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Exploring the rationale for lesson design as a tool for developing and evaluating science pre-service teachers' topic-specific pedagogical content knowledge

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Abstract

The primary goal of initial teacher education programmes is to develop pre-service teachers' pedagogical content knowledge (PCK). In science education, there have been calls for programmes to help pre-service teachers develop this knowledge at a topic-specific level. In this study, I investigated how lesson planning using a specific guideline called the rationale for lesson design (RfLD) can be used as a tool to develop science pre-service teachers' topic-specific pedagogical content knowledge (TSPCK). This study is positioned within the collective PCK realm of the refined consensus model of PCK and the five components of TSPCK. The participants were six third-year Life Sciences pre-service teachers. Data were collected through lesson plans on the topic of evolution and narrative interviews. A 4-point scale rubric was adapted to score the quality of pre-service teachers' PCK in terms of the five components of TSPCK in each section of the RfLD. Results indicate that the pre-service teachers showed higher levels of PCK especially, in terms of learner prior knowledge and curricular saliency. I argue these scores can be attributed to the RfLD guidelines. I recommend that science pre-service teacher programmes need to expose students to this guideline as a way of developing their PCK in teaching methodology modules. Furthermore, I argue for the value of the RfLD in tracking pre-service teachers' PCK.

Keywords: lesson planning, topic-specific pedagogical content knowledge, rationale for lesson design, evolution

Introduction

One of the roles of science pre-service teacher education programmes is to equip pre-service teachers (PSTs) with the knowledge for teaching (Aydin & Boz, 2012). This knowledge is the pedagogical content knowledge (PCK), described by Shulman (1986) as the knowledge that enables teachers to transform the subject matter knowledge in ways that make it understandable to learners. There have been developments in characterising this knowledge and its grain sizes in science education. One conceptualisation that drew scholars' attention was from Mavhunga and Rollnick (2013) who argued that PCK exists at a topic-specific level. The topic-specific PCK (TSPCK) model is comprised of five components (described later) that “when a particular element of SMK [subject matter knowledge] is thought about and reasoned through these content-specific components, understanding for teaching is generated that is specific to that topic” (Mavhunga & Rollnick, 2013, p. 115). Mavhunga and Rollnick (2016) suggested that the teaching of methodology modules in science teacher education needs to aim at teaching TSPCK and developing the PSTs’ knowledge at a topic-specific level. However, their study did not suggest tools that could be used to do this. There is, therefore, a lack of studies that put forth suggestions in terms of possible tools and practices that can afford science PSTs to develop TSPCK in initial science teacher education programmes.

Given that one of the ways for developing PSTs’ PCK is through lesson planning, over the last decade, there have been concerns regarding how PSTs are taught to plan their lessons (Flores, 2016; König et al., 2020). This is particularly because the PSTs’ lesson plans “lapse into a description of classroom procedures” (Rusznyak & Walton, 2011, p. 271). This undermines the conceptual complexity of designing a lesson plan (Kola, 2021) and teaching in general, thus constraining the development of PSTs’ PCK. Rusznyak and Walton (2011), therefore, developed rationale for lesson design (RfLD) guidelines that can scaffold PSTs’ knowledge for teaching. Although studies have acknowledged this guideline as a tool for equipping PSTs with lesson design skills (see for example Akyuz et al., 2013; König et al., 2020), there is a paucity of studies that look into the implementation of these guidelines and how the PSTs work with it in specific disciplines—yet, there is evidence that lesson design is discipline specific. For example, in science subjects, when designing a lesson plan, the emphasis should be on selecting conceptual teaching strategies (a component of TSPCK) that are aimed at addressing learners’ misconceptions (Mavhunga & Rollnick, 2013; Ndlovu & Malcolm, 2022). In this study, I argue that science PSTs’ PCK can be developed and tracked using the RfLD guidelines. I used the refined consensus model of PCK as a lens to analyse six Life Sciences PSTs’ lesson plans and their reasoning during lesson planning using the TSPCK framework. I argue that teaching science PSTs about lesson planning using the RfLD offers an opportunity for developing and evaluating their PCK. This study particularly addresses the following question: “In what ways can science PSTs’ PCK be developed and evaluated using the RfLD?”

Literature on lesson planning practices

A lesson plan is generally defined as a document that outlines how the teacher will go about teaching a specific topic in a particular timeframe to meet objectives that are set out (Farrell, 2002). Firstly, this definition suggests that lesson planning is essential for instructional effectiveness. According to Gall and Acheson (2011), when a teacher has thoroughly planned their lessons, their chances of teaching well are high because they would have reduced uncertainties. Mutton et al. (2011) found that it is through learning about designing a lesson that PSTs also learn how to teach effectively. This implies that PSTs need to be equipped with models for lesson planning that allow them to unpack their thinking while also thinking of their future teaching contexts. Secondly, the definition suggests that in detailing the plan, there is certain information that the teacher should focus on. For example, König et al. (2017) argued that the detailing of the plan has to do with pedagogical decisions the teacher has to make. These decisions can be categorised as generic, and discipline-specific. Given that teaching in itself is discipline specific, PSTs need to be taught how to make discipline- and perhaps, topic-specific decisions when planning to teach. Hence, this study focuses on PCK of PSTs at a topic-specific level.

The current practical guidelines on lesson plans are usually generic rather than discipline-specific. Most generic approaches follow what is described in the literature as the Tylerian approach (Karlström & Hamza, 2021) where PSTs need to answer questions about educational purposes and how they can be attained (Tyler, 2013). However, this assumes planning to be a linear process where one step follows the other (Karlström & Hamza, 2021). This explains why PSTs are given a generic lesson plan template to use during teaching practice, although other factors can be attributed to this. PSTs need to be given lesson-planning guidelines that aim to develop the PCK as the necessary knowledge in teaching. Although Rusznyak and Walton (2011) noted that good lesson plans should contain information regarding what the learners should learn, König et al. (2020) advocated for teaching PSTs how to plan using discipline-specific lesson plan guidelines. This is because they allow the teachers to elaborate deeply on the teaching and learning that is supposed to take place in that specific subject.

The rationale for lesson design guideline

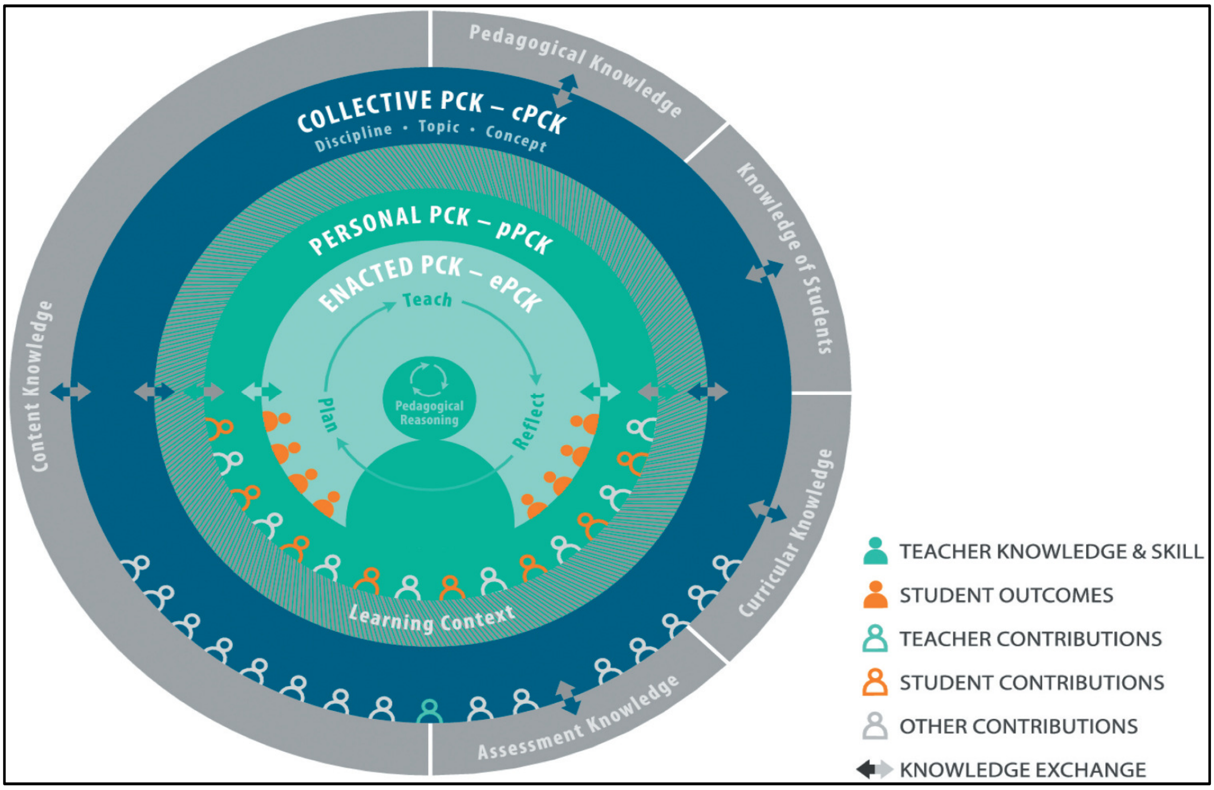
The rationale for lesson design (RfLD) guideline was developed by Rusznyak and Walton in 2011, who argued that lesson planning templates were not scaffolded, and presented lesson planning as a simple exercise. Their guideline has been acknowledged by several scholars as a powerful model for exposing PSTs to the complexities of planning to teach and pedagogical reasoning (see for example, Alanazi, 2019; Rusznyak & Bertram, 2021). Koni and Krull (2018) argued that this guideline also provides teachers with opportunities to develop contextually relevant instructional activities. Although the RfLD was not suggested as a discipline-specific guideline, I argue that it can be used to develop and evaluate science PSTs' PCK.

The RfLD guideline is composed of six sections. The first is a section that requires routine information like the grade, and the topic of the lesson—including the topic that came before and the topic that will follow (Rusznyak & Walton, 2011). In the second section, the PSTs have to outline the purpose of the lesson, divided into the knowledge, skills and attitudes, and values important for PSTs to think about when planning to teach a life sciences topic. This section is similar to formulation of lesson objectives. In their study with mathematics teachers, Umugiraneza et al. (2018) found that teachers were not able to formulate lesson objectives. The RfLD provides a framework to break down the objectives into knowledge, skills, and values, thus, allowing teachers to think beyond procedural and conceptual knowledge. In the third section, the PSTs are required to summarise the content that learners will learn in the lesson. The fourth section of the RfLD guideline deals with thinking about learners in relation to the content knowledge (Rusznyak & Walton, 2011). This includes thinking about learner diversity, possible learner prior knowledge including misconceptions, terminology inherent in the topic, resources, and examples to be used. In a study conducted by Koni and Krull (2018), PSTs were able to consider the context of learners as a result of this section. This confirms the point that the guideline is a suitable tool to assist PSTs in planning a variety of lessons emphasising different educational issues. Section 5 of the RfLD is about teaching and learning strategies and reasons for using such strategies. In science, teachers should not only consider general teaching and learning strategies. Instead, the strategies should be conceptual in the sense that they target difficult concepts (Mavhunga & Rollnick, 2013). I argue that this section could provide PSTs with an opportunity to do this. Section 6 is where PSTs are required to outline a series of systematic lesson steps, including descriptions of what the learners and the teacher will be doing in each step.

Theoretical framework

I draw on the refined consensus model (RCM) of PCK, which exposes the multi-dimensional nature of PCK and the TSPCK components. I position the TSPCK within the RCM of PCK (see Figure 1).

Figure 1
The refined consensus model (RCM) of PCK (Carlson, 2019, p. 90)



The RCM (shown in Figure 1) emphasises three important aspects. The first is that different types of professional knowledge bases inform an individual's PCK. These knowledge bases include knowledge of assessment, content knowledge, curricular knowledge, knowledge of learners, and pedagogical knowledge (Carlson et al., 2019). The second aspect of this model is the different realms of PCK: (1) PCK can be collective, meaning that it is knowledge about teaching commonly held by a community of professionals and science teachers; (2) personal PCK (pPCK), which is described as a subset of collective PCK—this kind of PCK is influenced by the teacher's experiences and skills in a specific context; (3) enacted PCK (ePCK), which is the application of an individual's knowledge and skills during the process of planning, teaching, and reflecting. The third aspect of this model is the different grain sizes (discipline, topic, and concept) through which PCK can be analysed. All grain sizes of PCK are visible across the different dimensions, called realms of PCK (Carlson et al., 2019). This study focused on the topic-specific grain size in the realm of pPCK reported in lesson plans. Like Mazibe et al. (2020), in this article, I refer to this as reported PCK (rPCK).

TSPCK is characterised by five components. The first is student or learner prior knowledge (LPK) defined as the knowledge, skills and attitudes, and values that learners bring to the lesson. Prior knowledge includes both the correct and incorrect conceptions about a topic or concept. The second component is curricular saliency (CS), described as the teacher's understanding of the sequencing of topics and the prior knowledge necessary for learners to learn the topic at hand. This also includes understanding the concepts that are core and those that are peripheral, as well as sequencing concepts and teaching processes in a single lesson (Mavhunga & Rollnick, 2013). Furthermore, a teacher who has the knowledge of CS would know the sequencing of topics across grades and within a grade. Consideration of CS during transformation is seen in how the teacher decides to sequence the teaching of specific concepts within a single lesson. The third component is about what is difficult (WD) to teach, and comprises the teacher's knowledge of gate-keeping concepts within a specific topic as well as awareness of misconceptions that perpetuate the difficulties. The fourth component is about representations (RP) and it encompasses the teacher's knowledge of appropriate analogies, models, and visual illustrations of a given concept that can be used to help learners to understand the topic and confront misconceptions that learners may have (Alonzo & Kim, 2016; Mavhunga & Rollnick, 2013). The last component is conceptual teaching strategies (CTS), defined as techniques that are used to address specific learners' misconceptions and areas of difficulty. In this study, I see this component as the heart of transformation (Shulman, 1987) because the ability of a teacher to select CTS rests on first understanding learners' misconceptions and what is difficult to teach, and then thinking about different representations to address those.

Research design and methodology

A qualitative research approach was used to unpack the PSTs' PCK. Qualitative research, stemming from the interpretivist paradigm allows researchers to do an in-depth analysis of a phenomenon (Kivunja & Kuyini, 2017).

Research setting and participants

This study was conducted in a South African university in a semester-long teaching methodology module (done in the second semester of the year). This module is offered to third-year PSTs studying to teach life sciences in secondary schools. Sampling was, therefore, purposive (Omona, 2013) in the sense that the PSTs were doing a life sciences teaching methodology module where lesson planning is taught. The participants were, therefore, third-year Life Sciences PSTs. There were 11 registered PSTs in the third-year Life Sciences teaching methodology module. Upon invitation to participate in the study, nine gave their consent. However, the data used in this study is from six PSTs because the other three only gave consent for the use of their lesson plans, but were not interviewed. In the Findings section, I use pseudonyms to refer to the participants.

The institution at which this module is offered follows a concurrent model, in which PSTs usually complete their content and methodology courses concurrently (see Musset, 2010). However, this concurrent model is of a different version because the Life Sciences PSTs attend core content modules with the Faculty of Science students. In Table 1, I show the structure of the Bachelor of Education programme for prospective secondary schools Life Sciences teachers (taken from Khoza, 2022, p. 3).

Table 1
The structure of the BEd programme for learners majoring in Life Sciences Education

Year of study	Disciplinary modules	Faculty
1st	Life Sciences content	Science
2nd	Life Sciences content	Science
3rd	Life Sciences “capping” modules	Education
	Methodology of life sciences	Education
4th	Methodology of life sciences	Education

As can be seen in Table 1, in their first two years, the PSTs complete life sciences content modules together with the Faculty of Science students who are studying to become botanists or chemists, for example. However, they would still come to the Education faculty for their other educational modules. Some of the topics they do in the science faculty include zoology and evolution. Thus, by the time they do the life sciences methodology module in their third year, they would have gathered the content knowledge for evolution. In their third year, the PSTs do a semester-long “capping” module designed to bridge the gap between the content completed at the Faculty of Science and the content that they are supposed to teach in schools. This module is taught in the first semester of the PSTs’ third year. Evolution is one of the topics that are taught in the module for three weeks. My assumption in this study is that these three weeks would have strengthened the evolution subject matter knowledge they had done at the science faculty. In addition to these, the PSTs, go for a 3-week-long teaching practice at the beginning of their second and third years, and are afforded opportunities to teach life sciences to learners. Consequently, they have had the chance of experiencing planning, and teaching learners in varied contexts.

Data collection

Data were collected using two methods: written lesson plans using the RfLD, and narrative interviews. The RfLD guideline was introduced to PSTs as a template for planning lessons. Its theoretical groundings were also covered during lectures to ensure that the PSTs understood that the guideline is based on the notion of pedagogical reasoning by Shulman (1987). After covering a section on lesson planning in the methodology module, the PSTs were requested to plan a lesson using any sub-topic under the main topic of evolution from Grade 12. Narrative interviews are used as a data collection method for the participants to tell a story (Muylaert et al., 2014). In this study, the narrative interviews were used to validate the lesson plans and to amplify the PSTs' reasoning in each section of the RfLD. For example, the narratives allowed me to explore the PSTs' reasoning in Section 1 where they need to make choices related to the sequencing of sub-topics (see Rusznyak & Walton, 2011). Table 2 shows questions that were used as prompts for the PSTs to reveal their thinking during the interview as aligned to different sections of the RfLD guideline.

Table 2
Guiding questions for the PSTs' narrative interviews

Lesson plan section	Guiding questions for the interviews
1. Routine information	How did you decide on the sequence to topics in this section? Why did you decide on that?
2. Purpose of the lesson	Explain how and why you decided on the purpose of the lesson.
3. Content knowledge	How did you decide on the content knowledge that you need to teach your learners in this lesson?
4. Thinking about learners in relation to the content	How do you respond to learners' backgrounds in your lesson plan? Why did you decide to respond to those in that manner?
5. Teaching and learning strategies	How and why did you select the teaching and learning strategies? What other strategies and approaches could you have selected to use for this lesson and why did you not choose those?
6. Sequence of lesson steps	Tell me about how you sequenced the lesson steps and why did you decide to sequence them in that manner.

The questions outlined in Table 2 were piloted with two students who did not form part of this study. These questions allowed the PSTs to refer to their lesson plans and narrate their reasoning regarding certain pedagogical decisions in each section of the RfLD. The interviews with the PSTs were audio recorded and transcribed for analysis. Each interview ranged between 20 to 37 minutes.

Data analysis

The argument I make in this article is that the RfLD can be used as a tool to develop PSTs' PCK during training. Therefore, the analysis involved assessing the quality of their TSPCK as emerged from the lesson plans. To assess the quality of reported PCK, I adapted a rubric developed by Mavhunga and Rollnick (2013), and shown in Table 3. The rubric was initially designed to assess teachers' PCK about chemical equilibrium in a PCK test. I adapted the rubric to suit the lesson plans and narrative interviews by including, for example, in the learner prior knowledge (LPK) component, that the PSTs needed to include reasons for the relevance of learner prior knowledge. The rubric was reviewed by an expert who has published articles in the PCK research area. Consensus was then reached.

Table 3
Rubric for assessing TSPCK about evolution as reported in the lesson plans and narrative interviews (adapted from Mavhunga & Rollnick, 2013).

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.
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.
Represent-ations 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.

TSPCK component	Limited	Basic	Developing	Exemplary
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.

As can be seen in Table 3, the rubric shows four categories of competencies for each TSPCK component. A score of 1 was given if a PST displayed a limited knowledge of each component, and a score of 4 was given if a PST displayed exemplary PCK in terms of that component. When scoring the PSTs' competency level, I also relied on the interviews because they served as an amplification of the lesson plans. I first aligned the interview data with the different sections of the PSTs' lesson plans. I then used the rubric for scoring the lesson plans and interview data per section. In other words, I looked at the PSTs' competencies/manifestation of the TSPCK component in each of the RfLD sections. For each TSPCK component, I then calculated the average of the score across the PSTs and across each component.

Results and discussions

The purpose of this article is to reveal the possibilities of using the RfLD to develop science PSTs' PCK. Below, I present the results of the scoring process. I present and discuss these results per section of the RfLD in Table 4, which summarises the level at which we scored the PSTs' competencies in various sections of the RfLD. You will notice that the tables have the last column labelled "average score." This score shows cumulative participants' competence in terms of each TSPCK component in each section of RfLD. The goal here is to illustrate that PSTs can transform the content through these components in the RfLD.

Table 4
Summary of the participants' reported PCK in various sections of the RfLD

TSPCK component	Section of the RfLD	Kate	Lebo	Kriek	Melo	Solo	Dineo	Average score per section of the RfLD	Average score on the TSPCK component
LPK	1	2	3	3	3	3	3	2.83	3.39
	2	2	3	2	2	2	3	2.33	
	3	3	3	3	3	3	2	2.83	

TSPCK component	Section of the RfLD	Kate	Lebo	Kriek	Melo	Solo	Dineo	Average score per section of the RfLD	Average score on the TSPCK component
	4	2	3	3	3	3	3	2.83	
	5	3	4	3	4	4	3	3.66	
	6	3	3	3	3	2	3	2.83	
CS	1	3	3	3	2	3	3	2.83	2.33
	2	1	2	1	2	1	1	1.33	
	3	3	2	2	2	2	3	2.33	
	4	3	2	3	3	2	2	2.5	
	5	2	2	2	2	3	3	2.33	
	6	3	2	3	3	3	2	2.66	
WD	1	2	1	3	2	2	2	2.16	2.10
	2	2	1	1	1	1	1	1.16	
	3	1	1	1	1	1	1	1.00	
	4	3	3	3	2	3	3	2.83	
	5	3	3	2	3	2	3	2.66	
	6	2	3	3	2	2	2	2.50	
RP	1	1	1	1	1	1	1	1.00	2.03
	2	1	1	2	2	1	1	1.33	
	3	1	1	1	1	1	1	1.00	
	4	3	3	2	3	3	2	2.66	
	5	2	4	3	4	3	2	3.00	
	6	3	4	3	3	3	3	3.16	
CTS	1	1	1	1	1	1	1	1.00	1.86
	2	1	1	1	1	1	1	1.00	
	3	1	1	2	1	1	1	1.16	
	4	3	2	2	2	3	2	2.33	
	5	3	4	4	3	4	2	3.33	
	6	2	3	3	2	2	2	2.33	

A noticeable trend from Table 4 is the average score revealing the PSTs' competencies of each TSPCK component where the average score is higher for LPK and lower for CTS. I discuss the trends in this table for each TSPCK component.

Learner prior knowledge including misconceptions

The PSTs scored higher in terms of LPK compared to the other four components. This reveals that they showed awareness of LPK, including misconceptions, in all the sections of the RfLD. Many showed an exemplary PCK in Section 5 of the lesson plan, and developing PCK in all the other sections. For example, Lebo, whose PCK was scored as developing in Section 1 of the RfLD, stated that she would give a lesson on evidence of evolution before one on human evolution. When she was asked why she sequenced the sub-topics from evidence of evolution, she said:

> Learners need to know the evidence first then during the lesson, I can ask them about this in the lesson. Sometimes they confuse the evidence and do not know what evidence would apply to human beings.

Here, Lebo highlighted knowledge of evidence of evolution as the knowledge learners would need when learning about human evolution. This illustrates that she thought about possible LPK that could be of use, as well as a misconception relevant to the teaching of human evolution. This is an important consideration; Hite (2020) explained that learners interpret evolution concepts from the perspective of what they have been introduced to before. In this case, Lebo had a view that learners' understanding of human evolution would be influenced by what they knew about evidence of evolution. In Section 5, the LPK manifested as follows (as seen from the lesson plans):

> Kate: I will use question and answer method in the beginning of the lesson to get what learners know about the topic. I will ask open-ended questions.
>
> Kriek: The picture below will be used and learners will be asked what it represents.

Kate reveals the importance of getting LPK at the beginning of the lesson. When she was interrogated on what she stated in the lesson plan, she said:

> You know learners think that we were once monkeys or apes; with the questioning, I want to get if they have this misconception.

Similarly, Kriek was aware of how the diagram in learners' textbooks reveals a misconception as he said in the interview:

> Learners always have a misconception that we come from apes . . . so with this picture, by the way, it comes from a textbook, I would see if they do have that misconception.

Thus, Kriek had planned to use a suitable strategy to elicit LPK. Neubrand and Harms (2017) argued that this is crucial for the teaching of controversial topics like evolution. A study by Lucero et al. (2017) revealed that teachers were not making use of LPK including misconceptions to direct their teaching. Instead, these conceptions were only corrected and not directly acknowledged. This study reveals that the PSTs acknowledged LPK in their lesson design. Although the PSTs' actual teaching may reveal not using the prior knowledge, I argue that the consideration at the lesson design phase is a starting point for the development of TSPCK, which determines teaching effectiveness. My assumption here is that the PSTs' showed evidence of a developing PCK because Sections 4 and 5 of the RfLD provided them with an opportunity to reveal their reasoning in terms of how and why they would use a particular teaching strategy.

Curricular saliency

Similar to LPK, the PSTs scored above 2 for their knowledge of curricular saliency (CS). They were able to reveal this knowledge mostly in Sections 1 and 6 (see the average score of 2.66) but could not articulate this consideration in Section 2. Kriek, who had indicated the topic of the lesson that would come before the current one as the origin of species, noted the following to denote that his decision was informed by what the learners would have done before—progression from one grade to another (CS):

> I have decided on this sequence because learners would be familiar with this content, they did some of this in Grade 10.

His decision was influenced by the curriculum in terms of what learners had done in the previous grades. In Section 4, when thinking about how learners' prior knowledge would impact her teaching, plan Melo stated:

> This lesson is a continuation of what the learners have done on genetics.

This indicates that she understood where evolution fits in relation to other topics in the curriculum (Rollnick et al., 2008), and how useful it is for learners to understand genetics as she uttered in the interview:

> The content about . . . will help my learners to understand the concept of . . . better.

Solo also revealed knowledge of CS in Section 6 by arguing:

> I will link this activity [activity on variation] to meiosis and what happens in Prophase 1 so that . . .

In his reasoning, he also alluded to the fact that if it were up to him, he would plan to teach evolution parallel to genetics. In this way, he saw the opportunity for him to show links between different topics through a learning activity that learners would do in the classroom. Thus, I scored his knowledge of CS as "developing." In many instances, teachers' knowledge of CS is restricted by the curriculum demands (Sibanda & Hobden, 2016). Some of the PSTs, like Solo in this study, have shown that they are aware of this challenge. However, they still showed sophisticated reasoning regarding the ideal sequencing of topics or concepts. This was afforded by different sections of the RfLD.

What is difficult to teach?

The average score of the PSTs competencies for this component was just above 2, thus showing a basic PCK. However, there are cases where some sections of the RfLD afforded the PSTs to think of gate-keeping concepts as a determinant of WD. For example, when sequencing sub-topics in Section 1, Kriek went beyond consideration of LPK and argued:

> What led me to this is that it is hard to understand human evolution if you don't know about the evidence, so I would cover the fossil record separately first then the others will follow.

What can be gleaned from Kriek's argument above, is the ability to reason based on gate-keeping concepts that can enable the learners to learn and understand human evolution. The gate-keeping concept here is evidence of evolution, of which Kriek said in the narrative:

> If there is evidence for learners to base the theory on, I think it becomes easier for them to accept it [the theory of evolution].

For some PSTs, this was reflected in the reasoning of Sections 4 and 5 of the RfLD. For example, Dineo, who planned to teach natural selection, stated the following in his narrative:

> A theory is a theory and no one has to believe in it. I chose to respond to learners' backgrounds by first explaining what a theory means in science because this is usually not dealt with in the lower grades. Most often, these learners think they have to believe in evolution. This makes it difficult for them to understand this theory.

In the quote above, Dineo stresses that learners need to first understand why evolution is just a theory. This as a difficulty when teaching about what a theory means in science, especially when teaching the topic of evolution (Williams, 2013). Dineo was able to identify this difficulty, and state how it could affect her teaching and how learners chose to learn the concept of evolution. This is one of the difficulties identified in the literature (see Siani & Yarden, 2021). Although the data in this study did not reveal whether Dineo had consulted literature, I assume that consideration of this difficulty may have emanated when she had to take into account the context in which the plan would be enacted—as afforded by Section 4 of the RfLD. She was then able to highlight this also in Section 4, thus, helping her to select a possible strategy targeting this specific difficulty.

Representations including analogies

The PSTs' knowledge of RP manifested mainly in Sections 4, 5, and 6 of the RfLD (see Table 4). The lesson plans and narratives showed no evidence of consideration of RP in the first three sections. This is evident from looking at the average score of 1 in each of these sections. Lebo, who scored higher in Section 5, stated that with respect to the demonstration teaching strategy:

> I have to show them the phylogenetic tree first for them to interpret and also show them a video because most of them struggle to see connections between concepts. I decided to use the analogy of tree branches in the middle of the lesson because . . .

These are three different representations that reveal different levels of representing content. Not only did she state these representations but she also provided reasons why the amalgamation of the representations would benefit learners. She stated:

> Learners will be able to see and look at the phylogenetic tree from a paper so that they are all catered for. Most of them have seen tree branches.

Section 6 of the RfLD also afforded PSTs (like Kate) to reveal their knowledge of RP. Kate had planned her lesson on the topic, Fossil and Genetic Evidence of a Common Ancestor for Living Hominids. Although Kate did not score high in Section 5, when she had to outline the sequence of the lesson steps in Section 6, she was able to incorporate RP that were not necessarily stated in Section 5, as Lebo and Melo had. In her narrative, she stated:

> I will first use a table for my learners to organise the difference between . . . as they observe the pictures. If I had the actual skulls and bones, I think it would have been interesting for them but examples like illustrating using my legs how the pelvis of early hominids looked like.

In Kate's description of the lesson steps, many representations are alluded to. Van Driel et al. (1998) argued that "the more representations teachers have at their disposal and the better they recognize learning difficulties, the more effectively they can deploy their PCK" (p. 675). These representations work together to explain the difference between the structures of apes and modern human beings. According to Carolan et al. (2008), representations are an aspect of the language of science in science classrooms. In a study conducted by Hansen and Richland (2020), it was found that although teachers believed representations worked best when presented one at a time, learning happened when multiple representations are used simultaneously, coupled with other prompts like explanations and responding to learners' needs and background. Amador et al.'s (2022) study indicated that first-year novice science teachers did not include representations in their planning yet, according to Reynolds and Park (2021), the integration of representations in lesson planning is considered one of the PCK components that determines the quality of teaching. In this study, the PSTs were able to show evidence of the use of representations in Section 4 (dealing with learners' needs and backgrounds) and Section 6. In other words, these sections of the RfLD afforded Kate an opportunity to structure in detail how the lesson would unfold when using representations alluded to in Section 4.

Conceptual teaching strategies

Although the average score for CTS was the lowest, the manifestation of this component was strongly visible in Section 5 of the RfLD, as seen by the PSTs' score of 3.33 (Table 4). For example, Melo stated the following in her narrative:

> I decided to use inquiry-based learning and demonstration as a strategy because I am assuming that my learners would struggle to just listen to me and get bored. So, if I provide them with a timeline and ask them questions in an inquiry manner, they might get excited. The demonstration will be through a video where they can imagine evolution. Most of them would dispute this because of their religions.

Melo planned her lesson on the topic of the origins of ideas about evolution. Her choice of the teaching strategy counts as CTS because she did not only state the strategy but also drew from learners' background knowledge and the difficulty of imagining the process of evolution over millions of years. For her, inquiry-based learning coupled with demonstrations could result in conceptual change as she further argued:

> I plan to strive for learners to accept this theory and somehow change their minds on how they view evolution.

As stated by Gafoor and Akhilesh (2010), strategies that build on learners' backgrounds and raise learners' curiosity can cause them to have conflicting ideas, thus facilitating conceptual change. A study by Makhechane and Qhobela (2019) with chemistry teachers showed that teachers were aware of a variety of teaching strategies but could not relate these to the topics they were teaching and the difficulty of the topics. In this study, the PSTs did not only show awareness of the teaching strategies but also related them to difficult areas of the topics. I argue that the RfLD served as a vehicle for this milestone, especially in Sections 5 and 6 of the guideline where the PSTs also drew on what they had stated in Section 4. However, although some PSTs provided reasons for their teaching strategies in the actual lesson plans (e.g. Lebo and Kriek), it was mainly in the narratives where they were able to reveal the link between their chosen strategies and what they argued for in Section 4. Nevertheless, this finding indicates that there was some reasoning at the back of their minds that reveals good PCK in terms of the CTS component.

Conclusions, limitations, and recommendations

In this article, I wanted to reveal the possibilities of using the RfLD to develop and evaluate science PSTs' PCK. Although not all the sections of the RfLD revealed high scores of PCK levels of PSTs, each TSPCK component was represented in at least one of the sections of the RfLD. The PSTs were able to articulate, for example, their knowledge of LPK and CS in almost all the sections of the RfLD as seen by the higher scores compared to the other components. What seemed difficult to articulate was the CTS in Sections 1 to 3 of the RfLD. However, this was possible in Sections 4 to 6. This was true with RP where the PSTs scored higher in Sections 4 to 6. My findings reveal that the RfLD guideline has significant pedagogical value in science PST education programmes. It emerged as a useful tool to develop and evaluate PSTs' PCK at topic level. The guideline exposes PSTs to the complex nature of teaching, particularly in terms of teaching necessitating nuanced pedagogical reasoning related to specific content knowledge.

This study was based on a sample of only six Life Sciences PSTs, and this can be seen as a limitation. Furthermore, only one topic, evolution, was used to form the above conclusions. The PSTs in this study were exposed to the RfLD only in their third year in a methodology course. I suggest that this tool be introduced to the PSTs at earlier stages of their journey to becoming teachers to ensure they learn how to reason pedagogically and develop their PCK on a variety of topics. Future research could uncover how PSTs develop PCK using this guideline at other stages or for longer durations during their training, and across a range of topics.

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