



Research Article

Bongani Prince Ndlovu*, Sphehile Winile Nsele and Hlologelo Climant Khoza

Enhancing conceptual teaching in organic chemistry through lesson study: a TSPCK-Based approach

<https://doi.org/10.1515/cti-2024-0124>

Received December 2, 2024; accepted March 4, 2025; published online April 2, 2025

Abstract: Conceptual teaching in science education and its implications for pedagogical research have been extensively studied. Likewise, lesson study (LS) has been recognized as a powerful tool for continuous professional development and effective teaching practices. Despite the recognized importance of LS and the affordances of topic-specific PCK (TSPCK) in developing conceptual teaching, the connection between these two approaches in fostering conceptual teaching, remains under-explored within science education. This study aims to explore the development of a conceptual teaching from the dynamic interplay of TSPCK components for teaching a section of organic reactions through a TSPCK-based LS. A qualitative research approach was followed with four teachers from Umkhanyakude district in KwaZulu-Natal. These teachers participated in a TSPCK-based LS to develop a conceptual teaching strategy using Content Representation (CoRe). The findings revealed that teachers progressed from a basic to a developing level of conceptual teaching expertise through LS, as measured by TSPCK component interaction. While the findings are not generalizable, they offer valuable insights into teacher development, highlighting LS as an effective approach for enhancing conceptual teaching in science. This study concludes by recommending large-scale research exploring the role of reflection and feedback during LS in developing conceptual teaching within TSPCK interventions.

Keywords: conceptual teaching; CoRe; lesson study; TSPCK; organic chemistry

1 Introduction

Conceptual teaching and understanding have been central to several educational research studies.^{1–3} In most studies, these concepts have been closely intertwined. Holme et al.⁴ defined conceptual understanding in chemistry as more than just memorizing steps or applying algorithms to solve problems. Instead, it emphasizes a deep grasp of the underlying physical and chemical phenomena that govern changes and properties of matter. Consequently, this deeper understanding allows students to predict or explain observations based on well-tested hypotheses about how chemical systems behave.⁴ To develop such a deeper understanding of science, particularly in chemistry, conceptual teaching is crucial in emphasizing the teaching of core concepts within the discipline. Conversely, Baron and Holman¹ defined conceptual teaching as the use of key concepts to facilitate deep student understanding and improve the retrieval of factual information. Research in science education has examined various aspects of conceptual teaching and conceptual knowledge, revealing a disconnect between effective approaches and everyday instruction. For example, Duit et al.⁵ focused on how various theoretical perspectives influence researchers' views on science teaching and learning, particularly regarding conceptual

*Corresponding author: **Bongani Prince Ndlovu**, University of KwaZulu-Natal, Durban, South Africa, E-mail: ndlovub7@ukzn.ac.za. <https://orcid.org/0000-0002-4229-8699>

Sphehile Winile Nsele, University of KwaZulu-Natal, Durban, South Africa

Hlologelo Climant Khoza, University of Pretoria, Pretoria, South Africa

change. Duit et al.⁵ identified a significant gap between existing knowledge about effective science teaching and the reality of classroom instruction. This gap highlights the need for teachers to adopt instructional approaches, such as conceptual teaching, that prioritize the development of deep understanding and meaningful connections between scientific concepts. Recent studies have emphasized that a strong grasp of topic-specific pedagogical content knowledge (TSPCK) is crucial for effective science teaching that fosters conceptual understanding.^{6,7} This can be achieved by leveraging suitable representations, analogies, and illustrations that teachers use to address students' misconceptions and areas of difficulty in learning.⁸ Within pre-service teacher education, TSPCK-based interventions have been implemented to enhance prospective teachers' conceptual knowledge for teaching challenging topics such as chemical equilibrium, stoichiometry, and the particle nature of matter.^{7,9,10} While these studies have reported successful improvements in the overall quality of TSPCK, they have also reported difficulties in significantly enhancing the quality of conceptual teaching strategies as one of the TSPCK components. We argue that conceptual teaching strategies can foster conceptual understanding in science classrooms. Recently, a study by Mapulanga et al.¹¹ provided evidence of using a lesson study to improve secondary school biology teachers' TSPCK. However, given the idiosyncratic nature and topic-specificity, there is a need for further empirical research exploring the role of lesson studies in the development of conceptual teaching strategies. Building upon the established significance of the TSPCK framework in fostering the development of conceptual teaching strategies, this study aims to explore the development of a conceptual teaching from the dynamic interplay of TSPCK components for teaching a section of organic reactions through a TSPCK-based lesson study. Therefore, the research question guiding this study is:

To what extent does a TSPCK-based Lesson Study enhance the quality of the development of a conceptual teaching strategy in teaching a section of organic reactions?

2 Lesson study as means for teacher professional development

Lesson Study (LS), originating from Japanese mathematics education (Fernandez and Yoshida),¹² involves collaborative planning, observation, and analysis of research lessons.¹³ Research has demonstrated its adaptability across diverse contexts, fostering continuous collaboration among educators.¹⁴ Borko¹⁵ highlights that LS fosters supportive professional communities and enhances teacher efficacy. Collaborative practices within LS positively impact instructional practices, increasing teacher confidence and encouraging experimentation and refining of effective pedagogical practices.¹⁶ This is crucial for our exploration of LS's potential to enhance conceptual science teaching. LS promotes innovative teaching strategies that cater to diverse learning styles. According to Dudley,¹⁷ feedback received during LS sessions enables teachers to refine their practices, shifting from teacher-centred to more student-active approaches, critical for fostering conceptual understanding.

There are several challenges associated with LS implementation. First, a limited time for professional development and research lesson planning.¹⁸ Second, the pressure to demonstrate short-term student outcomes.¹⁹ Third, the limited access to research skills, materials, and resources²⁰ and the fear of judgment during observations¹⁸ are among the challenges of LS implementation in teacher development.

3 Conceptual teaching and understanding in science

Effective science instruction hinges on cultivating deep conceptual understanding. While it is generally agreed that this involves grasping observable properties, processes, and utilizing models and symbols in a structured manner,²¹ there is a notable lack of consensus on what constitutes conceptual understanding and teaching.⁴ This gap underscores the need for a clear definition to guide effective instruction. Achieving conceptual understanding is particularly crucial in chemistry; however, numerous challenges persist. Traditional teaching often overemphasizes algorithmic problem-solving approaches, which hinders the development of deeper conceptual understanding.⁴ To overcome these challenges, research highlights several effective pedagogical strategies. For example, identifying and addressing students' preconceptions is fundamental to building upon

existing knowledge.^{5,22} Additionally, continuous evaluation of student understanding is essential for timely intervention.²³ Lastly, connecting concepts to real-world contexts, inquiry-based learning, and active learning strategies – such as experiments, discussions, and reflection – contribute to deeper learning.^{5,23} Conceptual teaching in science involves fostering deep understanding and meaningful connections between scientific concepts. This understanding has been guided by two main theoretical approaches in science education: Posner's conceptual change model and the TSPCK model. Posner's model primarily focuses on the cognitive shifts students undergo when confronted with information that contradicts their existing beliefs.²⁴ It outlines the conditions necessary for conceptual change, emphasizing the importance of dissatisfaction with current conceptions, intelligibility of alternative explanations, and applicability of new ideas.²⁵ In contrast, the TSPCK model centres on the teacher's knowledge and skills essential for effective science instruction. It highlights the need for teachers to possess a deep understanding of subject matter, pedagogical strategies, and the ability to connect these elements to students' prior knowledge.¹¹ While Posner's model offers a cognitive perspective on learning, TSPCK provides a pedagogical lens for conceptual teaching and learning. Both are regarded as valuable for understanding conceptual teaching, with the former aiding in identifying student misconceptions and the latter guiding instructional design and evaluation.

The significance of TSPCK in science education, particularly chemistry, lies in its ability to bridge the gap between teachers' content knowledge and their capacity to transform that knowledge for learner comprehension.^{9,26} Research indicates that teachers with strong TSPCK are better equipped to anticipate and address student misconceptions,²⁷ select appropriate instructional strategies,⁷ and foster meaningful learning experiences.⁶ Furthermore, TSPCK facilitates the development of inquiry-based teaching practices,²⁸ hence it positively impacting student engagement and achievement in chemistry. Ultimately, the integration of TSPCK into chemistry pedagogy facilitates the creation of dynamic learning environments that cater to diverse student needs and enhance overall educational outcomes.

4 Theoretical assumptions

This study used the TSPCK theoretical construct, which describes teachers' competence to transform their subject matter knowledge into forms of knowledge suitable for teaching. The understanding of how the transformation of content knowledge comes about was initially presented by Mavhunga and Rollnick⁹ who introduced TSPCK as a specialized form of PCK within the topic. They argued that the transformation of content knowledge emerges from the considerations of five different types of knowledge which are content-specific. These are (i) learner prior knowledge, (ii) curricular saliency, (iii) what is difficult to teach, (iv) representations, and (v) conceptual teaching strategies. According to Mavhunga and Rollnick,⁹ learners' prior knowledge encompasses an understanding of pre-existing knowledge and misconceptions held by the student related to the topic. Secondly, curriculum saliency entails the awareness of how the specific topic fits within the broader curriculum and assessment requirements. Thirdly, identifying and understanding the inherent challenges and complexities of the topic for students is linked to what is difficult to teach. Fourthly, the knowledge of various visual representations, illustration and analogies to make abstract concepts accessible to learners. Lastly, the knowledge of conceptual teaching strategies which entails instructional methods that foster deep understanding rather than superficial memorization of facts. Figure 1 below depicts the TSPCK model.

While initially presented as separate elements, subsequent research, particularly Mapulanga et al.,¹¹ Mavhunga²⁷ highlights the dynamic interplay among the other four components in shaping conceptual teaching strategies. This is in contrast to the narrower approach taken by Mazibe et al.⁸ which places the knowledge of representations as crucial for conceptual teaching strategies. We argue that the emerging quality of conceptual teaching strategies from the TSPCK component interaction is one way of mapping conceptual teaching in science.

Secondly this study leverages on Community of Practice (CoP) theory by Wenger.²⁹ A CoP goes beyond a social group; it centres around a shared interest or practice, with members committed to developing specific expertise. Within such a CoP, the LS approach offers a structured framework for collaboration, reflection, and continuous improvement of teaching practices.³⁰ LS offers a powerful approach to professional development, fostering collaboration and knowledge sharing among educators. Through this process in action, they share expertise and

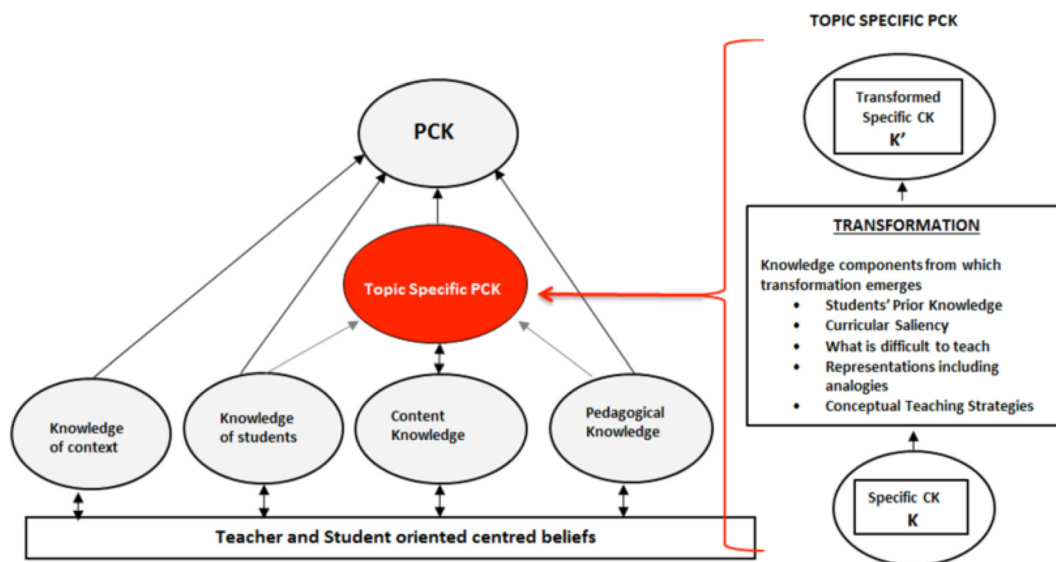


Figure 1: A model of TSPCK (Mavhunga & Rollnick,⁹ p. 115).

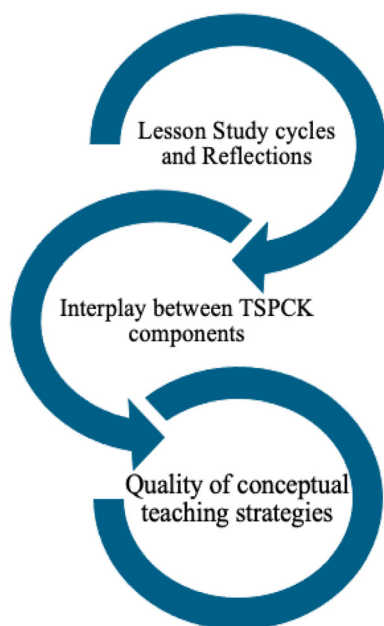


Figure 2: A model representing our conceptual framework.

improve their teaching practices.¹³ Figure 2 pictorially shows our conceptualisation of the LS impacts on TSPCK which ultimately foster conceptual teaching.

5 Methodology

Following the interpretivism paradigm, this study employed a qualitative research approach³¹ to investigate the impact of a TSPCK-based lesson study on the enhancement of a conceptual teaching strategy developed in organic chemistry. Participants (N = 4) were recruited from Umkhanyakude district in KwaZulu-Natal following a convenient but purposive sampling strategy. The selected participants were Grade 12 Physical Sciences teachers

Table 1: Biographic data of the Participants.

Pseudonyms	Gender	Age	Qualifications	Teaching experience
Peter	Male	>45	BSc Chem, PGCE	19 years
Mary	Female	40–45	B Ed Hons	25 years
Jane	Female	>45	SPTD, ACE	22 years
Thabo	Male	>45	FDE (Math & science)	30 years

who were experience in teaching organic chemistry. Table 1 summarises the characteristics of the selected participants in terms of their gender, age group, levels of qualifications and teaching experience.

To generate data, Content Representations (CoRes), which were originally developed by Loughran et al.³² as part of a strategy for exploring and gaining insights into the PCK of expert science teachers were used. CoRes are conceptual tools designed to help teachers make explicit their knowledge of content and pedagogy. They are typically represented in table format, with Big Ideas listed horizontally and pedagogical questions (related to curriculum and instructional decisions) listed vertically.

CoRe construction has been utilized as a scaffold to enhance teachers' PCK by helping them connect content, student thinking patterns, conceptual difficulties, and pedagogy.³³ Studies suggest that novice teachers possess naïve PCK, highlighting the need for development through practice and reflection.^{34,35} Even experienced teachers may struggle to design instruction that addresses student misconceptions.³⁶ Engaging teachers in CoRe construction, such as the study by Hume and Berry³³ with pre-service chemistry teachers, allows them to explore student misconceptions and align curriculum goals with their instructional strategies and hence, fostering conceptual teaching.

6 Explaining the TSPCK-based lesson study intervention

Generally, there are four stages in a lesson study cycle.²⁰ The first step involves planning a research lesson focused on a specific learning objective. The second step is observing one or more teachers deliver the lesson. The third step encompasses post-lesson reflections, and lastly, lesson improvements. The cycle continues to enhance the quality of the lesson plan. To establish the tone and familiarize the participants, an initial phase was included to diagnose the problem. During this phase, the participants discussed the diagnostic reports from the Grade 12 examination to identify common errors, misconceptions, and learning difficulties reported from 2021 to 2023. After this analysis, one of the researchers introduced the TSPCK construct and discussed the advantages of CoRe-based planning. Subsequently, the participants developed the first lesson plan for conceptual teaching, explicitly focusing on the TSPCK components while responding to the CoRe prompts. Three big ideas were identified based on the knowledge of organic reactions. However, for the purpose of this study, one major idea is presented: “*an ester is a product of a catalysed condensation reaction between an alcohol and a carboxylic acid.*” After the first CoRe was completed, one teacher (Thabo) presented the lesson, which was video recorded for reflection purposes. After the first lesson, the group convened to discuss the lesson and made improvements for the second CoRe. These improvements enhanced the conceptual teaching strategy developed in this study. The second lesson was presented, and final reflections were made to refine the final conceptual teaching strategy. This process also provided further insights into the value of the lesson study for conceptual teaching strategies. Figure 3 summarizes how the process unfolded.

7 Data analysis and findings

Data was analyzed using a performance rubric adapted from Mavhunga and Rollnick⁹ to assess the quality of planned TSPCK, ranging from limited to exemplary (see Appendix A). While the primary focus of this analysis was

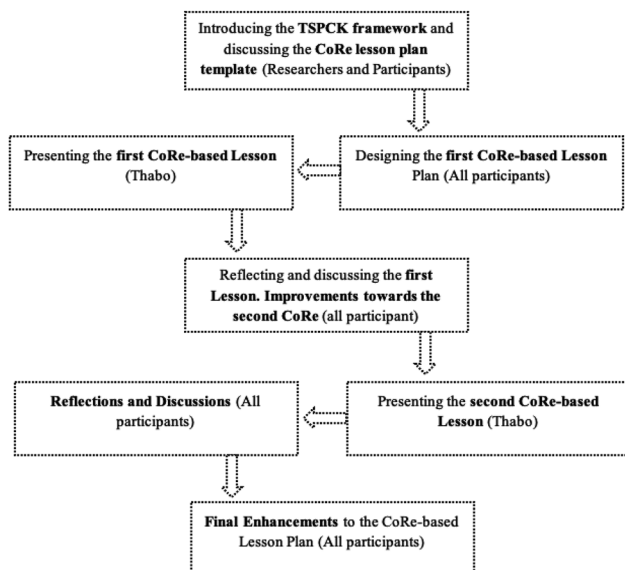


Figure 3: Stages in the lesson study process.

not on the overall quality of TSPCK, the rubric proved valuable in mapping the enhancements in the quality of the conceptual teaching strategy, specifically in relation to the TSPCK knowledge components outlined in our conceptual framework.

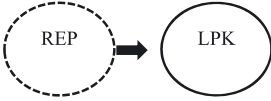

To achieve this, a qualitative deductive analysis was employed. The research question centered on the development of a conceptual teaching strategy for the big idea: “an ester is a product of a catalyzed condensation reaction between an alcohol and a carboxylic acid.” To track these improvements, each component of TSPCK was analyzed across the two lesson study cycles, drawing on the developed CoRes to highlight the progression. Table 2 presents the specific developments in each TSPCK component that contributed to the overall enhancement of the conceptual teaching strategy.

Firstly, regarding learner prior knowledge there was one item in the CoRe where teachers had to demonstrate their knowledge. In the first CoRe, they were able to identify one misconception about artificial flavours (from esters) against real fruit flavours. After the reflections, teachers added another misconception about vinegar not being considered a carboxylic acid. Further, the participants explicitly included the chemical formula of vinegar and indicated its common household colours (symbolic and macroscopic representation) to highlight this misconception. While this did not exemplify exemplary knowledge of learner prior knowledge, it marked a shift from basic to developing quality. Additionally, they highlighted the difficulty in teaching carboxylic in terms of their chemical behaviour from Bronsted theory and Lewis’s theory. The participants unpacked the misconception by drawing on macroscopic and symbolic representations and the consideration of what is difficult to teach. See Table 3 for this development.

Table 2: Improvements in the other TSPCK components between the lesson study cycles.

Knowledge components	First CoRe	Second CoRe
Learner prior knowledge	Basic	Developing
Curricular saliency	Limited	Basic
What is difficult to teach	Limited	Developing
Representations	Basic	Exemplary

Table 3: Developments in the learner prior knowledge component.

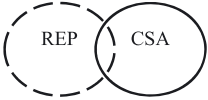
	First developed CoRe	Additions towards the second CoRe
What are typical students' misconceptions when teaching this idea?	<ul style="list-style-type: none"> Learners drink fruit-flavoured drinks or sweets believing they are made from actual fruits, but their flavours are created using esters. 	<ul style="list-style-type: none"> Vinegar (black or white), despite being a carboxylic acid with the formula CH_3COOH, is not considered a household acid due to its culinary use. Carboxylic acids behave like Lewis bases and alcohols behaves like Lewis' acids Carboxylic acids are like Bronsted acids (they give-H)
Component(s) interactions		

Considering the second component related to curricular saliency, the CoRe has three items that probes the quality of teachers' knowledge. On the construction of the first CoRe, participants showed a limited knowledge of curricular saliency. While they were able to identify relevant big ideas, not enough concepts were initially identified. Additionally, they could link curricular saliency with other components of TSPCK. However, while developing the second CoRe, they expanded the identified concepts, including reaction conditions and Brønsted and Lewis theories, and illustrated them with examples. In addition, they used some representations (symbolic) to magnify these examples. This signalled an enhancement from limited to basic level of the knowledge of curricular saliency. See Table 4 for this enhancement.

During the first feedback, the reflections facilitated the development of TSPCK. For example, Thabo said:

...[we] got the chance to scaffold the concepts into simpler ways to be well understood by learners. Concepts were arranged in an order of increasing degree of difficulty.

Table 4: Development in the curricular saliency component.

	First developed CoRe	Additions towards the second CoRe
What do you intend students to learn from this idea?	<ul style="list-style-type: none"> The ester is formed during a reaction called esterification. Esterification is a reaction of alcohol and carboxylic acid in the presence of sulfuric acid as a catalyst. 	<ul style="list-style-type: none"> e.g. alcohol + carboxylic acid $\xrightarrow[\Delta]{\text{H}_2\text{SO}_4}$ ester + water Reaction conditions: Add a few drops of H_2SO_4. Heat in a water bath.
Why is it important for students to know this idea?	<ul style="list-style-type: none"> Esters are essential in the food industry because they have fruity smells. 	<ul style="list-style-type: none"> Ester is also used in medicine to produce flavors in syrups and in the cosmetic industry to produce a fruity smell in lotions.
What else you might know about this idea that you intend students not to know yet?	<ul style="list-style-type: none"> The reaction of esters to form polyester. 	<ul style="list-style-type: none"> The distinction between Lewis's acid and Bronsted acid in organic chemistry.
Component(s) interactions	No component interaction	

In addition, during the feedback session, Mary added that:

Learners are failing to respond to organic reactions when they are given flow diagrams with only one clue [referring to exam type questions]. Learners need to understand reaction condition for them to predict the next reaction.

Furthermore, Thabo highlighted that they need to be aware of the aspects of content that are not examinable. He said:

We must not concentrate on the polyesters, even if they are in the book. They are not for examination purposes

These reflections pointed the participants to the need to include reaction conditions explicitly when dealing with the knowledge of organic reactions. Also, they were being cognisant of the content that they know but do not intend for students to learn.

The next component focused on the difficult aspects to teach. There was one item related to this component in the CoRe. On the first CoRe, participants were able to identify an area of difficulty in teaching the big idea. This identification of what is difficult to teach was not explained, hence indicated limited knowledge as per the rubric. On the second CoRe, teachers did not identify new gatekeeping concepts. However, they were able to outline a reason linked to the common misconception which they earlier identified are regarded as contributing to what is difficult to teach. This signalled a developing knowledge of this component. This response was quite interesting in the sense that the participants did not focus on what is difficult to teach but the interplay of this component and representation to address a particular prior knowledge.

Next, is the focus on the knowledge of representations. In the first CoRe, teachers showed basic knowledge of representations. While three levels of representations were identified, this was found to be basic since participants provided no reasoning regarding how they could support conceptual learning. In the second CoRe, teachers attempted to explain how for example a ball and stick model can help explain the acid donating an $-OH$ rather than $-H^+$. In addition, participants added that an experiment can support the idea that esters have a pleasant smell. This signalled an enhancement from basic to exemplary knowledge as the representations were aimed to support the confrontation of a specific learning misconception.

After the first lesson presentation, the participants noted the need for using more than one level of representations, this signalled the development in their knowledge for teaching. For example, Mary added that:

We have not used the models [particulate level] in the past to show learners how the reaction of a carboxyl acid and an alcohol takes place. We need to use them so that we can help learners understand that $(-OH)$ comes from the acid.

In addition, Peter also indicated that they need a simple experiment to allow student to physically detect the smell of the produced ester. During the feedback, he said:

Let us consider using a simple experiment [macroscopic representation] so that learners can also identify the smell of the ester produced

These two assertions show how the feedback and reflections fostered the use of multiple representations towards conceptual teaching.

The next section focuses on other essential components of the CoRe related to the understanding of teaching strategies. It is important to note that these elements alone do not constitute a comprehensive conceptual teaching strategy. For instance, other factors such as context, culture, cognitive styles, and resource availability also influence the teaching of this concept. Additionally, assessment knowledge is crucial for a well-rounded teaching strategy as it offers essential evaluation points. When combined with the other four components of TSPCK (learner prior knowledge, curricular saliency, what is difficult to teach, and representation), these aspects collectively form a comprehensive conceptual teaching strategy. Table 7 outlines the enhancements made in relation to the other aspects of teaching strategy aspects between the two cycles.

For instance, teachers recognized learners' common exposure to alcohol in social settings and the prior teaching of acids and bases in inorganic chemistry as contextual issues potential impacting the teaching. These

Table 5: Development in the “what is difficult to teach” component.


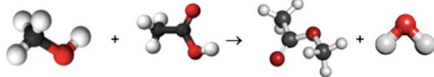
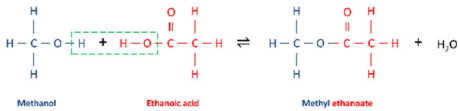
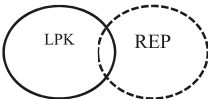
	First developed CoRe	Additions towards the second CoRe
What do you consider easy or difficult about teaching this idea?	<ul style="list-style-type: none"> — The knowledge of structural formulae of alcohols and carboxylic acids can lead to an incorrect ester. — It is difficult to explain that hydroxyl group (OH) is from a carboxylic acid, and it bond with hydrogen atom (-H) from an alcohol during esterification. 	Teachers need to use different colours when presenting that (-H) is from an alcohol during esterification and further demonstrate it using models. This can help understand that carboxylic acids do not behave like Bronsted acids during esterification.
Component(s) interactions	No component interaction	

Table 6: Development in the REP component.

	First developed CoRe	Additions towards the second CoRe
What representations would you use in your teaching strategy?	<ul style="list-style-type: none"> — Symbolic representations can be used to write balanced equations for esterification. — Models can be used for microscopic representation. — The experiment can be done to represent the macroscopic level. 	<ul style="list-style-type: none"> — e.g. Ball and stick Models will be used for microscopic representation. To demonstrate the formation of ester and how an acid release an-OH rather than-H, a simple experiment will be conducted to represent the process macroscopically and learners will get to smell the ester. <p>Ball and stick model Clue: Black - C, Red - O, Grey - H</p>  <p>Structural formulae and IUPAC names:</p>  <p>Methanol Ethanoic acid Methyl ethanoate</p>
Component(s) interactions	No component interaction	

points were noted by what is difficult to teach and learner prior knowledge. The second CoRe group also emphasized the influence of functional group chemistry and homologous series knowledge on teaching this concept. Hands-on teaching was identified as an effective strategy. Following the initial cycle, the value of visual aids in simplifying the ester formation process was acknowledged.

The analysis of the two CoRes above generated between the two lesson study cycles indicated that there was an improvement in the quality of conceptual teaching strategy from the perspective of TSPCK. According to the rubric there was an attempt by the teachers to use specific strategies that exposes learner prior knowledge. For

Table 7: Other aspects of teaching strategies.

	First developed CoRe	Additions towards the second CoRe
What other factors influence the teaching of this idea?	<ul style="list-style-type: none"> — Learners associate alcohol with the ones found in taverns e.g. beer. — The knowledge of acids and bases in grade 11, especially the acid-base theories. 	The learners know the structural formula for a functional group of alcohol and carboxylic acids from knowledge of homologous series.
What effective teaching strategies would you use to teach this big idea?	Demonstration: <ul style="list-style-type: none"> — The teacher can demonstrate the formation of esters using for example ethanol and ethanoic acid. Learners can identify the characteristic smell. — Using the above example, a balanced chemical reaction can be represented in IUPAC names, condensed structural formula, and structural formula. Learners can write the balanced equation to represent this chemical change 	Visual aids Learners can be given models to build compounds and re-arrange them to form products. From this, learners can write the balanced equation to represent this chemical change
What questions would you consider important to ask in your teaching strategy?	<ul style="list-style-type: none"> — Teachers can probe questions on the importance of esters in industry. — Teachers can use the IUPAC name for reactions of alcohols and carboxylic acids and allow learners to give products and then present balanced chemical equations using a structural formula, condensed structural formula, or molecular formula. 	<ul style="list-style-type: none"> — The teacher can probe questions on reaction conditions for esterification.

example, learners tend to believe that candy and juice always come from the actual fruits. However, the flavour of many juices and candies comes from esters since they often have pleasant fruity or floral scents, which contribute significantly to the smell of these product. Using an experiment can prove this. Also, there is evidence of what the learners' activity will be as the lesson progresses (see Tables 3). This indicated basic knowledge of conceptual teaching strategy.

After the first cycle, the development made in the second indicated a shift in the quality of conceptual teaching strategy. For example, there is evidence of exposing and confronting misconceptions and there is an indication towards using representations for some difficult concepts to teach. For example, in the use of a visual aid (ball and stick model) to show the complex formation of an ester and the intricate reaction mechanism in which an -OH is produced by an acid instead of -H^+ produced according to the Bronsted theory. What is more particular about the improvement is the extent to which there is integration of TSPCK components such as learner prior knowledge, what is difficult to teach and representation in Tables 3–6. Additionally, when teachers made an example regarding curricular saliency, they used an example with a particular form of symbolic representation. Similar to what is difficult to teach, the component of representations was used. In summary, this signalled a shift from basic quality of conceptual teaching strategy to a developing quality of conceptual teaching strategy.

8 Discussions

This paper offers an analysis of the development of a conceptual teaching strategy in science teaching because of a lesson study. As highlighted by Holme et al.,⁴ there exists a significant lack of clarity regarding what precisely constitutes a conceptual teaching strategy. This ambiguity presents substantial challenges for educators and researchers alike, as the absence of a shared understanding can hinder the development and implementation of effective pedagogical approaches. The implications of this confusion are far-reaching, potentially leading to inconsistencies in teaching practices, variations in student learning outcomes, and difficulties in evaluating educational effectiveness.

In our exploration, we draw upon the TSPCK model to align with the perspectives of Mavhunga²⁷ and Ndlovu and Malcolm⁷ who argued that the quality of conceptual teaching strategies arises from the dynamic interplay among the various components of TSPCK. While⁸ emphasize the role of representations in developing conceptual teaching strategies, their perspective, as outlined in the grand PCK rubric by Chan et al.,³⁷ also incorporates the selection of instructional strategies that are student-centred and promote meaningful learning. Our approach extends this discussion by considering the interdependence of multiple TSPCK components beyond representations and instructional strategies alone. We maintain that a holistic approach, which considers the interconnections among TSPCK components, is essential to enhance conceptual teaching strategies, particularly in the context of collaborative lesson study.

The results of our investigation indicate a marked improvement in the quality of the conceptual teaching strategy across two cycles of lesson study. This finding resonates with the earlier work of Mapulanga et al.,¹¹ which reported successful enhancements in enacted-TSPCK within a biology context. While Mapulanga et al.¹¹ concentrated on the broader application of TSPCK in action, our study specifically examines the development of a collective conceptual teaching strategy, particularly during the critical phase of lesson planning. This focus underscores the essential role of collaboration among educators in fostering a deeper understanding of conceptual teaching. Through collaborative lesson study, teachers can share insights, refine their instructional methods, and collectively navigate the complexities of teaching science concepts effectively.

In literature, both TSPCK and PCK are characterized as inherently tacit and dynamic.³⁸ Our findings corroborate this characterization, revealing that the enhancement of the conceptual teaching strategy is inextricably linked to broader components of PCK, such as contextual factors and assessment practices, which extend beyond the interactions of TSPCK components. This interplay highlights the necessity of considering these additional elements to fully appreciate and improve the quality of teaching and learning. For instance, understanding the cultural and socio-economic contexts in which students learn can significantly shape instructional strategies and engagement levels.

Moreover, our study reveals a pressing need for further investigation into the explicit levels of generality within PCK taxonomies. Current studies have adopted a topic-specific approach to conceptual teaching strategies,^{8,26} which, while beneficial, may overlook the finer details inherent in conceptual understanding. A concept-specific approach, which aligns more closely with the essence of how concepts are understood and taught, could yield richer insights into effective teaching strategies. This nuanced perspective not only enhances the understanding of conceptual teaching but also empowers teachers to tailor their instructional methods to better meet the diverse needs of learners.

This paper advocates for a comprehensive understanding of conceptual teaching strategies that transcends simplistic representations and embraces the dynamic interplay of various pedagogical components. Through collaborative reflection and shared practice, educators can refine their conceptual teaching strategies, thereby empowering students to achieve greater academic success in science and other disciplines. This transformative approach not only enriches the teaching and learning experience but also contributes significantly to the ongoing discourse in educational research. Moving forward, it is essential for educators and researchers to engage in continuous dialogue and exploration of conceptual teaching strategies, ensuring that they remain responsive to the evolving needs of students in a rapidly changing educational landscape. Through such commitment, we can cultivate a generation of learners who are not only knowledgeable but also capable of applying their understanding in meaningful ways.

Through a series of collaborative reflection cycles (CoRes), teachers engaged in collective planning, observation, and analysis of lessons. This process allowed them to identify and address students' common misconceptions. They also recognized the importance of incorporating diverse teaching strategies, including hands-on experiments and visual aids, to foster a deeper understanding of complex concepts. The study revealed that lesson study fostered a shared repertoire of effective teaching practices among the participating teachers. They developed a common purpose and took ownership of the collaborative process, demonstrating a strong commitment to improving student learning.¹³ The findings suggest that lesson study can be a powerful tool for enhancing teacher professional development and ultimately improving student outcomes in science education.

9 Conclusions

One limitation linked to this study was the reliance on a small participant group, as only one teacher (Thabo) delivered the lesson, and two LS cycles were studied. This narrow focus restricts the generalizability of the findings, as it may not represent the diverse range of teaching styles and classroom dynamics present in other contexts. A larger and more diverse participant pool would have allowed for a more comprehensive exploration of the enhancement of conceptual teaching within the topic.

Despite this limitation, the study offers valuable insights into the ongoing professional development of teachers and suggests directions for future research. Learning Study appears to be a particularly effective approach for refining conceptual teaching strategies in experienced educators. LS facilitated the development of a shared understanding of effective teaching practices by providing a structured framework for collaborative inquiry and reflection. To maximize the impact of professional development, a strong emphasis should be placed on deepening teachers' TSPCK, as this underpins the ability to design and implement conceptually rich lessons. Additionally, creating a supportive and collaborative environment where teachers can openly share experiences and learn from one another is crucial. Continuous professional development that prioritizes the development of conceptual teaching strategies, coupled with opportunities for reflection and adaptation, can significantly enhance teachers' capacity to foster deep student understanding. Future research needs to explore the role of reflections in developing conceptual teaching strategies.

Research ethics: The study was ethically cleared by UKZN under the protocol HSSREC 00005272 2023.

Informed consent: Informed consent was obtained from all individuals included in this study, or their legal guardians or wards.

Author contributions: BN conceptualized the article and the major sections of the manuscript. SW collected the data and introduced the TSPCK construct during the lesson study. CK contributed by writing the literature review and refined the discussion section.

Use of Large Language Models, AI and Machine Learning Tools: AI was used to improve the spelling and the readability of some paragraphs.

Conflict of interest: All other authors state no conflict of interest.

Research funding: None declared.

Data availability: The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Appendix A: TSPCK Rubric

TSPCK component	Limited	Basic	Developing	Exemplary
Learner prior knowledge	No identification/acknowledgement of learners' prior knowledge and/or misconceptions. Reasons for the relevance of prior knowledge are absent.	Identified possible learner prior knowledge, one major misconception, and other minor misconceptions.	Identified possible prior knowledge, two major misconceptions, and other minor misconceptions.	Identified possible prior knowledge, three or more major misconceptions, and other minor misconceptions. Reasons for relevance of prior knowledge are compelling.
Curricular saliency	Identified irrelevant sub-topics. Illogical sequencing of concepts and/or teaching and learning activities. Reasons for the importance of sub-topics and sequencing are absent.	Identified relevant sub-topics. The reasoning of the interrelatedness between sub-topics, concepts, and teaching and learning activities is clumsy. The teaching and learning activities are not scaffolded.	Identified relevant sub-topics sequenced logically. Reasoning for the interrelatedness between concepts is evident in the teaching and learning activities, and includes scaffolding.	Identified relevant sub-topics logically. Concepts and teaching and learning activities are sequenced logically. The indication of the interrelatedness among concepts is adequate.

(continued)

TSPCK component	Limited	Basic	Developing	Exemplary
What is difficult to teach?	No indication of concepts/ ideas that are difficult to teach. Reasons for the difficulty or gate-keeping concepts are not specified.	Identified broad concepts as difficult. Reasons for the difficulties are provided but not specific to the key ideas.	Identified specific concepts as difficult. Outlined reasons related to learners' common difficulties.	Identified specific concepts as difficult. Outlined gate-keeping concepts as well as learners' misconceptions perpetuating the difficulties.
Representations including analogies	Representations not identified.	Identified a relevant representation. No reasoning regarding how the representation works and which concepts it supports.	Identified a relevant representation. Reasoned how the representation supports the explanations of concepts.	Identified a variety of relevant representations with reasons on how the representations support the confrontation of misconceptions and difficult concepts.
Conceptual teaching strategies	There is no identification of a strategy to address a specific misconception and no intention of using representations to teach the topic. Overall, highly teacher-centred lesson.	There is evidence of ways of using specific strategies that expose learners' misconceptions. Representations are used but concepts to be supported are absent. Evidence of how learner involvement will be achieved is limited.	Evidence of a plan to use, expose, and confront learners' misconceptions with an indication of representations to use for some key difficult ideas, in general. There is evidence of how learner involvement will be achieved.	Evidence of activities designed to expose learners' misconceptions and difficulties. Representations to be used to explain concepts in general and the ones identified as difficult. The planning shows evidence of a learner-centred lesson.

References

- Baron, K.; Holman, R. Developing Conceptual Teaching Skills Using the ABCDEs. *Nurse Educ.* **2023**, *48* (1), 56–57.
- Hiebert, J.; Lefevre, P. Conceptual and Procedural Knowledge in Mathematics: An Introductory Analysis. In *Conceptual and Procedural Knowledge*; Routledge: New York, 2013; pp. 1–27.
- Scott, P.; Mortimer, E.; Ametller, J. Pedagogical Link-Making: a Fundamental Aspect of Teaching and Learning Scientific Conceptual Knowledge. *Stud. Sci. Educ.* **2011**, *47* (1), 3–36.
- Holme, T. A.; Luxford, C. J.; Brandriet, A. Defining Conceptual Understanding in General Chemistry. *J. Chem. Educ.* **2015**, *92* (9), 1477–1483.
- Duit, R.; Treagust, D. F.; Widodo, A. Teaching Science for Conceptual Change: Theory and Practice. In *International Handbook of Research on Conceptual Change*; Routledge: New York, 2013; pp. 487–503.
- Belayneh, D.; Belachew, W. TSPCK-Based Instruction and Academic Achievement of Grade 11 Students on Chemical Kinetics and Equilibrium. *Cogent Educ.* **2024**, *11* (1), 2292873.
- Ndlovu, B. P.; Malcolm, A. Changes in Pre-Service Teachers' Planned TSPCK in Stoichiometry after a TSPCK-Based Practicum. *Afr. J. Res. Math. Sci. Technol. Educ.* **2022**, 1–17. <https://doi.org/10.1080/18117295.2022.2103291>.
- Mazibe, E. N.; Gaigher, E.; Coetzee, C. Exploring Dynamic Pedagogical Content Knowledge across Fundamental Concepts of Electrostatics. *Eurasia J. Math. Sci. Technol. Educ.* **2023**, *19*. <https://doi.org/10.29333/ejmste/13023>.
- Mavhunga, E.; Rollnick, M. Improving PCK of Chemical Equilibrium in Pre-Service Teachers. *Afr. J. Res. Math. Sci. Technol. Educ.* **2013**, *17* (1-2), 113–125.
- Pitjeng-Mosabala, P.; Rollnick, M. Exploring the Development of Novice Unqualified Graduate Teachers' Topic-Specific PCK in Teaching the Particulate Nature of Matter in South Africa's Classrooms. *Int. J. Sci. Educ.* **2018**, *40* (7), 742–770.
- Mapulanga, T.; Ameyaw, Y.; Nshogoza, G.; Sinyangwe, E. Improving Secondary School Biology Teachers' Topic-specific Pedagogical Content Knowledge: Evidence from Lesson Studies. *JBSE* **2023**, *22* (1), 20.
- Fernandez, C.; Yoshida, M. *Lesson Study: A Japanese Approach to Improving Mathematics Teaching and Learning*; Routledge: London, 2012.
- Coenders, F.; Verhoef, N. Lesson Study: Professional Development (PD) for Beginning and Experienced Teachers. *Prof. Dev. Educ.* **2019**, *45* (2), 217–230.
- Postholm, M. B. Teachers' Professional Development in School: A Review Study. *Cogent Educ.* **2018**, *5* (1), 1522781.

15. Borko, H. Professional Development and Teacher Learning: Mapping the Terrain. *Educ. Res.* **2004**, *33* (8), 3–15.
16. Cajkler, W.; Wood, P.; Norton, J.; Pedder, D.; Xu, H. Teacher Perspectives about Lesson Study in Secondary School Departments: a Collaborative Vehicle for Professional Learning and Practice Development. *Res. Pap. Educ.* **2015**, *30* (2), 192–213.
17. Dudley, P. How Lesson Study Works and Why it Creates Excellent Learning and Teaching. In *Lesson Study*; Dudley, P., Ed.; Routledge: London, 2014; pp. 1–28.
18. Seleznyov, S. Lesson Study: Exploring Implementation Challenges in England. *Int. J. Lesson and Learn. Studies* **2020**, *9* (2), 179–192.
19. Walker, J.; Donaldson, C. *Intervening to Improve Outcomes for Vulnerable Young People: A Review of the Evidence*; Department for Education: United Kingdom, 2000.
20. Murata, A. Introduction: Conceptual Overview of Lesson Study. In *Lesson Study Research and Practice in Mathematics Education: Learning Together*; Hart, L. C.; Alston, A. S.; Murata, A., Eds.; Springer: Netherlands, 2011; pp. 1–12.
21. Gabel, D. Enhancing the Conceptual Understanding of Science. *Educ. Horiz.* **2003**, *81* (2), 70–76. <http://www.jstor.org/stable/42925990>.
22. Hattan, C.; Alexander, P. A.; Lupo, M. Leveraging what Students Know to Make Sense of Texts: What the Research Says about Prior Knowledge Activation. *Rev. Educ. Res.* **2024**, *94* (1), 73–111.
23. Konicek-Moran, R.; Keeley, P. *Teaching for Conceptual Understanding in Science*; NSTA Press, National Science Teachers Association Arlington, 2015.
24. Posner, G. J.; Strike, A.; Hewson, P. W.; Gertzog, W. A. Accommodation of a Scientific Conception: Toward a Theory of Conceptual Change. *Sci. Educ.* **1982**, *66* (2), 211–227.
25. Potvin, P. Response of Science Learners to Contradicting Information: a Review of Research. *Stud. Sci. Educ.* **2023**, *59* (1), 67–108.
26. Ndlovu, B. P. Retaining Knowledge for Practice: A Study of First-Year Chemistry Teachers' Planned TSPCK in Stoichiometry. *S. Afr. J. Chem.* **2024**, *78* (1), 283–292.
27. Mavhunga, E. Revealing the Structural Complexity of Component Interactions of Topic-specific PCK when Planning to Teach. *Res. Sci. Educ.* **2020**, *50* (3), 965–986.
28. Shinana, E.; Ngcoza, M.; Mavhunga, E. Development of Teachers' PCK for a Scientific Inquiry-Based Teaching Approach in Namibia's Rural Schools. *Afr. J. Res. Math. Sci. Technol. Educ.* **2021**, *25* (1), 1–11.
29. Wenger, E. Communities of Practice: The Key to Knowledge Strategy. In *Knowledge and communities*; Routledge: New York, 2009; pp. 3–20.
30. Corcoran, D. Learning from Lesson Study: Power Distribution in a Community of Practice. In *Lesson Study Research and Practice in Mathematics Education: Learning Together*; Hart, L. C.; Alston, A. S.; Murata, A., Eds.; Springer: Netherlands, 2011; pp. 251–267.
31. Cresswell, J. W.; Cresswell, J. D. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*, 5th ed.; Sage Publication, Inc.: USA, 2018.
32. Loughran, J.; Mulhall, P.; Berry, A. In Search of Pedagogical Content Knowledge in Science: Developing Ways of Articulating and Documenting Professional Practice. *J. Res. Sci. Teach.* **2004**, *41* (4), 370–391.
33. Hume, A.; Berry, A. Constructing CoRes—A Strategy for Building PCK in Pre-service Science Teacher Education. *Res. Sci. Educ.* **2011**, *41* (3), 341–355.
34. Adadan, E.; Oner, D. Exploring the Progression in Preservice Chemistry Teachers' Pedagogical Content Knowledge Representations: The Case of “Behavior of Gases”. *Res. Sci. Educ.* **2014**, *44* (6), 829–858.
35. Hashweh, M. Z. Teacher Pedagogical Constructions: a Reconfiguration of Pedagogical Content Knowledge. *Teach. Teach.* **2005**, *11* (3), 273–292.
36. Halim, L.; Meerah, S. M. Science Trainee Teachers' Pedagogical Content Knowledge and its Influence on Physics Teaching. *Res. Sci. Technol. Educ.* **2002**, *20* (2), 215–225.
37. Chan, K.K. H.; 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*; Hume, A.; Cooper, R.; Borowski, A., Eds.; Springer Nature: Singapore, 2019; pp. 253–271.
38. Alonzo, A. C.; Berry, A.; Nilsson, P. Unpacking the Complexity of Science Teachers' PCK in Action: Enacted and Personal PCK. In *Repositioning Pedagogical Content Knowledge in Teachers' Knowledge for Teaching Science*; Hume, A.; Cooper, R.; Borowski, A., Eds.; Springer Nature: Singapore, 2019; pp. 273–288.