPCK Enactment				
	Very limited (0)	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)
3.	Not answered	Identified concepts are relevant to the topic of respiration but not pre-requisites to the chosen idea	At least one identified concept is a pre-requisite to the chosen idea	Two or more identified concepts are pre-requisites to the chosen idea	All identified concepts are pre-requisites to the chosen idea
4.	Not answered	Identified concepts are not relevant for the current topic/ grade level of learners	Identified concepts are not relevant to the current key idea but relevant to the grade level of learners	Identified concepts are relevant to the current key idea and grade level of learners i.e., relevant for the current level of learners	Identified concepts are within the grade level of learners i.e., relevant for the current level of learners

Trustworthiness

The trustworthiness of the study was ascertained following various criteria for credibility, confirmability, dependability, and transferability (Jita & Sintema, 2022; Poti et al., 2022). For example, to ensure credibility, the authors were immersed in the data over a prolonged period during which the coding and qualitative analysis were done. Furthermore, the initial analyses by the first and fourth authors were regularly checked by the second and third authors. The data collection and analysis procedures were reported in detail to ascertain the study's dependability. Regarding confirmability, the study adopted TSPCK as a theoretical framework to guide the framing of the study and data analysis procedures. Also, data on teachers' TSPCK enactment were reported verbatim and data collection and analysis instruments, CoRe and rubric, respectively, were described in detail. The CoRe was attached in Table 2, and part of the rubric is shown in Table 6. Lastly, a detailed description of the context of the study was given for transferability.

Research Results

Respiration Topic-specific PCK Components Enacted during the Lesson Study

The detailed qualitative analysis of the transcripts of the lesson planning, teaching, and reflecting sessions revealed the enacted TSPCK aspects assigned to seven salient themes. Table 7 shows the enacted TSPCK aspects, the themes to which they were assigned, and the description of the themes.

Table 7
Summary of Enacted Topic-Specific Pedagogical Content Knowledge (eTSPCK)

Enacted TSPCK Aspects	Themes (eTSPCK Components)	Description
• Question-and-answer • Lecture • Group activity/student presentation • Individual activity • Rewording & repeating questions • Repeating students' answers • Responding to students' answers	Teaching strategies	Teacher's actions or methods used to deliver the content.
• Students responding to the teacher • Teacher responding to student • Students responding to other students	Classroom interactions	interactions between the teacher and students and among students.

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Enacted TSPCK Aspects	Themes (eTSPCK Components)	Description
• Oral • Written • Oral + written • Equations (chemical and word) • Diagrams	Representations	ways or forms of representing the content or concepts
• Science/respiratory concepts • Personal life/society • Inadequate explanations	Curricular saliency	the teacher identifies or refers to salient knowledge of respiration (e.g., definition, an equation, importance of respiration, including personal life or society).
• Link between what makes the topic easy or difficult and curricular saliency • Link between curricular saliency and students' prior knowledge • Link between representations and curricular saliency • Link between students' prior knowledge, curricular saliency, and representations	Conceptual teaching strategies	the teacher used two or more PCK components to present the content or respond to students' adequacies or inadequacies.
• Reference to students' prior knowledge • Checking students' prior knowledge	Students' prior knowledge and misconception	the teacher refers to, checks, or addresses students' prior knowledge and misconceptions.
• Identified some learning difficulties • Missed/not addressed some learning difficulties	What makes teaching or learning difficult	the teacher identifies and responds to teaching/learning difficulties related to respiratory concepts.

The evidence of the observed enactment of TSPCK is presented below. It should be noted that some evidences presented were assigned to more than one theme as they represented different TSPCK components. This is in line with the integrated nature of TSPCK (Suh & Park, 2017). The analysis of the two lessons revealed some high and low-order pedagogical actions by the teacher. High-order pedagogical actions refer to the actions that were considered more effective and likely to promote high-order learning. In contrast, low-order pedagogical actions are those actions that were considered less effective and may promote low-order student learning.

Teaching Strategies

The results revealed that although the teacher employed the question-and-answer approach to engage the students in the lessons, the lessons were generally teacher-centred. The teacher asked most questions and only three students asked a question in research lesson 2 and none in research lesson 1. The teacher did not encourage students to seek clarifications or ask questions on any aspect of the lesson they were not clear about. The lecture method was used in the conclusion of both research lessons. Other than the oral questions asked during the lesson, the teacher presented a written exercise at the conclusion of the lesson to see if students comprehended the ideas.

The other teaching strategies used were rewording or repeating questions and repeating students' answers. These were categorised as high-order pedagogical actions because they have the potential to promote students' comprehension of the concepts. An example of rewording questions is shown in the excerpt below.

Teacher: …Now among the life processes or characteristics of living things, which one is supported by some of the products we get from plants? as outlined by someone here...
Student 6: Feeding and nutrition,
Student 7: Reproduction
Teacher: Ok let me help you, someone said that plants produce oxygen, which process is supported by oxygen?
Student 7: Respiration

Rewording questions helped the students easily understand what answer the teacher expected from them. Most students raised their hands to answer when the teacher reworded the questions. It can be seen from the excerpt above that after the teacher rephrased the question, student 7 was able to give the correct answer. Rewording questions was categorised as a high-order pedagogical action.

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Classroom Interactions

The study found that most classroom interactions between the teacher and students involved the students responding to the teacher's questions. An example of teacher-student interaction is shown in the excerpt below.

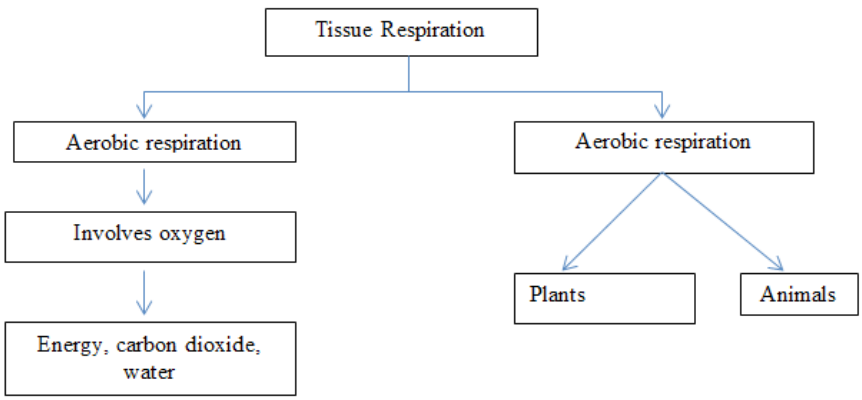
Student: Tissue respiration- this is when cells in living things take in oxygen and release carbon dioxide.
Teacher: [repeats the answer] So what I will do is that I will write that definition and we will consolidate [writes on the board].
Student: The process by which living organisms take in oxygen and release carbon dioxide as an unwanted product.
Teacher: Ok, similar to this one [points at the answer on the board]
Class (Chorus answer)**:** Yes
Teacher: what is cardinal here is the taking in oxygen and releasing carbon dioxide [underlines taking in oxygen and releasing carbon dioxide]. Yes, this group, are you ready, yes?
Student: This is the process of absorbing oxygen in the cells and releasing carbon dioxide.

It can be seen that the teacher rarely responded to students' answers to indicate whether or not the given answer was correct. Also, minimal student-to-student interactions were observed in both lessons. Interestingly, the teacher rarely encouraged students to interact with each other or to ask questions.

Representations

The study found that oral and a combination of written and oral representations were the most predominant forms of representing the content in both lessons. The latter form was considered a high-order pedagogical action because it enabled the students to use both visual and auditory senses to learn. This is likely to enhance students' retention of concepts learned. Aside from using chemical and word equations to express the types of tissue respiration, the teacher also used the flow diagram in Figure 2. Although the teacher combined oral and written representations well, he did not instruct the students to copy what he had written or emphasised.

Figure 2
A Representation Used to Summarise Tissue Respiration



Curricular Saliency

The teacher demonstrated a mix of both respiratory concepts and contextual knowledge. However, respiratory (scientific) concepts were more dominant as the lessons were based on content delivery. The teacher connected knowledge of anaerobic respiration in plants to personal and society when he stated, "In plants fermentation results in the production of alcohol……this is how kachasu [a local beer] is produced…." (Teacher, research lesson 1). Furthermore, the excerpt below shows that the teacher highlighted the content he intended the students to know.

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Teacher: Even me I have a feeling that in plants it's A. The reaction where glucose is broken down into carbon dioxide, alcohol, and energy [underlines alcohol] takes place in plants. This one where lactic acid is produced takes place in animals [underlines lactic acid].

The teacher highlighted the concepts that differentiate anaerobic respiration in plants and animals. However, in some instances, the teacher could not provide adequate explanations of the science concepts, for example in the following excerpt: "…some of you were saying how can alcohol be produced in plants? ….. it is the way we have written it here" [Research lesson 2]. The teachers' response lacks scientific explanation to challenge the students' thinking, suggesting inadequate knowledge of curricular saliency for this concept.

Students' Prior Knowledge

The study found that the teacher checked and referred to students' prior knowledge during the lessons as can be seen in the following excerpt.

Teacher: I am waiting, is this correct? If you are saying yes, explain a bit, if you are saying yes tell us why. Who wants to comment....?
Student: I feel since the definition says we are breaking down glucose to give out energy in the presence of oxygen. So, I feel it is supposed to start with: water + carbon dioxide + oxygen + glucose → energy (and then oxygen above the arrow since it is in the presence of oxygen)
Teacher: Then the only product here should be energy?
Student: Yes
Teacher: We respect your response.

In the excerpt above, the teacher did not give feedback to the student but just proceeded to get other responses from other students. This is an example of a low-order pedagogical action the teacher made. The students' response shows the misconception that energy is the only product of respiration. This misconception stems from the definition of respiration that emphasises energy production.

What makes Teaching or Learning Difficult

The teacher demonstrated some awareness of some aspects that make it difficult for students to learn respiratory concepts, as seen in the excerpt below.

Teacher: Let me clarify also as I end, on this one [pointing at equations for anaerobic respiration] some of you were saying how can alcohol be produced in plants. That is the statement I got from this side [pointing in one direction]. It is the way we have written it here.

In the above excerpt, the teacher identified an aspect that makes learning difficult, but he was unable to address it. This indicates limited knowledge of the components of conceptual teaching strategies.

Conceptual Teaching Strategies

There was some evidence of the link between some TSPCK components. For example, curricular saliency and students' prior knowledge were linked two times. Curricular saliency and representations were linked two times while students' prior knowledge, curricular saliency and representations were linked once. An example is shown in the excerpt below.

Teacher: **...**Yes, respiration. And today we are going to look at respiration and in particular, we're looking at tissue respiration [Teacher writes the term tissue respiration on the board]. I would want each one in your capacity just to write the definition of respiration.

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Student 5: They lose excess water in parts of the body,
Teacher: I will comment later
Student 6: The process of releasing energy from the breakdown of sugar in cell organisms
Student 7: The process of breaking down sugar in living organisms
Student 8: The process by which plants breathe
Teacher: We have heard the different definitions, what is key …from these definitions…. except one which I need to emphasise which came from this direction (points in one direction) that respiration is the release of water from plants. This is not respiration, it is transpiration. [Teacher wrote the definition of tissue respiration on the board i.e., tissue respiration is the process of breaking down food molecules (glucose) or any simple sugars inside the cells to release energy]. So, it is very important to understand that this process is important in the release of energy.

This excerpt shows that the teacher drew upon his knowledge of students' prior knowledge, representations, and curricular saliency to emphasise important concepts about tissue respiration.

Improvements in Teachers' Planned Topic-specific PCK (eTSPCKp) Components in Respiration

The eTSPCKp components that teachers enacted were measured using the content representation and analysed using the rubric. The results for five components: curricular saliency, what makes the subject easy or difficult, students' prior knowledge and misconceptions, conceptual teaching strategies, and representations are presented below. Table 8 shows the results for teachers' personal eTSPCKp.

Table 8
Teachers' Personal eTSPCKp Scores

Teachers' ID	Teaching experience	eTSPCKp Components					eTSPCKp (Average)
		Curricular Saliency	What makes a topic easy or difficult	Students' prior knowledge	Conceptual teaching strategies	Representations	
T3	Experienced	1.8	3.0	3.0	1.5	1.0	2.1
T1	Novice	1.3	1.0	1.0	1.5	1.5	1.3
T4	Experienced	1.3	0.0	1.0	1.5	1.5	1.1
T6	Experienced	1.0	1.0	1.0	1.5	1.0	1.1
T5	Novice	1.3	1.0	1.0	1.0	1.0	1.1
T2	Experienced	1.3	0.0	0.0	1.5	1.5	0.9
Average		1.3	1.0	1.2	1.4	1.3	1.3

The results in Table 8 show that the average of the teachers' personal eTSPCKp was 1.3, indicating that teachers' personal eTSPCKp was limited. The enactment of the eTSPCKp components was also limited with scores ranging from 1.0 (for what makes the topic easy or difficult) to 1.4 (for conceptual teaching strategies). The results also show that T3 (experienced teacher) enacted the highest eTSPCKp (basic level) while the rest of the teachers enacted limited eTSPCKp.

A collectively constructed CoRe was analysed using the rubric to determine the teachers' collective eTSPCKp, and the results are shown in Table 9.

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Table 9
Teachers' Collective eTSPCKp Scores

	eTSPCKp Components					eTSPCKp (Average)
	Curricular saliency	What makes a topic easy or difficult	Students' prior knowledge	Conceptual teaching strategies	Representations	
Average Score	2.8	3.0	2.0	3.5	3.0	2.9

The results show that the teachers' eTSPCKp ranged from 2 to 3.5, representing basic and developing eTSPCK, respectively.

To determine the improvement in the teachers' personal and collective eTSPCKp, the scores of the personal and collective CoRes were compared. The results show that the teachers' average score was 2.9 representing basic eTSPCKp. The teachers' collective eTSPCKp components were at the developing level except for curricular saliency and students' prior knowledge, which were at the basic level. The results are shown in Table 10.

Table 10
Comparison between Teachers' Personal and Collective eTSPCKp

Type of eTSPCKp	eTSPCKp Components					Average
	Curricular saliency	What makes a topic easy or difficult	Students' prior knowledge	Conceptual teaching strategies	Representations	
Personal	1.3	1.0	1.0	1.4	1.3	1.2
Collective	2.8	3.0	2.0	3.5	3.0	2.9
Gain(s)	1.5	2.0	1.0	2.1	1.7	1.7

Table 10 shows that the teachers' collective eTSPCK was more developed than their personal eTSPCKp suggesting that participation in the lesson study improved the teachers' eTSPCKp components. The highest improvement was recorded for conceptual teaching strategies and what makes the topic easy or difficult, followed by representations, curricular saliency, and students' prior knowledge, respectively.

Discussion

This study explored the secondary school biology teachers' enacted topic-specific pedagogical content knowledge in respiration during a lesson study. The meaning and implications of the findings are discussed in light of the related literature. Firstly, the findings related to the enactment of respiration TSPCK during the lesson study are discussed. Secondly, a discussion of the findings related to improvements in teachers' planned eTSPCK in respiration.

Enactment of Respiration Topic-specific Pedagogical Content Knowledge (TSPCK) during the Lesson Study

The findings indicate that the taught lessons were predominantly teacher-centred and teacher-controlled. These results are consistent with previous studies such as Poti et al. (2022) and Makhechane and Qhobela (2019). However, such teaching and learning environments may not effectively influence students' learning. As observed in this study, students' role was answering teachers' questions, without asking questions or seeking clarifications on taught concepts. This role may not make respiratory concepts easy to learn. Teachers need to provide students opportunities to ask questions and seek clarifications where they may not be clear.

The lesson analysis showed high-order and low-order pedagogical actions, indicating enactment of developed and limited TSPCK respectively. Teachers ought to be aware of these actions and how they affect learning so

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that they may plan and enact lessons that promote students' comprehension of science concepts. Like Poti et al. (2022), this study found that the teachers demonstrated limited knowledge of students' prior knowledge during the planning, teaching, and reflecting stages. However, this contradicts Mavhunga and van der Merwe (2020) who found that teachers enacted developed knowledge of students' prior knowledge. For teachers to conduct lessons that promote students' learning, they need to possess adequate knowledge of students' thinking prior to, during and after instruction.

The study found limited integration of TSPCK components (enactment of knowledge of conceptual teaching strategies). This result supports Makhechane and Qhobela (2019) who found that efforts to combine different teachers' knowledge areas were minimal. However, researchers have articulated the need for teachers to integrate the PCK components to successfully transform the content (Park & Chen, 2012). The inability to integrate eTSPCKp components would make it difficult for teachers to assist students in achieving intended learning outcomes. It is worth noting that the findings highlight some unique pedagogical actions the teacher made that would promote students' learning. These included rephrasing questions to allow students to understand what the teacher expected from them, and repeating students' answers to allow students capture the classroom discourse.

Improvements in Teachers' eTSPCKp Components in Respiration

Previous studies have compared teachers' pre-test and post-test scores on CoRes (Miheso & Mavhunga, 2020; Ndlovu & Malcolm, 2022). However, this study compared individual teachers' scores on CoRes with the scores of the same teachers in a collectively constructed CoRe during a lesson study. The difference in the eTSPCKp scores could be attributed to participation in the lesson study, Therefore, participation in the lesson study improved teachers' knowledge in the five eTSPCKp components. The activities that contributed to improvement in teachers' eTSPCKp were discussion of the respiratory concepts (i.e., it had a focus on content) and collaborative planning through which all teachers discussed their TSPCK (Coenders & Verhoef, 2019). Although more data may need to be collected to ascertain the contribution of the lesson study to each teacher's TSPCK, this claim is supported by previous studies (Agricola et al., 2020; Ndlovu & Malcolm, 2022; Thi et al., 2019). The CoRes stimulated teachers' reasoning about respiratory concepts through the chosen big ideas, thereby supporting them in articulating and reflecting on their teaching (Nilsson & Karlsson, 2018).

The study found that the teachers' personal eTSPCKp for respiration was limited in all the eTSPCKp components apart from Teacher 3 (experienced teacher) who demonstrated developed PCK for "what makes the topic easy or difficult to learn" and "students' prior knowledge". Overall, both experienced and novice teachers demonstrated limited personal eTSPCKp. The results indicate that there were no differences in the level of eTSPCKp between experienced and novice teachers. This finding supports the assertion by Kind (2017) that teaching experience does not necessarily mean developed PCK, and hence eTSPCKp. A possible explanation for this finding is that these teachers have not been supported with professional knowledge for reflecting on their teaching and using their experience to develop TSPCK. Perhaps, teachers lack the knowledge to use students' knowledge to develop their TSPCK. The implication is that experienced and novice teachers may need enhancement of their eTSPCKp in respiration.

The teachers' collective eTSPCKp for respiration was higher than their personal and average personal eTSPCKp. Although these results may not be entirely attributed to participation in the lesson study, a large portion of the difference could have resulted from the teachers' participation in the lesson study. This is in line with the assertion that participation in professional development activities may develop TSPCK (Dudley et al., 2019). Therefore, participation in lesson study enhanced the teachers' eTSPCKp in all five components. These findings support previous findings that lesson studies enhanced teachers' TSPCK (Agricola et al., 2020). Similarly, Ndlovu and Malcolm (2022) observed an increase in all the TSPCK components following teachers' participation in a practicum. These findings point to the potential contribution of effective lesson study-based teacher professional development to enhance teachers' eTSPCKp in respiration.

Limitations

The study only presents data on two observed research lessons the same teacher (demonstrator) delivered. As some of the eTSPCK may reflect the demonstrators' own eTSPCKp, it would have been advantageous if the study analysed research lessons demonstrated by different teachers. The study was also limited by comparing teachers' personal eTSPCKp with collective eTSPCKp thereby assuming that each teacher's personal eTSPCKp improved to

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the same extent. This assumption needs further investigation. However, reflecting on the teachers' contributions during the two lesson study cycles (planning, teaching, and reflecting sessions) and triangulating the findings from each stage helped counter these methodological limitations.

Conclusions and Recommendations

This study explored the secondary school biology teachers' enacted TSPCK in respiration during a lesson study. The results revealed that teachers enacted seven TSPCK components: teaching strategies, classroom interactions, representations, curricular saliency, students' prior knowledge, conceptual teaching strategies, and what makes a topic easy or difficult. These results also indicated an improvement in all the TSPCK components after teachers attended the lesson study. The conversations in the planning and reflecting processes, and engagement with the researcher could have contributed to the improvement in eTSPCKp. Furthermore, the results suggest that a teacher may employ a mix of high-order and low-order pedagogical actions in a single teaching-learning cycle based on their knowledge of the TSPCK components at play. The study has also established that teachers' planned personal eTSPCKp in respiration was limited and less developed than their collective eTSPCKp. The findings suggest that teachers can improve their TSPCK by participating in lesson studies. Based on the results, the following recommendations were made:

a) Teachers should become more reflective during their planning, and teaching sessions
b) The school should provide teachers with the necessary support in their teaching by encouraging collaborative planning, teaching, and reflecting.
c) The school should implement lesson study activities aimed at enhancing teachers' topic-specific pedagogical content knowledge
d) Future research should investigate the aspects of lesson studies that afford the improvement of teachers' topic-specific pedagogical content knowledge
e) Future research may compare pre-test and post-test scores for personal and collective topic-specific pedagogical content knowledge.

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Declaration of Interest

The authors declare no competing interest.

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