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Comparing pedagogical content knowledge on-action and in-action in physics teaching in Lesotho secondary schools

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Abstract
Effective teaching requires both pedagogical content knowledge (PCK) on-action and PCK in-action. However, the interplay of knowledge on-action and in-action is unclear in classroom practice. Therefore, studies are required to investigate the interplay of the two types of knowledge. This paper presents an explanatory sequential mixed method design to investigate physics teachers' pedagogical content knowledge on-action through a sample of 87 physics teachers who responded to a paper-and-pencil test. The study also involved a subsample of two physics teachers as case studies engaging a qualitative investigation entailing interviews and video recorded classroom observations. Data were quantitatively analyzed using the extended Rasch model and qualitatively analyzed using the narratives. The findings revealed significant gaps in teachers' knowledge on-action, suggesting challenges in applying this knowledge effectively in classrooms. This study recommends the involvement of teachers in continuous professional development meant to stimulate reflection in teacher knowledge, focusing on different PCK components.

Keywords: professional knowledge, pedagogical content knowledge, classroom practices, PCK components, knowledge on-action, and knowledge in-action

INTRODUCTION

Theoretical Background and Literature Review

The knowledge of teaching can be viewed as the knowledge that has developed in the mind of the teacher, the actions in the classroom and the way the teacher solves convolutions from the interactions with students and resources used in the classroom. Shulman (1986, 1987) referred to the knowledge of teaching as pedagogical content knowledge (PCK). Researchers envision PCK as an important constituent of professional knowledge that contributes towards effective teaching (Ekiz-Kiran et al., 2021; Keller et al., 2017; Pitjeng-Mosabala & Rollnick, 2018). Although PCK is said to play an important role in effective teaching, Barendsen and Henze (2017) argue that relating teachers' PCK and their actions in the classroom is not straight forward hence studies are required to explore the relationship between the knowledge in the mind being knowledge on-action and the knowledge used to teach referred to as knowledge in-action.

Kirschner et al. (2016) contend that teachers' professional knowledge has an effect on both teaching and student outcomes. Researchers have found PCK to be related to the poor quality of classroom practice in both developed and developing countries. In the Netherlands, Barendsen and Henze (2017) reported the dominant use of teacher-centered methods in the teaching of science when teachers have a weak knowledge base of students as a PCK component. In South Africa, Rollnick (2017) found teachers with a weak knowledge of content in a topic having a challenge when teaching the same topic to students. These reports unveil the dire straits in the pedagogy of science, leading to compromised classroom practices. Some studies in Lesotho reported that physics teachers often use

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Contribution to the literature

- This study adds to literature that examines PCK, acknowledging its idiosyncrasy and involves multiple data collection methods to study physics teaching in a developing country.
- The study extends the works done in previous literature where one research approach would be involved to study PCK by involving a sequential mixed method approach.
- The study provides insights into the PCK components which are less developed and how this translates into classroom practice, pointing direction for areas of continuous professional development.

inadequate teaching strategies to teach physics in classrooms partly due to what is considered to be weak PCK on the topics they teach (Makhechane & Qhobela, 2019; Qhobela & Moru, 2014). Qhobela and Moru (2014) and Makhechane and Qhobela (2019) agree that teaching science through teacher-centered methods contributes to low students' performance. It is in this regard that this study sought to measure the PCK components and to investigate how these PCK components are manifested in classroom practice. To understand and explain classroom practices, it is therefore important to investigate the knowledge on-action, which teachers draw on to exhibit knowledge in-action in the classroom context.

Barendsen and Henze (2017) assert that there have been inconsistent findings in large-scale studies to relate PCK and classroom instructional practices, thus the call for more studies that explore the relationship between PCK and classroom practices so as to understand the role of PCK in teachers' classroom actions. This study sought to close the gap and contribute insights by measuring physics teachers' PCK on-action and illustrating how physics teachers use their PCK on-action to transform it to PCK in-action in a senior secondary level classroom context of a developing country. To understand better the relationship between PCK and the construction of classroom practice, the following research question is proposed:

How can the PCK on-action of physics teachers be described in relation to the PCK in-action exhibited in classroom practices?

The Use of Knowledge On-Action to Construct Knowledge In-Action

The teacher with pedagogical excellence is envisioned as a teacher who has a deeper understanding of the knowledge base for teaching, understands the sources of knowledge and appreciates the complications of the pedagogical process (Shulman, 1987). For teaching to be effective, teachers need to possess diverse components of PCK. These components are viewed as "the secret of an expert system's expertise, the body of understanding, knowledge, skills, and dispositions that a teacher needs to perform effectively in a given teaching situation" (Wilson et al., 1987). The diverse PCK components develop in the mind of a teacher from the training, curriculum materials, textbooks and teaching profession structure (Oztay & Boz, 2022).

PCK is located in classroom practice where PCK on-action and classroom context interact (Gess-Newsome, 2015). In the act of teaching, the transformation of knowledge occurs to respond to the situation that the teacher experiences in class, which require quick decision-making drawing on the teachers' PCK components. While other researchers focus on the PCK components which are required and integrated to guide lesson planning and classroom practice (Nilsson & Vikström, 2015; Park & Chen, 2012; Park & Oliver, 2008). Gess-Newsome (2015) asserts that classroom practice is not only guided by what the teacher knows, but it is also shaped by the context of the classroom. The context includes "the types of curriculum materials, supplies, and support available" and all these influence the way the instruction is delivered (Gess-Newsome, 2015, p. 37).

Conceptual Framework

This study has adapted the consensus model of Gess-Newsome (2015) to explore the PCK on-action and to guide the selection of the PCK components incorporated in the PCK test (**Figure 1**). The model of Magnusson et al. (1999) has been incorporated into the model of Gess-Newsome (2015) to guide the analysis of how these PCK components are used in the classroom practices of the teachers. The following model shows how the consensus model has been modified for the purposes of this study.

According to Gess-Newsome (2015), the teachers' professional knowledge bases are PCK components characteristic of the teachers' knowledge that can be expected from all teachers in the teaching profession irrespective of their disciplines; this knowledge is context free. This model allows PCK to be researched as PCK on-action and PCK enacted as a skill in classroom practice referred to as PCK in-action. This model was used to construct a PCK paper-and-pencil test, and to categorize PCK is investigated through the teachers' classroom practices.

Teachers' professional knowledge bases: PCK components

The PCK components discussed in this section are the ones assumed to be in use for the construction of science teachers' knowledge in-action. This does not mean other

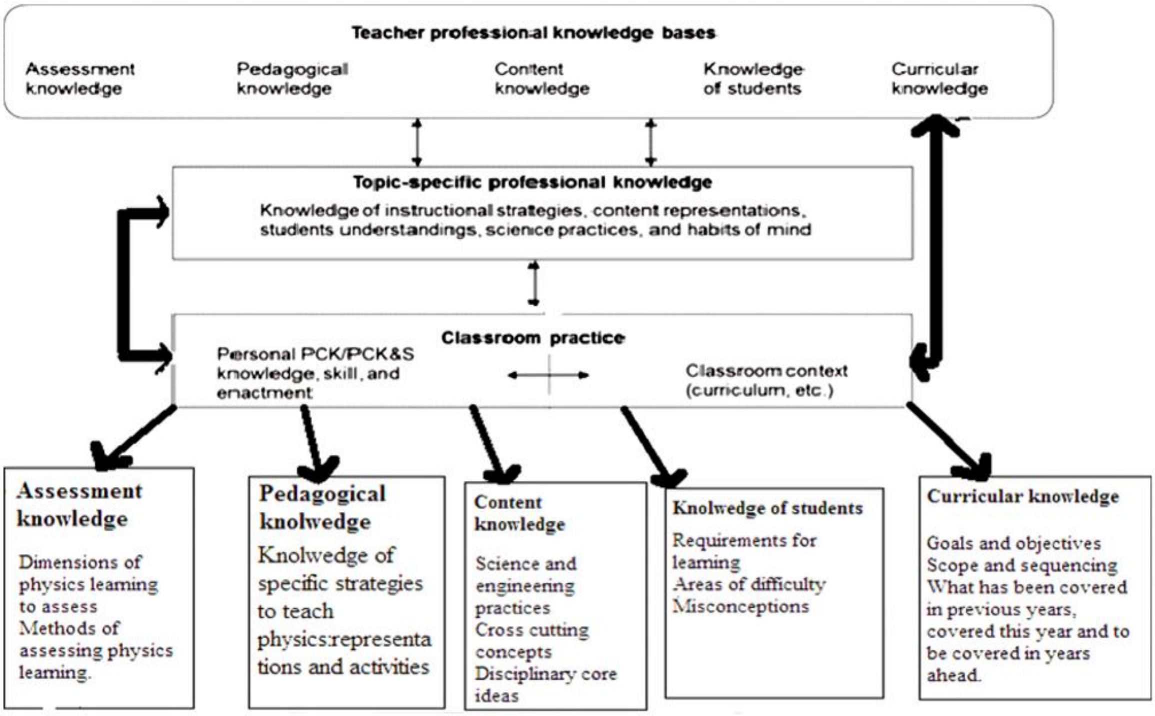

Figure 1. Modified consensus model (Adapted from Gess-Newsome, 2015)

knowledge components are not important but for the scope of this study, only the knowledge bases included in the consensus model (Gess-Newsome, 2015) are discussed.

Assessment knowledge

This refers to the ability of the teacher to design formative and summative assessments and use the designed assessments' results to modify or restructure instruction (Gess-Newsome, 2015). Magnusson et al. (1999) divide this knowledge into two categories: knowledge of the aspects of science learning that are essential to assess and the knowledge of assessment methods. It is expected that a teacher with developed PCK will consider the dimensions of science learning to assess the goals aligned of the curriculum to test students' scientific literacy around a particular concept. Magnusson et al. (1999) outline examples of such methods to include written tests, journal entries, laboratory reports, drawings and designing models. Chabongora and Jita (2013) assert that the impact of instruction is detected through the use of a variety of assessment tasks that resemble the curriculum. This implies that in the case where there are different assessment objectives from the curriculum, teaching should be characterized by the use of assessment methods that address the different objectives.

Pedagogical knowledge

In this study, pedagogical knowledge (PK) is narrowed to the teachers' knowledge of instructional strategies. Instructional strategies are taken to be all ideas the teacher involves in enacting science instruction. They may be general subject specific strategies or constrained to topic specific strategies (Magnusson et al., 1999). Topic specific strategies are divided into knowledge of representations and possible activities used for the topic being taught. Representations include illustrations, examples, models or analogies. Mainali (2021) gives examples of classification of representations as being visual, verbal or symbolic and argue that a variety of representations should be engaged with in the teaching process, so as to better develop the understanding of concepts by students. Activities on the other hand include demonstrations, simulations, investigations or experiments. It is not enough for the teacher to know different strategies, but it is also required that the teacher knows both the advantages and the disadvantages of using particular strategies for the particular concept being taught (Magnusson et al., 1999).

Content knowledge

Oztay and Boz (2022) define content knowledge (CK) as knowledge about fundamental concepts, facts and principles of the subject. In his definition of PCK, Shulman (1986, 1987) emphasizes the importance of CK for the teacher to teach effectively by pointing out that the PCK of the teacher is the integration of content and pedagogy. According to Shulman (1986, 1987), to teach a particular subject teachers should have CK in that subject and not only understand the concepts of the discipline but also be able to explain the concepts. This said, Magnusson et al. (1999) do not include CK in their model, therefore making their model incomplete to consider in isolation when examining teachers' PCK. Gess-Newsome (2015) considers CK to be academic knowledge, meaning it is the knowledge the teacher gains from school or university in a certain discipline. Compared to the content taught to students, teachers are expected to have a more developed understanding of the content they teach in their disciplines (Rollnick, 2017). To emphasize the importance of CK in teaching, Jacob et al. (2020) point out the influence of CK on students' achievement and quality classroom practice. Jacob et al. (2020) provide examples of findings in empirical studies, which found that teachers with insufficient CK led to the development of misconceptions and misunderstanding.

Knowledge of students

Knowledge of students (KS) helps teachers focus their instruction on targeted learning of scientific knowledge that encompasses student cognitive and physical development, understanding of student differences that might require instructional differentiation and how to capitalize on personal and community assets to enrich instruction (Gess-Newsome, 2015). Magnusson et al. (1999) divide this knowledge into two categories: the knowledge of the requirements for learning and the KS' difficulty. The knowledge of the requirements for learning entails the teacher's KS' prerequisite knowledge, KS' different learning styles and knowledge of different ways to represent the content to a particular group of students. To the KS' understanding of science, Smith and Banilower (2015) add the knowledge of how to sequence ideas, moving from less complex to more complex ideas so that students can understand the concepts.

Curricular knowledge

This knowledge "include[s] the goals of a curriculum, curriculum structures, the role of a scope and sequence, and the ability to assess a curriculum for coherence and articulation" (Gess-Newsome, 2015, p. 32). Coetzee et al. (2020) refer to this PCK component as "curricular saliency" and define it as the knowledge that teachers have about identifying the key concepts in the topic and sequencing them in a manner that enables the students to understand. Magnusson et al. (1999) divide curricular knowledge (CuK) into two categories: knowledge of goals and objectives in the mandate of teaching science and specific curricular programs and materials. Knowledge of goals and objectives focuses on how the goals and objectives are stated in the curriculum guiding the teaching and how they can be achieved within specific topics taught in a certain discipline. Ergönenç et al. (2014) indicate that knowledge about curriculum is exhibited in the teachers' planning of instruction, being able to analyze the content to select what is central to what is being taught and also designing artefacts to help students understand within the context of learning. According to Nilsson and Vikström (2015), knowledge of selecting the correct content and focusing on the important ideas exhibits the teachers' knowledge of the science curriculum-one of the PCK components in the knowledge base of the teacher.

Magnusson et al. (1999) assert that the teacher to teach effectively the knowledge of components of PCK, should be well-developed in all topics that are taught in the discipline. In addition, the knowledge of all these components forms a strong PCK, which makes the classroom practices of the teachers effective. When some components are more developed than others, classroom practice becomes less effective because these components complement each other in the daily practice of the teacher.

METHODOLOGY

Research Methodology and Design

This study involved mixed methods approach, a combination of quantitative and qualitative research (Kivunja & Kuyini, 2017). The PCK test survey was used to gain information on the overall PCK possessed by physics teachers while interviews and video-recorded classroom observations were used to explain how this PCK was used in teachers' classroom practices as PCK in-action. The study involved an explanatory sequential design, comprising two phases of data collection: quantitative data collected first and qualitative data collected afterwards (Creswell & Creswell, 2018; Hanson et al., 2005; Lodico et al., 2006). In this study the survey in the form of a PCK test was first given to physics teachers and then analyzed to examine both the teachers with the highest PCK test scores and those with the lowest PCK test scores.

Quantitative Research Methods: Survey

The purpose of the survey that is part in this study was to examine the PCK components that physics teachers draw on to teach physics excluding the classroom context. The PCK components examined were assessment knowledge (AK), CK, PK, KS, and CuK. These PCK components were also used to construct the PCK test as Gess-Newsome (2015) indicates that these PCK components are generic, they do not depend on the content to be taught, and they are also normative and therefore can be used to assess what teachers know. The PCK test is attached as **Appendix A**. The examination of these PCK components was important because it was hoped that it would shed light on what physics teachers know in general about teaching physics without being influenced by classroom contexts. This is knowledge on-action.

Qualitative Research Methods: Multiple Case Studies

The study followed a sequential explanatory design that involved case studies. Multiple case studies were engaged to compare the PCK of two physics teachers with extreme scores in the PCK test, comparing their

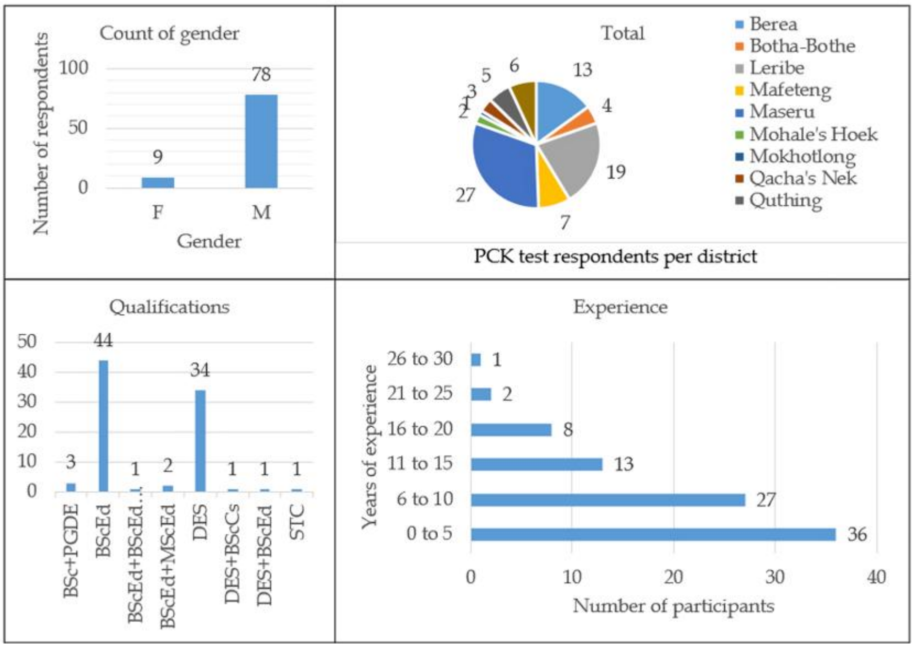

Figure 2. Demographic information of teachers (Source: Authors' own elaboration)

construction of his classroom practice with respect to the components of PCK they used. The selection of the teachers who made up the cases came from those teacher with the highest PCK test score and the lowest PCK test score. The manifestations of PCK components in classroom practices that were investigated could be considered as the effects of the PCK components developed in the minds of the chosen teachers (cases), portrayed in their actions observed in the classroom which is Knowledge in-action.

Sampling Procedure

This study used a sequential mixed method sampling, which involved the sequential use of non-probability convenience sampling, and purposive sampling strategies in which the quantitative data from the first non-probability convenient sample was used to draw the second purposive sample. In this study the group of focus groups was qualified physics teachers who are teaching in schools that can easily be reached by car and teach physics as one of their major subjects. This study engaged 87qualified physics teachers with the demographic information provided in **Figure 2**.

Quantitative data from the first non-probability sample was used to draw the second extreme case purposive sample (Teddlie & Tashakkori, 2009; Teddlie & Yu, 2007). The type of purposive sampling that was engaged with is extreme case sampling, in which the participants represent the extreme (Creswell & Creswell, 2018; Lodico et al., 2006). The chosen extreme case sample was used to look for variations between the teacher with high PCK test scores and the teacher with low PCK test scores.

Data Analysis

Analysis of quantitative data

The analysis of the PCK test started with the marking of the test by the researcher using a rubric. The rubric was developed such that it had a four-point scale to depict different levels of PCK from the responses. The rubric scale consisted of four levels of PCK: 1 = undeveloped, 2 = limited, 3 = intermediate and 4 = developed. The lowest level for the PCK test was awarded one point. The highest level was awarded four points. The rubric is attached as **Appendix B**. Two raters, the researcher and another, rated the PCK test. Two raters scored the PCK test because some responses were long sentences in which the meaning of the words might be differently interpreted by the researcher. This called for the need for another rater to give a score for the test to increase reliability.

The involvement of another rater in the rating process required expert judgement to be observed in this study. Expert judgement is defined by Escobar-Pérez and Cuervo-Martínez (2008) as an engagement of 'knowledgeable others' to give an opinion or to take part in assessment of a subject. The inter-rater agreement was calculated using the irr package for R version 0.84.1 (Gamer et al., 2019). The inter-rater reliability entails the degree of agreement between two or more raters or the degree of consistency between the raters and it is expressed as a number between 0 and 1 where 0 indicates no agreement and 1 shows perfect agreement (ten Hove et al., 2017). The data reported in this study is the PCK of physics teachers and therefore needed to minimize subjectivity by engaging a second rater. The inter-rater reliability is calculated using Cohen's kappa; the kappa is a form of correlation coefficient that ranges from -1 to 1. The negative values indicate no agreement

Table 1. Description of teachers

Teacher identity and pseudonym	Experience (years)	Highest qualification	Gender	PCK skill (logits) (Rasch analysis)	PCK skill mean and level (SPSS)	Content taught
002 Jay	16	MScEd	Male	0.95	3.30 Developed	Effects of force: • Moment of a force • Principle of moments
029 Jimmy	16	BScEd	Male	-0.80	1.93 Limited	Effects of force: • Moment of a force • Principle of moments

at all; zero also shows no agreement while 1 represents perfect agreement (McHugh, 2012). The inter-rater agreement was calculated by item and then the overall agreement was found to be 0.967. This suggests that the agreement was almost perfect, which suggests that the raters rated most of the items similarly (McHugh, 2012).

Extended Rasch model

The scores obtained from the PCK test were analyzed using the extended Rasch model. According to Boone and Noltemeyer (2017), the Rasch measurement model is guided by the following mathematical assumptions: when measuring a single trait, easy items are more likely to be answered than difficult items and that people with high ability are more likely to answer all items correctly than people with low ability. For data types such as tests and rating scale surveys the extended Rasch model is engaged (Boone & Noltemeyer, 2017). The Rasch model is aligned with the idea of objective measurement. With the use of Rasch measurement, Boone and Noltemeyer (2017) argue that it is easier to confidently inform decisions, since the measures are expressed on an equal interval logit scale.

Analysis of Qualitative Data

The qualitative data analysis began after pre-observation interviews. The interview questions were taken from the CoRe prompts, which were designed by Loughran et al. (2004). These prompts were used to capture and portray the teachers' PCK, covering different PCK components that teachers draw from when constructing their classroom practices. The prompts were adapted to suit the consensus model of Gess-Newsome (2015) used in this study to examine teachers' PCK. Some of the questions were left unchanged while others were changed to accommodate the areas interrogated. The prompts were adapted to result in semi-structured interviews, so that teachers could be probed where more information was required; the interview schedule is attached as **Appendix C**.

Data collected from the pre-observation interviews, video-recorded classroom observations with the area of focus on different PCK components and post-observation interviews were analyzed. The analysis focused on the narratives of how the participants articulated their PCK, both as verbalized PCK through pre and post-observation interviews and enacted PCK seen through their practice in the classroom.

Table 2. Teachers' PCK component raw scores mean (M)

Teacher	AK	PK	CK	KS	CuK	M	Level of PCK
002Jay	4.00	4.00	2.00	3.50	3.00	**3.30**	**Developed**
029Jimmy	2.50	3.50	1.00	1.17	1.50	**1.93**	**Limited**

Note. The maximum raw score is 4.00 per PCK component and the minimum raw score is 1.00

RESULTS

The results presented depict two teachers, Jay and Jimmy with physics as one of their major subjects, teaching in poorly resourced schools, with the same years of experience (**Table 1**).

The extended Rasch model revealed that the two physics teachers' PCK was rather low since the person measures ranked in the interval $-0.8\,logit < PCK < +0.95\,logit$. The outcomes of the descriptive statistics from SPSS complemented the extended Rasch model's findings. The means of the PCK components were calculated using SPSS. **Table 2** shows the two case teachers' PCK test results.

Table 2 shows that Jay's PCK was developed with different levels of development where the least developed component was content was CK. On the other hand Jimmy's mean shows his PCK limited with the developed component being PK. The following section presents the results of the two case teachers for ease of comparison between PCK on-action and PCK in-action.

Jay's Classroom Practices on the Teaching of 'Turning Effects of Force' for Grade 11

Jay was observed teaching two grade 11 lessons on the 'turning effects of force'. In one lesson Jay was teaching about the moment of a force while in the other he was teaching about the principle of moments.

Pedagogical knowledge

There were several activities that Jay planned to use in the lesson. He mentioned during the pre-observation interview that he had planned to use experimentation and discovery to teach both torque and the principle of moments. He gave reasons for his choice, arguing that these teaching strategies help students retain information for a longer time and also deepen their

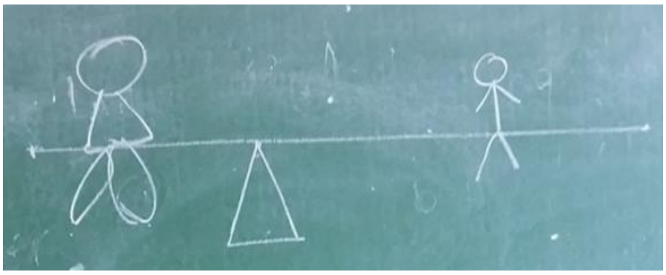

Figure 3. Representation of a seesaw (Source: Field study)

understanding. Although he had planned to conduct his lesson by engaging the said teaching methods, he had no worksheet prepared to guide students towards discovering the concepts he was going to teach. The set-up in his classroom had only one table with apparatus in front of the class, which suggested that only this demonstration was possible as a teaching strategy in this classroom and not experimentation as Jay had stated in the pre-observation interview. When interviewed later, after observing lesson 1 about why he did not engage the strategies he intended to use in his actual classroom practice, Jay pointed out that:

> Jay: Discovery and experimentation could be very good to use for students to observe what happens when forces are moved, recording their observations of increasing torque as distance is increased or decreasing torque as distance is decreased. Bothata ke lisebelisoa, joalo ka liforce metre, ha li eo (the problem is the apparatus, like the force meters, they are not there). The problem is that some would see while others would not see because we have limited apparatus to use. Again, these things take a long time and I wanted to spend less time to cover many concepts.

This excerpt shows that Jay was conversant with appropriate teaching strategies that he could use to develop the concept of toque, but he was hindered by the limited availability of resources and a shortage of time. In his actual teaching, the dominant activities observed were demonstrations where he would involve one or two students to illustrate the concepts. This also shows where knowledge on action is limited by time constraints and lack of resources in the classroom.

Consistent with his choice of beginning his lessons with familiar experiences, Jay began his second lesson by showing a seesaw diagram, where he placed people of different weights on either side of the pivot. He challenged his students by asking questions to develop the concept of the principle of moments.

> Jay: […] Joale batho bana ba babeli, ka nqe ka moo ho leng ho khuts'oanyane ho tla palama ea joang? (So there are two people, who is going to occupy the shorter side?

> S in chorus: Ea motenya (the fat one) (**Figure 3**).

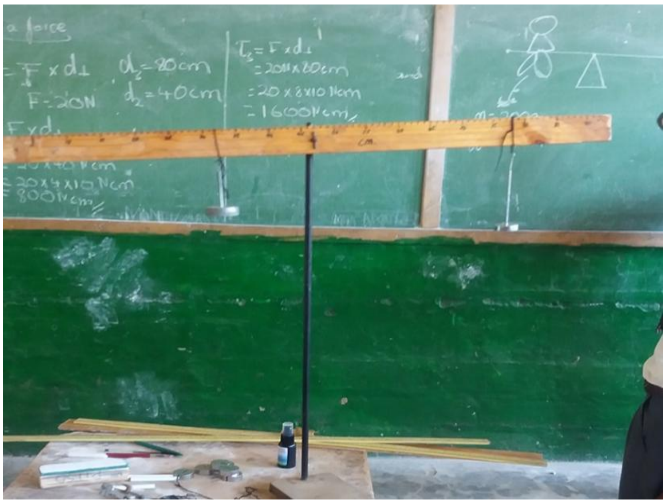

Figure 4. Weights representing people on the seesaw (Source: Field study)

> Jay: Ea motenya, ebile o chechella kae? (The fat one, where does s/he move to?)

> S in chorus: Morao (backwards).

> Jay: So you have played this seesaw, were you even aware why this person goes back? What is this person trying to increase here?

> S in chorus: Moment.

> Jay: Moment. Is it ok? Suppose we don't want this seesaw to go either side. What do you think should happen?

> S6: Ea mosesane o tlameha a atamele pele (the thin one should go forward).

> Jay: O tlameha a atamele pele? (should s/he move forward?)

> S in chorus: O tlameha a ee morao (s/he should move backwards).

It was evident from the students' responses that there was some confusion about how the big person should be positioned for the seesaw to be in equilibrium. The confusion could have been brought about by students' failure to infer from a diagram the effects of force, since the diagram does not portray the effects of different forces at different distances from either side of the pivot. This shows the limitations of using a 2-dimensional diagram to demonstrate the effects of a force. On noticing the confusion, Jay decided to use a different representation to help students understand better. To address the apparent confusion as to how the fat person on the seesaw should move to get equilibrium, Jay involved one student in a demonstration to move unequal weights hung with a string on a meter stick clamped on to a retort stand.

With this, Jay illustrated the principle of moments where he represented the people on the seesaw by different weights (**Figure 4**). The student moved the weights until the meter stick balanced. With the two representations involved, Jay developed the concept involving not just one representation but using different representations. Ball et al. (2008) and Chabongora and Jita (2013) expound that to transform CK effectively, it is important for the teacher to use different representations and registers while also dealing with problems arising during the teaching of the concept. Jay aroused his students' thinking by using a diagram of two people of different weights on a seesaw. He also used apparatus that helped students to do the resulting calculations. This illustrates Jays' developed knowledge on how to engage different strategies of representing content, which Shulman (1986) considers to be evidence of developed PCK-when the teacher is adept at using different techniques to present the same content to students.

In the pre-observation interview, Jay had situated the importance of this topic in the curriculum in daily life applications. The examples he used to help his students understand were daily life examples. These are the examples illustrating applications of torque in daily life. He used these examples at the end of teaching the concept 'moment of a force' or 'torque'.

> Jay: […] torque, which is a moment of a force. Ke ntse ke soka papa mehla ena, lesokoana lena ke le ts'oarelloa morao ka nako enngoe ke lets'oarella pele. Re bula litlhapi malapeng mona, ntho eo e bulang is a lever, e hana ho buleha u chechellisetsa letsoho ho kae?
>
> S in chorus: Morao.

Translation

> Jay: […] torque, which is a moment of a force. I always stir the pap; I hold the stirring rod at the end or at times near the beginning. We open a fish tin at home that which we open with is a lever, when it cannot be opened, where do you move your hand?
>
> S in chorus: Backwards.

Using examples that students are familiar with from their experience at home to wrap up the topic, Jay added more examples such as lifting big stones with a crowbar, opening a bottle of canned fruit using a spoon, showing how a longer distance is important to multiply force to produce a greater moment with less application of force to do more work. From the students' responses, it could be concluded that they were aware from their experience how the distance should be increased to increase torque.

Knowledge of students

The difficulty that Jay was aware of was the inclusion of units of the moment of a force calculations, which he indicated in the interview as being one challenge when teaching this topic. In his words he said:

> Jay: More especially, the challenges which I refer to as difficulties, more especially students have a problem of completing units when calculating torque, you will realize that eh… they have a problem with units.

To show his awareness of students leaving out units in calculations, Jay included units in all his calculations of torque in class, communicating with his students every time he added units about the physical quantities involved in calculations with the end product of the calculations being torque.

Assessment knowledge

Jay intended to focus on assessing calculations. Referring to the LGCSE physical science syllabus (NCDC, 2019, p. 5). Among the three objectives of assessment, Jay's focus on assessing calculations falls under objective B, which is "[h]andling information and problem solving".

Knowledge of methods by which learning can be assessed: While teaching Jay used oral questions to ascertain students' understanding, as he had intended and had mentioned in the interview. He had also said that he would test students' knowledge of the calculations. This was observed in his teaching and in the two questions he posed; one tested knowledge of the calculations needed to find the distance and in the other question he asked students to find the weight in questions that involved the principle of moments.

> Jay: Em le tle le nchekele mona (writing on the board). Re tle re etse liweight tsa rona neh! Ebe kere ena weight ea teng ke se ke e calculatile le mass, ebe li tharo hle ke cho ha kere! Li re etsetsa 3N. Ebe kere from here to here, it is 20cm. Ebe weight ea ena ke 1N. Hantle weight ee ea clockwise moment, difference ea ho tloha mo ho tla mo e tla tlameha ebe bokae hore this system e qetelle ele in equilibrium? Yes (pointing at the student).

Translation

> Jay: Em check this for me. Let us do our weights, let me say I have already calculated the weight and mass, let's say they are three … they make 3N. And say from here to here it is 20cm and the weight for this one is 1N. For this system to be in equilibrium, what should the distance from here to here be? Yes (pointing at the student).

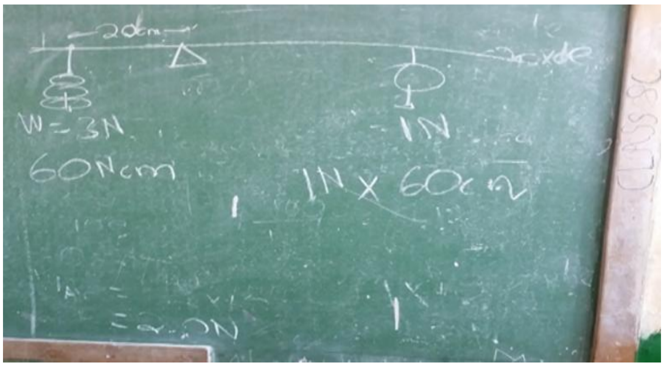

Figure 5. Jay's assessment question 1 solution (Source: Field study)

S12: 4 cm.

Jay: 4 cm?

S13: 10 cm.

Jay: 10 cm?

S14: 60 cm.

Jay: 60 cm? Why 60? Can you tell us why 60?

S14: Is to balance.

From the students' responses, it could be heard that some were still a bit confused about the concept that had been developed since there were several different responses given, but Jay concentrated only on the one that was correct and ignored the rest. One would think Jay would find out more from the students who gave incorrect answers to help them understand as Gess-Newsome (2015) point out that knowledge of assessment entails the teacher's use of a designed assessment to direct a modification of instruction to help concept development, but Jay was more interested in the correct answer and went on to explain how the 60cm was appropriate. He explained solving the question on the board, as shown in **Figure 5**.

Jimmy's Classroom Practices When Teaching the 'Turning Effects of Force' in Grade 11

Jimmy had neither any apparatus nor a workstation for doing demonstrations in his class. He taught the required concepts having engaged with only one illustration of clockwise and anticlockwise directions using a stick placed on his head. To teach the principle of moments, he used 2-dimensional diagrams drawn on the board. When I asked why he could not do this practical topic in the laboratory so that his students would be able to answer the practical examination, he indicated that he was very satisfied with his teaching technique. He made this claim in the post-observation interview:

> Jimmy: […] when I teach, in most of my teachings, I teach this bearing in mind that my students write what we call alternative to practical, and that is to say I know that there is not any point where they are going to be engaged in the lab in the exam where it will be said put this thing here and then measure the distance but all those things are going to appear as theories. So, I engage them in much of the theories such that even if they are not going to be hands on, they master the theory […] I knew that I could do it in the lab but knowing the fact that they are doing an alternative to practical I said let me do it this way, remembering that they are not going to be exposed to saying do this in the exam practically. […] I imparted knowledge to them in the absence of practical, the knowledge was imparted in the absence of practical (emphasizing). […] Believe you me; I would not take them to the lab, for reasons of time and other reasons of course because I believe in myself. I believe that things that I say with my mouth, they make students understand fully what I am driving them towards, so I believe that what I am doing in class is sufficient for them to face the exam of either kind.

When Jimmy reflected on his teaching, there was a contradiction with what he had said earlier in the pre-observation interview and that was that he would engage his students in the laboratory, provided the laboratory equipment was sufficient and if he was not limited by time constraints. In this instance he emphasized that he was not willing to do experiments in the laboratory because of the nature of the examinations that his students would write. This indicates that Jimmy had appropriately selected teaching strategies, according to his understanding, that were the best for teaching according to examination requirements. Realizing that Jimmy thinks he is teaching in the best way he could ever teach; the following discussion portrays his activities in the classroom.

The examples used by Jimmy to develop the concept of the principle of moments they were limited, with only case A demonstrating the principle of moments while case B did not the conditions of equilibrium. The examples used are illustrated in **Figure 6**.

In case A, the conditions of equilibrium hold while case B could never be in equilibrium and so the principle of moments could not be applied but Jimmy chose to use this example. This brings into question Jimmy's PCK because of his choice of examples. While Gess-Newsome (2015) contends that PCK grows with experience, one would expect that Jimmy might have gathered more useful examples to teach this concept because of his experience, but this was not the case in this classroom. When asked about his choice of examples in the post-observation interview, Jimmy argued that his choice of

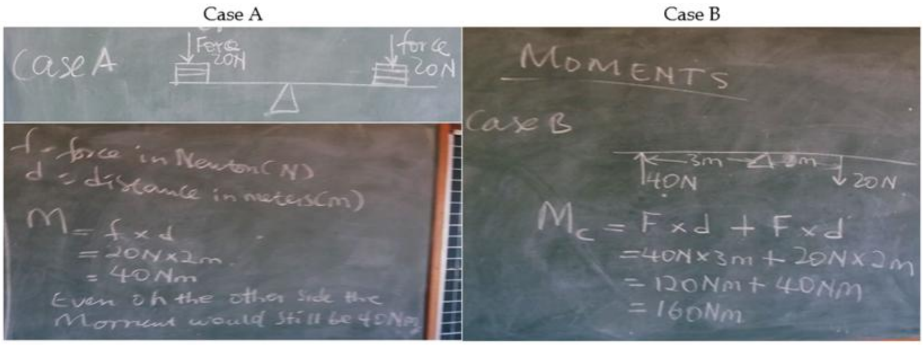

Figure 6. Examples used by Jimmy (Source: Field study)

examples was appropriate since it helped students to see that the system cannot always be at equilibrium and, according to him, the inclusion of examples not obeying the principle of moments was one way of developing the concept of moment of a force. This is how he responded to the question he was asked:

> Jimmy: Look at it from this perspective, I started with those that are balanced, then you derive from something that is known to something that is unknown, try to be a little complex, you are trying to be smart by saying let me try to bring something that is a little challenging there. […] This time they are going to see that there is going to be some toppling on only one side, with that example, it was to open their eyes that it is not going to always be the case that the system balances.

Although Jimmy's example did not obey the principle of moments, he was contending that this example was still helpful in developing the concept of the principle of moments since it would make his students see that the principle is violated. He believed that it was an indicator that his students understood the principle if they could tell that the principle of moments had been violated. In his classroom unfortunately, no student noticed this; they just looked at Jimmy working out at the clockwise moment, as shown in **Figure 6**.

Pedagogical knowledge

In his pre-observation interview, Jimmy had shown that he would use illustrations and discussion as his teaching strategies, because he believed that they help to bring reality into the classroom and to address the abstract nature of the concepts he was dealing with. In our conversation, he indicated that:

> Jimmy: Illustrations, discussions.
>
> I: Why would you choose to use such procedures?
>
> Jimmy: To try to bring it to reality, to make these abstract things come to life.

The choice of teaching strategies was based on knowledge of the nature of the concept taught, but in Jimmy's classroom there was no apparatus used to develop the concept, contradicting what was said earlier. He had indicated that if he had a laboratory, he would teach this concept differently. He also showed that he was aware that in the absence of resources he had to use improvisation and that would help, but due to time constraints he could not improvise. He said:

> Jimmy: Lilab, ha ke ne kena le lab, ke ne ke tla li etsa labong re li behe hantle re sebelise li ruler, but mokhoa oa ho improviser o ntse o le teng re ka li etsa, empa feela ele hore taba ke nako, re tlameha ho covera a lot.

Translation

> Jimmy: Laboratories, if I had laboratories, I would treat these concepts in the laboratory using rulers, but there are still ways to improvise, we can do that, but there is no time, we have to cover a lot.

Jimmy seemed to know the best ways of teaching this concept and the teaching aids he would require to develop the concept but factors such as a lack of laboratories (George, 2017) limited his utilization of known teaching strategies and he resorted to choosing other methods which are often deemed inappropriate to teach physics (Qhobela & Moru, 2014). Although in our discussion he mentioned that the laboratory was there, he considered it not helpful as there was not enough equipment and that is why he referred to it as non-existent. This is contrary to what he had said in the post-observation interview where he reveals that he was not going to the laboratory on purpose, to rather teach the theory so that his students might be able to face the alternative to a practical examination.

Knowledge of students

Jimmy stated in his interview that one of the challenges he had when teaching this topic is the lack of prior knowledge amongst the students of the concepts involved. He indicated 'direction' as one important

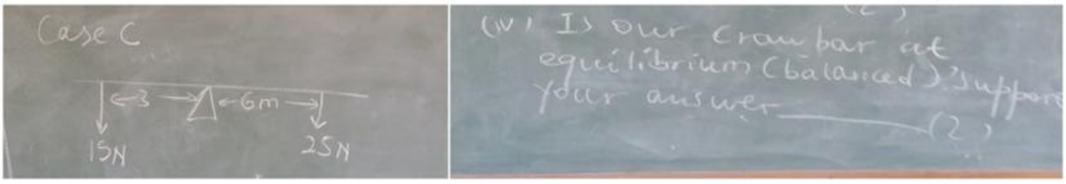

Figure 7. Case C as an example (Source: Field study)

concept needed when learning this topic, but students do not always understand this concept. He said:

> Jimmy: One would think they know the clockwise and anticlockwise direction, but the moment you teach, you find that they do not understand these.

This is the prerequisite knowledge that Jimmy was expecting from students before teaching this concept. Being aware of this Jimmy engaged in an illustration to show these directions at the beginning of the lesson.

Misconceptions: Jimmy was aware of the misconceptions that students have on this topic, which were revealed in his pre-observation interview:

> Jimmy: Ba na le ho etsa clockwise ebe anticlockwise, ba etse (they have a tendency of treating clockwise as anticlockwise and write) N/m instead of Nm.

In his teaching Jimmy tried to address these misconceptions when he illustrated the clockwise and anticlockwise directions using a stick on his head and explained why the units for moment should be Nm not N/m, he said:

> Jimmy: So, our moment here is N thaemese metres. So, u tla bona motho e mong a sa itse N/m. Feela re sena per. Empa re itse ke force in Newtons multiplied by distance in metres. So, it should be Nm not N/m. So, our force F is in Newtons, N, and our distance d is in meters m. So, that is why we come up with these units because we multiply force by distance, so we have Nm like we said.

Translation

> Jimmy: So, our moment here is N multiplied by meters. So, you will see one having written N/m. While we do not have 'per'. But we said it is force in Newtons multiplied by distance in meters. So, it should be Nm not N/m. So, our force F is in Newtons, N, and our distance d is in meters m. So, that is why we come up with these units because we multiply force by distance, so we have Nm like we said.

With this Jimmy was emphasizing the origin of the units for the moment of a force to try to prevent students expressing these units as N/m. Although Jimmy was aware of some of the possible misconceptions, others came up during his teaching; where some students thought the forces have to be equal on either side of the pivot for the crowbar to be at equilibrium. This might have been the result of Jimmy stating the principle of moments without emphasizing the conditions needed for equilibrium. Jimmy used the example in **Figure 7** to ascertain students' understanding.

From the students' responses, it could be deduced that some students did not understand the conditions needed for equilibrium.

> Jimmy: Is our crowbar at equilibrium? That means is it balanced or not?
>
> S5: Yes sir.
>
> Jimmy: Oh it is at equilibrium? Support.
>
> S6: No, because the clockwise is 25N and anticlockwise is 15N.

In the responses there was a student who thought the crowbar was at equilibrium and had not been given a chance to state the reasons for thinking like that. Giving this learner a chance to explain his answer might have led Jimmy to clarify the student's problem so that he could help the student understand what was being taught. There was also a student who thought the crowbar was not at equilibrium because the forces were not equal on either side of the pivot. This might have emerged because of the use of only one example where equilibrium was achieved when forces were equal on either side of the pivot. This suggests a need for a variety of examples catering for different occasions where the system is in equilibrium, to develop the concept - not just one example.

Assessment knowledge

In his pre-observation interview, Jimmy indicated that he intended to assess knowledge of theories and calculations in this topic. In the LGCSE syllabus, NCDC (2019), the assessment of understanding and knowledge of theories appears in objective A: Knowledge and understanding while the assessment of calculations is under objective B: Handling information and problem solving. This indicates that Jimmy's assessment goals were in line with the LGCSE syllabus assessment objectives.

Knowledge of methods by which learning can be assessed: Jimmy intended to engage in oral questions and written classwork to ascertain students'

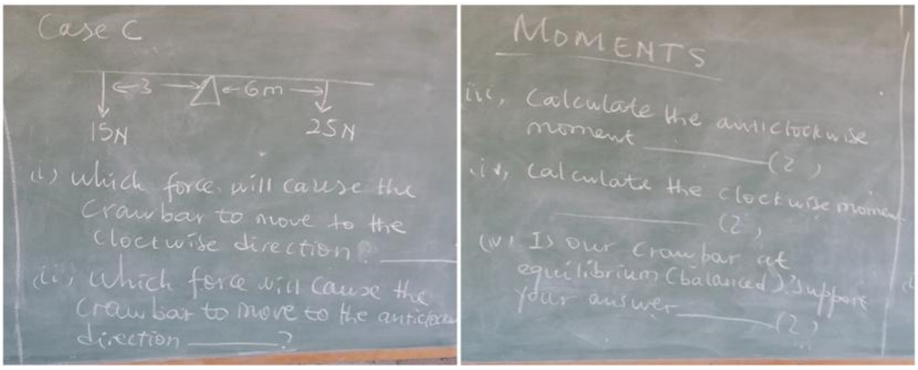

Figure 8. Assessment questions for case C (Source: Field study)

understanding, as stated in his interview and the intended methods of assessment were engaged with in his classroom. He dedicated the whole of the second lesson to assessment, marking in the class and then discussing the students' responses to the questions. When I asked in his post-observation interview about why he assessed what he had taught in the previous lesson for the whole of the second lesson, he argued:

> Jimmy: Assessment gives information about what students understand, the misconceptions they still have in the topic and the gaps that need to be filled in their understanding. Le hanka ba ka hloloa ho ruta hantle, ka assessment ke bona hantle moo bana ba nang le bothata ebe ha ke ntse ke ba ts'oaea ke ruta ka liphoso tsa bona (Even if I may fail to teach effectively, with assessment, I am able to see where students have problems, and while I am marking, I teach based on the problems I identified).

Jimmy showed that he valued the assessment stage, as it directs and channels his teaching to the identified points of misunderstanding. The time spent on assessment was indeed characterized by marking and going around the classroom, calling students' attention to talk about challenges he had observed, as he marked and addressed these challenges. The questions Jimmy included in his assessment are shown in **Figure 8**.

Jimmy used the students' answers to address learning difficulties. He spent most of his time explaining the concepts after every question was revised. Some of the learning difficulties Jimmy mentioned in the interview were that of leaving out units in calculations or writing units for the moment of a force as N/m, but there were further difficulties observed in students' responses such as writing the Newton(s) with a small letter. Also, they often failed to differentiate between clockwise and anticlockwise moments. This was seen when a student answered the same question in two different ways, first adding both clockwise and anticlockwise moments to find the anticlockwise moments and then calculating the anticlockwise moment using one anticlockwise force. The same student had been able to identify the force causing a clockwise moment and also the force causing an anticlockwise moment correctly.

Jimmy seemed to have noticed the challenges faced by his students as they answered the question and he was more direct with explanations targeting the challenges that emerged during his assessment. Identified in his assessment were more misconceptions, such as students treating force and distance as separate entities when determining the equilibrium of the system, while their product is what is important. Jimmy was able to emphasize important concepts emerging from his assessment, directed by the learning difficulties.

DISCUSSION

CK is envisioned as one important ingredient of a teacher's PCK (Rollnick, 2017). In CK, Jay scored 2.00 while Jimmy scored 1.00, being limited and undeveloped levels, respectively. Although Jay showed that he had developed CK of the concepts he was teaching, Jimmy showed less CK portrayed in the examples he chose, as some did not illustrate conditions of equilibrium which is one important concept to be learned in the 'turning effects of force'. Since Jimmy had taught the topic for so many years, it would be expected that he had gained the ability of selecting suitable examples, which could develop the concept better as it is argued that PCK grows with experience. The inconsistent results between the examined component of CK and CK exhibited by Jay in the classroom lead to a suggestions that teachers do not readily have CK when outside the classroom but know the relevant CK for what they are going to teach. This means that CK may not be considered a readily available PCK component but the component available when used. On the other hand there was an agreement on the low CK score for Jimmy and his inappropriate choice of examples used to teach he topic.

In this study, PK was limited to the knowledge of instructional strategies and their advantages. Both teachers had PK test scores at developed level, Jay 4.00 and Jimmy 3.50. In their interviews, the four teachers indicated that they were going to engage in demonstration, experimentation, and discussion as effective teaching strategies in their classrooms. These strategies are also considered appropriate for teaching science according to Magnusson et al. (1999). In their actual classroom practices, none of the teachers used experimentation. This indicates that they were aware of effective teaching strategies that they could use to help their students learn even though they were limited to use some by time and resources constraints which is in line with (George, 2017) about teaching science in Lesotho.

The knowledge of what to place central in the lesson when teaching a certain topic is considered vital in the teaching profession (Ergönenç et al., 2014). The two teachers were aware of the main concepts to look at in teaching the topics they selected. They both mainly focused on calculating torque and verifying the principle of moments. Being able to select the main concepts and sequencing the topics is one attribute that shows curriculum knowledge (Coetzee et al., 2020). Both teachers indicated knowledge of the curriculum guiding their teaching.

According to Magnusson et al. (1999) and Gess-Newsome (2015) knowledge of curriculum entails the teachers' knowledge of goals and the objectives of the curriculum. Looking at the LGCSE physical science syllabus (NCDC, 2019), aim number 3 focuses in part on developing abilities and skills that are useful in daily life. The knowledge on-action deviated from the knowledge in-action in this PCK component since Jay scored 3.00; intermediate CuK, while Jimmy scored 1.50; undeveloped which would imply anticipation of differences exhibited in classroom practices, but both teachers illustrated developed curriculum knowledge.

The two teachers were familiar with difficulties associated with teaching the concepts. Jay and Jimmy identified one of the difficulties being incomplete units when calculating torque. The two teachers showed that they have knowledge about the students since they were able to identify students' difficulties in the topics they taught (Magnusson et al., 1999). The KS' difficulties prior to teaching informs the teacher about the ways to treat the content so as to address difficulties in class and to use appropriate teaching strategies that could be useful to change misconceptions about the scientific knowledge that is deemed appropriate (Ergönenç et al., 2014; Shulman, 1986). The misconceptions that were identified as associated with the teaching of the topic indicate that both teachers were cognizant of their students' thinking and this is attributed to their knowledge about the students (Magnusson et al., 1999), which may better inform their choices of teaching strategies to modify their students' thinking. Whereas their PCK test scores were different Jay 3.50 and Jimmy 1.17, their classroom practice could not differentiate their KS.

Knowledge about assessment was also examined through the interviews and classroom observations. Jay and Jimmy focused on assessing calculations. Referring to the LGCSE physical science syllabus (NCDC, 2019, p. 5), from the three objectives of assessment the three teachers' focus on assessing calculations falls under objective B, which is "[h]andling information and problem solving". The objective includes questions involving calculations, which form part of the physics assessment. As much as the teachers' selection and assessment of the dimensions of scientific literacy were aligned with the physics syllabus, objective C which is 'experimental skills and investigations' was not mentioned in the interviews nor seen being assessed in the classroom. This might be attributed to the teachers' limited PCK as Magnusson et al. (1999) mention that teachers with developed PCK align the dimensions of science learning towards the goals of the curriculum when they assess students' scientific literacy. The teachers had intended to engage different aspects of the students' understanding, as they described in their pre-observation interviews, but they used limited methods of assessment in their actual classroom teaching. Jay and Jimmy selected written short answers to assess their students. It is expected that teachers with developed PCK would engage a variety of assessment methods in their teaching (Magnusson et al., 1999). The small number of observed lessons might have contributed to the limited number of assessment methods communicated and observed in this study. The other reason might be that the teachers had limited AK; maybe lacking in their training, as this concurs with the observation made by Mabejane et al. (2017) that student teachers at fourth year level of their teaching practice exhibited a lack of AK, citing that they feel they did not get enough assessment training during their teacher training.

Although the PCK test scores for the teachers selected as cases differ as follows: Jay 4.00 (developed), Jimmy 2.50 (limited), the knowledge of assessment in practice did not differ much amongst the teachers. These teachers portrayed partially developed skills for assessment because their intentions and actual practice showed that they assessed their students aligning themselves with the LGCSE syllabus assessment objectives, although they left out objective C of the assessment objectives. The AK exhibited by the two teachers could not differentiate them as teachers, even with high PCK test scores and low PCK test scores. They both exhibited limited knowledge of assessment in their actual teaching.

CONCLUSIONS & RECOMMENDATIONS

There is a mismatch between manifested PCK, PCK in-action and the PCK of the teachers measured through a paper-and-pencil test PCK on-action. This is not startling since the PCK measured through the paper-and-pencil test was canonical PCK. This excludes the context of practice according to the consensus model of PCK, while the manifested PCK is measured in the context in which the teacher teaches (Gess-Newsome, 2015). This study has shown that knowledge in-action is more influenced by their teaching context than the knowledge on-action. For instance, the case teachers' PK was found to be more developed than all other components of PCK emerging from the PCK test and in the interviews. These teachers were able to mention more effective teaching strategies that they were going to employ to teach their lessons. However, the manifested teaching strategies excluded some of the strategies that they had communicated as being effective for teaching. Nonetheless, it was discovered that fewer strategies were used for contextual reasons, such as time constraints and lack of resources. This study recommends a larger study with a similar design to this one to be undertaken, with a topic-specific PCK test and a greater number of items per PCK component, as Pitjeng-Mosabala and Rollnick (2018) state that PCK is topic specific. The study further recommends regular workshops to revive teachers' PCK, both experienced and novice teachers since experience has proved to have not been the best teacher in Jimmy's case.

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Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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APPENDIX A: PCK TEST INSTRUMENT

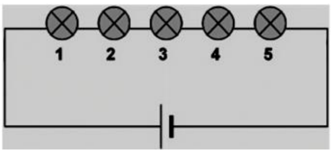
Table A1. PCK test instrument for physics teachers (Please answer all the questions. The information you will provide is for research purposes only. Your responses will be kept confidential)

Background information				
Name and surname (use pseudonyms)				
Sex (tick)	Female		Male	
Name of the present school where you are teaching				
District				
Please fill in details about all post school qualifications (since you left secondary school)				
Qualification, e.g., (Dip. Sec. Ed or BScEd or any)	Major subjects			
1				
2				
3				
4				
Please provide the following information about your teaching experience, from your first year of teaching				
School	Subjects taught	Classes taught	Number of years	
1				
2				
3				
4				

Question 1. Imagine you are teaching speed-time graph in a lab and students report their results graphically in a diagram using smoothing functions. Write at least **three points** of the general criteria you would use to score students presentation of their results.

Criteria for scoring students presentation of graphical results:

Question 2. You have discussed the topic, '**electric current in series and parallel circuits**'. The concept of current is already familiar to your students. You will use the following circuit to assess students' understanding of current in both **series and paralle1 circuits:** The five light bulbs connected in this circuit are identical. **What can you say about the brightness of the five lamps?**



a. One student's answer to the above task is that the brightness decreases from lamp 1 to lamp 5. What reason would the student give for this answer? Please explain giving at least **two** points, the thought processes behind this response.

Reason given by students:

Explanation of the student's thought process:

b. Write down **three** questions you would use to assess students' understanding of current **in series or parallel circuits.** One question per assessment objective:

A. Knowledge with understanding
B. Handling information and problem-solving
C. Experimental skills and investigations

Assessment objective

A. Knowledge with understanding
Question:

B. Handling information and problem-solving
Question:

C. Experimental skills and investigations
Question:

Question 3. Why do you use experiments in physics lessons? Please give at least **three** reasons.

Reasons for using experiments in physics lessons:

Question 4. You would like to introduce a law of physics by conducting a student experiment. After all student groups completed the experiment, there are 20 minutes left before the end of the lesson. The results are so poor that they do not clearly support the law. During the experiment, you had the impression that the students had been working carefully, and you were unable to find any errors. Considering that your goals are to maximize learning opportunities, which of the following tactics would you use to proceed with this lesson? Select your choices and write them in the space provided.

A. If you have pre-prepared values available, you tell your students that you do not know what they did wrong. You then use the prepared values to tabulate the experiment results.

B. You tell your students that you cannot work with the results and use modified values.

Table A1 (Continued). PCK test instrument for physics teachers (Please answer all the questions. The information you will provide is for research purposes only. Your responses will be kept confidential)

C. If the students recognize that their results are poor, you try to find the source of the errors together and apply any recommended changes in a follow-up experiment.

D. You be honest and tell your students that the experiment did not work as expected, and then you conduct a different experiment.

E. You postpone the tabulation/analysis of results to the next lesson so that you can think further about it and decide to start another experiment.

F. You have the students formulate their own physics law using their current results, and in the next lesson you let them conduct an experiment that proves their formulation wrong. After this, you and your students reflect on all that you have done.

Write your choice(s) as alphabet(s)	Choice(s)

Question 5. Force, energy, and power are different, although related concepts:

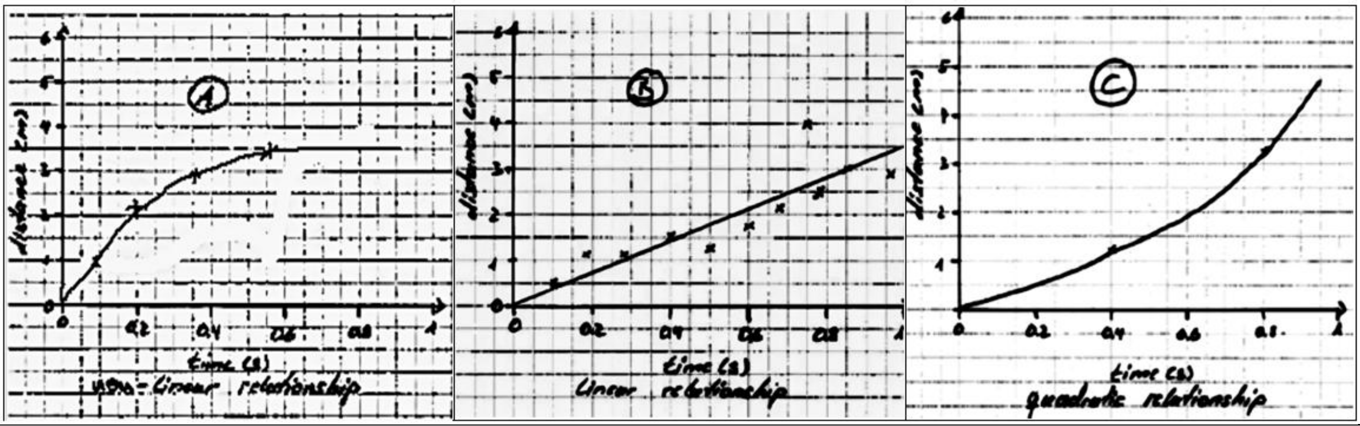
a. Show the relationship between force and energy, force and power, power, and energy. Use 100 N and 100 J, 100 N, and 100 W and lastly 100 W and 100 J to provide examples which show these relationships.

Force and energy	
Relationship	Example: **100 N and 100 J**
Force and power	
Relationship	Example: **100 N and 100 W**
Power and energy	
Relationship	Example: **100 W and 100 J**

b. What makes it difficult for students to understand the concepts of force, energy, and power? Explain giving at least **three** points.

Explanations:

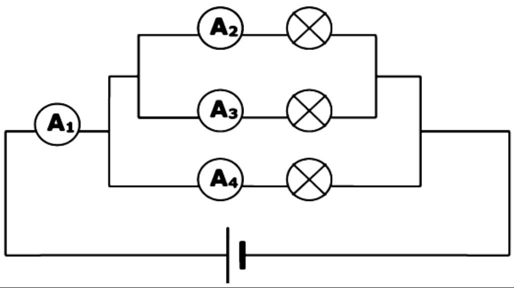
Question 6.Imagine that you are planning to teach a lesson whose purpose is for students to experimentally determine the relationship between distance and time for an object in free fall. The groups of students present their data in the form of distance-time diagrams and derive the relationship with smoothing functions. Select a group whose distance-time diagram best defines the relationship between distance and time in free fall. Explain with **one** reason per group why the **two** groups which you have not chosen are incorrect.



Correct group: __________

Group __________	Incorrect because
Group __________	Incorrect because

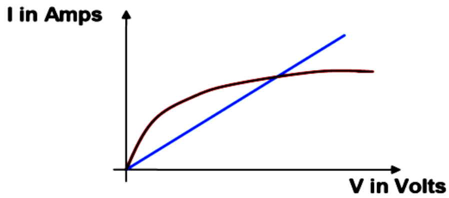
Question 7. You have covered the topic of 'current in series and parallel circuits' with your students in the previous lesson. You set the following task to examine the content in more depth. **Ammeter A_1 in the circuit below shows a current of 1.2 A.**



a. What do the other meters read? *(all lamps are identical)*

Meter	Reading
A_2	
A_3	
A_4	

Table A1 (Continued). PCK test instrument for physics teachers (Please answer all the questions. The information you will provide is for research purposes only. Your responses will be kept confidential)

b. One student gives the following answer: A_2 reads 1.2A. A_3 reads 1.2A. A_4 reads 1.2A. What reason would the student give for this answer? Please explain, giving at least **two points** why the student would give these responses.
Student reason:
Explanation:
Question 8. Literature on students learning says that it is important for the learning process to consider students' preconceptions while planning lessons. Please give at least **three** reasons to explain why.
Reasons:
Question 9. Students may have misconceptions having to do with the physics concepts of **speed and velocity**. Write down one misconception about velocity related to the following: (a) Direction, (b) Force, or (c) Calculations of speed and velocity.
a. Misconception about direction in speed and velocity
b. Misconception about speed and velocity related to force
c. Misconception about speed and velocity related to calculations
Question 10. What are the benefits of emphasizing units in physics lessons? Please explain, giving at least **three** points.
Explanations:
Question 11. When you enter a physics classroom, you see the sketch below from the previous lesson on the board. What might the sub-topic of the previous lesson have been **and** what content was covered in the lesson? 
Sub-topic:
Content covered in the lesson:
Question 12. In which grade level would you teach the content in question 11? List at least **two** concepts you would need to have covered before you could teach this concept.
Level: ___________
Prior concepts:

Thank you very much for your participation, your contribution is highly appreciated.

APPENDIX B: PCK TEST RUBRIC

Table B1. Rubric for scoring physics teachers' PCK test

Question 1.

Expectations: General criteria to score students' presentation of their results graphically in a diagram using smoothing functions.
- Graphs should have a title
- Variables must be correctly labelled on the axes.
- Appropriate units of variables must be shown
- Appropriate scale must be used
- The best fit line must be drawn
- The graph should take most of the x and y scales
- Or any other points, important in marking smoothing functions

1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
No relevant point from the expectations or no response at all.	One relevant point mentioned.	Two relevant points mentioned.	Three relevant points mentioned.

Question 2.
- Expectations: Reasons
- Large quantity of current is consumed by bulb 1 as it is the first bulb and consumption decreases along the bulbs.
- Bulb1 receives more voltage that decreases along with the bulbs.
- Resistance of bulb 1 is lower than the resistance of all other bulbs.
- Bulb 1 is nearer the current source than other bulbs.

Student's thought process:
- Current is consumed by bulbs.
- Bulb 1 receives more voltage which is used up and the remaining voltage goes to the other bulbs.
- The first bulb has lower resistance because there is more energy to push electrons to flow through.
- The positive terminal is the source of current, bulb 1 is near the current source.
- The amount of charge entering the light bulb is less than the charge exiting the light bulb, so the next bulbs get less charge.

1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
No relevant point from the expectations or no response at all.	Correct reason given, no thought processes give. Or no reason given, one correct though process.	Correct reason, one correct thought process or incorrect reason, two correct thought processes.	Correct reason, two correct thought processes.

a. Expectations according to LGCSE syllabus

A. Knowledge with understanding: Question often beginning with one of the following words: define, state, describe, explain or outline, testing the knowledge of one of: scientific phenomena, facts, laws, definitions, concepts and theories, scientific vocabulary, terminology and conventions, scientific instruments and apparatus, including techniques of operation and aspects of safety, scientific quantities and their determination, scientific and technological applications with their social, economic or environmental implications, related to current in parallel and series connection.

B. Handling information and problem-solving: Questions testing these objectives will often begin with one of the following words: discuss, predict, suggest, calculate, or determine. Questions testing these skills may be based on information that is unfamiliar to candidates, requiring them to apply the principles and concepts from the syllabus to a new situation, in a logical, reasoned or deductive way.

C. Experimental skills and investigations: A question assessing the knowledge to plan simple investigations and use techniques, apparatus and materials, to make and record observations, measurements and estimates to interpret and evaluate experimental observations and data to plan investigations and/or evaluate methods and suggest possible improvements.

1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
All questions do not assess the stated objectives.	One question correctly testing one objective.	Two questions correctly testing two objectives.	Three questions correctly testing the three objectives.

Question 3.
- Experimentation develops causal and functional thinking and creativity
- Experimenting develops the ability to work in a team
- Experiments are motivating, increase variety and arouse interest
- Experiments make it easy to experience learning
- Students are actively engaged

Table B1 (Continued). Rubric for scoring physics teachers' PCK test

- Experiments support the learning of scientific research methods
- Experiments are an established method of gaining knowledge in physics (generating hypotheses and working with them)
- Experiments make physical facts visually concrete
- Experiments make physical facts/relationships plausible/explain them
- Experiments support concept formation
- Experiments may lead to cognitive conflict
- Students practice handling data and data analysis
- Students practice handling deviances/establish a relationship with them
- Haptic/psychomotoric aspects are developed
- Retention of concepts

Examples of incorrect answers:
- Experiments are required by the curriculum
- To practice
- To use diverse methods

1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
Wrong answer or no response.	One point from expectations.	Two points from expectations.	Three points from the expectations.

Question 4.

Expectations:
- Choices C to F can maximize learning.

1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
No choice or choices A and B.	One of C, D, E, or F.	Two of C, D, E, and F.	Three of C, D, E, and F or all 4 correct.

Question 5

a. Expectations:

Force and energy	
Relationship: Energy (J) = Force (N) × distance (m)	Example: How much energy would it take to lift a stone weighing 100 N over a distance of 1 m? Any example that would relate to 100 J and 100 N. 100 J = 100 N × 1 m. Energy transfer of 100 J results when a force of 100 N is applied over a distance of 1 m. Or any examples showing the relationship.
Force and power	
Relationship: Related by the amount of work done by a force. Power = Rate at which work is done by a force applied over a distance.	Example: 100 W = $\frac{100\ N \times 1\ m}{1\ s}$. How much power would it take to lift a stone weighing 100 N over a distance of 1 m in 1 second? A force of 100 N applied over a distance of 1 m on an object for a period of 1 second produces 100 W. Or any example can relate 100 W to 100 N.
Power and energy	
Relationship: Power = Energy transferred per unit time. When the rate of energy transfer is 100 J/s, the power is 100 W.	Example: 100 W = $\frac{100\ J}{1\ s}$. When Pule climbs up the hill, the energy transferred is 100 J every second. Calculate Pule's power. Or any example relation 100 W to 100 J.

1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
No answer or answers showing no relationships.	One example and corresponding relationship correct.	Two examples and corresponding relationships correct.	Three examples and corresponding relationships correct.

b. Expectations:
- The language problem, students use the words force, energy, and power interchangeably.
- The limited mathematics concepts required to use equations involve in problems engaging force, energy, and power.
- Failure to use units for force, energy and power correctly.
- The misconceptions around the concepts: examples of such misconceptions given: Energy is used up. Objects at rest do not have energy. An object stops moving because energy is used up. An object with more energy has high power etc.

1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
No response or irrelevant responses given.	One relevant response given.	Two relevant responses given.	Three relevant responses given.

Table B1 (Continued). Rubric for scoring physics teachers' PCK test

Question 6.

Expectations:

- Group C

Group A, incorrect because

- The graph shows that speed decreases as the object falls, which contradicts what actually happens.

Group B, incorrect because

- The graph shows the object moving with a constant speed, while in free fall the object accelerates.

1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
No answer or A or B.	Answer as C, both reasons are incorrect.	Answer as C One reason is correct.	Answer as C Two reasons are correct.

Question 7

a. Expectations:

- A_2 = 0.4A
- A_3 = 0.4A
- A_4 = 0.4A

1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
All responses incorrect.	One response correct.	Two responses correct.	Three responses correct.

b. Expectations:

Reason:

- The bulbs are identical and therefore have the same amount of current flowing.

Explanation

- Current is the same at all points of the circuit irrespective of the connection.
- The bulbs are identical therefore consume the same amount of current.
- Identical bulbs have the same amount of charge flowing.
- Identical bulbs draw the same amount of energy from the battery, therefore have the same current flowing.

1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
No responses or all responses incorrect.	Reason correct and explanations incorrect or reason incorrect and one explanation correct.	Reason and one explanation correct or reason incorrect and two explanations correct.	Reason correct and two explanations correct.

Question 8

- To select the best teaching strategies that can help address the misconceptions.
- To build on existing acceptable concepts.
- To select the best examples, analogies and representations informed by the misconceptions around the concepts.
- To logically sequence conceptual change strategies in the classroom etc.

1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
No answer or answers not related to lesson planning.	One correct reason.	Two correct reasons.	Three correct reasons.

Question 9

Misconceptions related to the direction:

- Velocity and speed are the same.
- Velocity has no direction.
- Two bodies have the same direction of motion when the have the same goal.

Misconceptions related to force:

- A body in motion can cause something/has force; it has more force when it moves faster.
- Without force there is no motion.
- A uniform movement requires a force.
- Bodies become slower by themselves.
- High speed is the result of a large force (neglecting the time aspect).

Misconceptions related to the relationship between distance and time:

- $v = s/t$ always can be used for calculation.
- The formula is $v = s \times t$.
- Average speed and mean speed are the same.

Table B1 (Continued). Rubric for scoring physics teachers' PCK test

1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
Incorrect responses or no responses given.	One misconception correct.	Two misconceptions from two categories correct.	There misconceptions from three categories correct.
Question 10			
Expectations: Units help students to: • express measurements of physical quantities. • describe observations quantitatively. • compare the amount of the same physical quantity. • establish a common understanding of the quantity of a physical quantities irrespective of the location. • differentiate between physical quantities which are used to describe nature quantitatively. • establish mathematical relationships between physical quantities.			
1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
No responses or incorrect responses given.	One correct explanation given.	Two correct explanations given.	Three correct explanations given.
Question 11			
Sub-topic: Resistance **Content covered in the lesson** • The relationship between current and voltage in ohmic and non-ohmic materials. • Resistance of ohmic and non-ohmic materials. • V/I characteristic graphs for ohmic and non-ohmic materials.			
1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
No sub-topic given, no content given or incorrect sub-topic and incorrect content.	Sub-topic given and no content or no sub-topic or incorrect sub-topic and one concept given in content.	Correct sub-topic and one correct concept or incorrect sub-topic and two correct concepts given for content.	Correct sub-topic and two or more correct concepts given as content.
Question 12			
Expectations • Level: Grade 11 or 12 or 9 and 10 because of the new syllabus. Prior concepts • Current • Emf, p, d, or voltage • Resistance • Electric circuits • Measurement of current and voltage			
1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
No grade, no prior concepts or wrong grade and wrong prior concepts.	Correct grade and wrong prior concepts or wrong grade and one correct prior concept.	Correct grade and one correct prior concept or wrong grade and two correct prior concepts.	Correct grade and two or more correct prior concepts.

APPENDIX C: INTERVIEW SCHEDULE

Questions

1. Which topic or sub-topic are you going to teach today?
2. What are the main concepts you are going to teach in this topic?
3. Why do you think it is important for students to know these concepts?
4. What else do you know about these concepts that you do not intend students to know yet?
5. What are the difficulties connected with teaching these concepts?
6. What knowledge can you share about students' thinking that influences your teaching of these concepts?
7. Are there any other factors that would influence your teaching of these concepts?
8. What teaching procedures would you employ?
9. Why would you use these procedures?
10. What aspects of science learning are you going to assess in this topic?
11. What methods would you use to assess students' understanding of this topic?

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