JOURNAL OF BALTIC SCIENCE EDUCATION

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

EXAMINING PHYSICS TEACHERS' DOMAIN-SPECIFIC PEDAGOGICAL CONTENT KNOWLEDGE COMPONENTS IN LESOTHO SECONDARY SCHOOLS

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Abstract. *Pedagogical content knowledge (PCK) is considered an important ingredient in shaping classroom practice. PCK requires valid measurement at domain-specific level on different components excluding the teaching context. While the research focuses on measuring the PCK of unqualified teachers and pre-service teachers, the description of qualified teachers' domain-specific PCK is often overlooked. The purpose of this study was to measure quantitatively the domain-specific PCK of qualified physics teachers focusing on the five PCK components: content knowledge, pedagogical knowledge, assessment knowledge, knowledge of students and curricular knowledge. Data were collected through the paper-and pencil PCK test that was responded to by 87 Physics teachers teaching the last two years of secondary school. Data were analyzed using the Extended Rasch Model and descriptive statistics. The results revealed that Physics teachers have a low PCK in general and low levels of PCK components, the lowest being content knowledge. The study recommends regular refresher workshops for qualified teachers focused on developing different PCK components, with more emphasis on content knowledge.*

Keywords: *pedagogical content knowledge, physics teachers, domain-specific PCK, PCK components*

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Introduction

Teachers are assumed to have developed the necessary pedagogical content knowledge (PCK) which informs their classroom practice from their training. However, the level of development of teachers' PCK is often not measured. This makes it difficult to characterize the PCK that teachers have, which might have an impact on learners' achievement or the quality of classroom practice. PCK has in previous research been identified as the foremost predictor of student achievement (Gess-Nesome, 2019; Keller, Neumann & Fischer, 2017; Kind & Chan, 2019). Shulman (1986) termed the knowledge of transforming subject matter knowledge into a teachable form that can be comprehended by students as PCK. Teachers draw on different knowledge bases to construct their classroom practice and teach in certain ways in part because of the knowledge bases they possess (Gess-Newsome, 2015; Gess-Newsome 2019; Shulman, 1987). These Knowledge bases are referred to as PCK components by some researchers (Ezik-Kiran, Boz & Oztay, 2021; Magnusson, Krajcik & Borko, 1999). PCK components have to work in unison to produce high quality PCK in classroom practices (Sæleset & Friedrichsen, 2022). This implies that the PCK components have to be well developed to be used as an amalgamation of individual components, complementing each other to produce effective teaching in classrooms. When PCK is not well formed, the quality of classroom practice is often compromised (Barendsen & Henze, 2017; Rollnick, 2017). To understand and explain classroom practices, it is therefore important to investigate the knowledge bases, termed PCK components in this study, that teachers draw on to execute their classroom practices.

Keller et al. (2017) have associated the PCK of teachers to students' performance while Rollnick (2017) has argued that teachers need profound PCK for planning, teaching, and reflecting on their lessons. This suggests that PCK is necessary for both the quality of classroom practice and, subsequently, students' achievement. While PCK is envisioned as an essential ingredient in classroom practice, some researchers have found PCK to be related to the poor quality of classroom practice in both developed and developing countries when some PCK components are not well developed (Barendsen

https://doi.org/10.33225/jbse/24.23.240

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

& Henze, 2017; Rollinick, 2017). 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, Rollinick (2017) found teachers with a weak knowledge of content in a topic having a challenge when teaching the same topic to students. In support of this, Jacob, John and Gwany (2020) have provided examples of empirical studies showing that teachers with insufficient content knowledge led to the development of misconceptions and misunderstandings in the classroom teaching. These reports unveil the dire straits in the pedagogy of Science, leading to compromised classroom practices. Similarly, Lesotho Physics teachers often use inadequate teaching strategies to teach Physics in classrooms partly due to what is considered to be weak PCK on the topics they teach (Qhobela & Moru, 2014). Makhechane and Qhobela (2019) have also found that Lesotho Chemistry teachers use teacher-centered methods to teach Chemistry. This was evident in the chemistry teachers' choice of teacher-centered strategies to teach Chemistry. These studies suggest that Lesotho Science teachers might have a weak PCK as PCK is seen in the ability of the teacher to select appropriate strategies to transform the content (Shulman, 1986).

Research Problem

Research focuses more on the PCK of pre-service teachers (Meier, 2020; Schiering et al., 2023; Sorge et al., 2019) overlooking the PCK of qualified in-service teachers. This might be due to the assumption that qualified teachers have developed intense PCK from their training and experience and therefore have high levels of PCK and PCK components. Großschedl, Welter and Harms (2019) advocate for frequent rigorous examination of teachers' PCK as PCK is the main ingredient that impacts the quality of classroom teaching, students' learning process and also their success. While there is not enough literature in studies exploring the PCK of Physics teachers, a few studies done in Lesotho (Makhechane & Qhobela, 2019; Qhobela & Moru, 2014) highlighted the poor PCK of Science teachers. However, these studies have not clarified the PCK components, which are not well developed by the teachers, leading to the ineffective teaching of Science. If teachers' PCK is fundamental to the quality of teaching that determines students' learning in the classroom, we, therefore, need to measure teachers' PCK before we understand how they enact their PCK in the classroom. It is in this regard that this study sought to examine the PCK components that Physics teachers in Lesotho possess. It is important to investigate what teachers know about teaching Physics, focusing on different PCK components excluding their classroom context.

Research Focus

This study draws on research that explores the professional knowledge base for teaching. Shulman (1987) views the professional knowledge base of teachers as being organized into seven categories of which PCK is the most important. Researchers envisage PCK as an important constituent of professional knowledge that contributes towards effective teaching (Ekiz-Kiran, Boz & Oztay, 2021; Keller, Neumann & Fischer, 2017; Pitjeng-Mosabala & Rollnick, 2018). Gess-Newsome (2015) maintained that the way the teacher teaches is influenced by what the teacher knows. This implies that a teacher draws on the PCK components that they have to enact classroom practices to help students understand when a learning difficulty is presented to the students. This raises curiosity of how the teacher behaves in cases where the teacher has limited knowledge in one PCK component that they need to draw on to make learning possible in times of challenges arising in the classroom. Shulman (1987) and Oztay and Boz (2022) share a common view that the knowledge base for teachers is built from the teachers' knowledge of content from their training, the materials such as the curriculum and textbooks and the setting of the institutionalized educational process being the school organization and teaching profession structure. It is therefore important to measure this knowledge to give insights into how much is known by the teachers to teach physics.

The Consensus PCK Model of Gess-Newsome (2015) was used to guide this study. The model is called the model of teacher professional knowledge and skills (TPK&S) that includes PCK or the Consensus Model of (Gess-Newsome, 2015). The model was formulated to reveal the connection between knowledge bases, which collectively form teachers' professional knowledge bases. In the Consensus Model, the knowledge base of teachers is viewed as a general knowledge of teaching, and this knowledge base can be used to assess what teachers know with respect to their teaching, excluding the classroom context. Liepertz and Borowski (2019) assert that teaching a particular subject needs different knowledge bases to be integrated. Although different scholars differ in the number of knowledge bases required to teach effectively, most of the scholars agree

https://doi.org/10.33225/jbse/24.23.240

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

on some of the knowledge bases considered in the Consensus Model. For instance, pedagogical knowledge, students' knowledge, and content knowledge have been considered in different models (Cochran et al., 1993; Rollnick et al., 2008; Shulman, 1987).

The Consensus Model suggests a strong framework for understanding how different professional knowledge bases inform teachers' PCK. This model suits this study because this study seeks to assess the general knowledge of teaching that Physics teachers have by looking at the different knowledge bases termed PCK components included in this model. The PCK assessed in this study is the canonical knowledge that excludes the context in which the teacher teaches. As a result, this study seeks to understand the teachers' knowledge of PCK components out of the classroom context, considered to be PCK on-action (Barendsen & Henze, 2017; Kirschner et al., 2016). Other researchers refer to this knowledge as personal PCK (pPCK) (Schiering et al., 2022). Gess-Newsome (2015) terms this kind of knowledge teacher professional knowledge bases (TPKB) and argues that it is context free, meaning it can be investigated outside the classroom context. TPKB was used in this study to construct the PCK test to assess what teachers know with respect to the professional knowledge components that inform their PCK. Table 1 shows the knowledge bases, called PCK components in this study and what each component entails.

Table 1
PCK Components Description

PCK component	Description
Assessment knowledge (AK)	The ability of the teacher to design formative and summative assessments and use the designed assessment results to modify or redesign instruction (Gess-Newsome, 2015). Magnusson et al. (1999) view this as the knowledge of the dimensions of Science learning that are important to assess and the knowledge of the methods by which learning can be assessed.
Pedagogical knowledge (PK)	Ways to engage students may be illustrated through applying instructional strategies that address the different needs of students (Gess-Newsome, 2015). These strategies may be general subject-specific or constrained to a specific topic (Magnusson et al., 1999).
Content knowledge (CK)	Gess-Newsome (2015) considers content knowledge to be academic knowledge, meaning it is the knowledge the teacher gains from school or university in a certain discipline.
Knowledge of students (KS)	Knowledge of students that encompasses students' cognitive and physical development (Gess-Newsome, 2015). Magnusson et al. (1999) describe this as knowledge of students' difficulties, prerequisite knowledge, different learning styles and knowledge of different ways to represent the content to a particular group of students.
Curricular knowledge (CuK)	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).

Research Aim and Research Questions

Barendsen and Henze (2017) have revealed the complexity of relating the PCK possessed by a teacher outside a classroom context with the PCK used by the teacher in the classroom. The complications are brought about by the difficulty in measuring the PCK in the mind of the teacher and the PCK that is used in the construction of classroom practices. The hurdles in measuring and depicting PCK result from the nature of the construct that PCK is tacit (Rollnick, 2017). Some studies used qualitative methods to investigate PCK where PCK was captured through the CoRes constructed by teachers, interviews and/or classroom observations (Mazibe, Coetzee & Gaigher, 2020; Nilsson & Karlsson, 2019). Some researchers engaged quantitative methods to measure PCK (Cauet et al., 2015; Davidowitz & Potgieter, 2016; Kirchner et al., 2016; Liepertz & Borowski, 2019; Marake, Jita & Tsakeni, 2022). The different studies carried out on PCK presented inconclusive results about what matters as the necessary knowledge for effective teaching (Barendse & Henze, 2017). This study, therefore, adds to the literature that examines PCK by engaging a paper-and-pencil PCK test that measures the domain-specific PCK for teaching Physics. The paper-and-pencil test examines the episteme of teaching Physics as a discipline of Science to find out how much teachers know about the five components of PCK, guided by the following research question: What levels of development of PCK components do physics teachers possess?

https://doi.org/10.33225/jbse/24.23.240

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Research Methodology

General Background

This study used a quantitative survey design to measure Physics teachers' PCK. A survey was in the form of a paper-and-pencil test and measured the PCK components which have been described in Table 1. The paper-and-pencil test was distributed to schools by the first author and left for teachers to respond to it during their spare time. Data collection occurred from December 2020 to March 2021. The purpose of the survey was to examine the PCK components that Physics teachers have developed excluding the classroom context. 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. In this study, the test scores of Physics teachers were used to describe their PCK components level.

Sample

The sample for this study was 87 qualified Physics teachers. These are Physics teachers who are certified to teach Physics and who have obtained a qualification from institutions of higher learning in which one of their major subjects is Physics. This study was carried out in all Lesotho districts. Non-probability convenience sampling was used in this study because this is the sampling type that allows a researcher to focus on a certain group within the population that is easily accessible (Cohen et al., 2018). The PCK test was distributed to 109 schools and 265 teachers but responded to by 88 teachers, where one was excluded from the data set because she was an outlier who only responded to two items leaving the other items unanswered. In this study the group of focus was qualified Physics teachers who were teaching in schools that can easily be reached by car, teaching grade 11 or grade 12. These are the last two years of the upper secondary level and preparing students for the LGCSE (Lesotho General Certificate of Secondary Education) certification. The teachers had a range of qualifications ranging from a Secondary Teachers' Certificate to a Master of Science with the dominant qualification being a Bachelor of Science with education. The sample had differing years of experience ranging from 0 to 30 years with the majority at 0 to 10 years' experience.

Instrument and Procedures

The PCK measured by the PCK test in this study was domain-specific PCK. Domain specific PCK is defined by Veal and Makinster (1999) as PCK at the level of the sub-discipline, in this study Physics, which is a sub-discipline of Science. The PCK test was adapted from Kirschner et al., 2016). The PCK test items were adopted and adapted to assess the PCK components possessed by Physics teachers. The Consensus Model has five knowledge bases, which guided the development of the PCK test items. The items were divided into categories of knowledge bases from the Consensus Model being: (AK), (PK), (CK), (KS) and (CuK). The items on CuK were adopted and adapted from Ergönenç, Neumann and Fischer (2014) and Neumann and Fischer (2018) because there were no questions related to this knowledge base in the items developed by Kirschner et al. (2016). Out of the seventeen items in Kirschner et al., the items that were not used in the PCK test were not in the syllabus of LGCSE, like items about projectile motion. The PCK test in this study was made up of twelve questions, where some questions had sub-questions yielding fifteen items, testing the knowledge of different PCK components. Most of the items of the PCK test covered topics in mechanics, as these take a larger portion of the LGCSE Physics syllabus and form the basic knowledge of understanding Physics and some covered electricity, which is the second largest topic in the syllabus. The topics covered in mechanics were: velocity/speed and the relationship between force, energy, and power. In electricity, the topics covered were: series and parallel circuits and resistance.

The PCK test was analyzed quantitatively by means of a rubric constructed using the five context-free PCK components, described in Table 1. Some of the expected responses were taken from Kirschner et al. (2016). The other expected responses were added by the first researcher. By rephrasing the PCK test items with the help of 12 qualified Physics teachers in a pilot study, the PCK test's validity was established. To confirm the material, the pilot test was given to 12 Physics teachers with varying years of experience and qualifications as well as to a Physics teacher trainer. Furthermore, the Extended Rasch Model was also used to validate the PCK test tool and none of the items were excluded by the Model.

https://doi.org/10.33225/jbse/24.23.240

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Data Analysis

The analysis of the PCK test started with the marking of the test by the first researcher using a rubric. The rubric was developed such that it had a four-point scoring 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. Two raters, the first 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 of 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 the assessment of a subject. Such experts are selected based on their experience in the subject and are qualified in the area of judgement. In this study, the following steps, as proposed by Escobar-Pérez and Cuervo-Martínez (2008) were followed in the process of getting expert judgement: the other rater was selected as someone who could be involved in this study for the following reasons:

(a) The expert had been a secondary school Physics teacher for more than ten years, had been a Physics teacher trainer at the College for more than ten years, had been a Physical Science marker and a senior team leader at the Examination Council of Lesotho for more than ten years; implying she is conversant with assessment standards and the confidentiality required in assessment.

(b) The first researcher discussed the objectives of the study and the objectives of the PCK test with the expert. The discussion included looking at each PCK test item and clarifying what it was intended to test. The PCK test rubric was also discussed to verify that the responses proposed by the first researcher were in line with what the items were testing.

(c) The Physics teacher trainer and the first researcher rated the PCK test responses, and agreement between the two raters was calculated, as discussed in the following paragraphs.

The inter-rater agreement was calculated using the irr package for R_version 0.84.1 (Gamer et al., 2019). McHugh (2012) refers to inter-rater reliability as the measurement of the similarity of the scores assigned by data raters to the same variable. In this study the variable was the teachers' responses to the items of the PCK test. The inter-rater reliability assessment is essential as a way of quantifying the degree of agreement when two or more independent raters are involved in making independent ratings about the characteristics of a set of subjects (Hallgren, 2012). In addition, 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, Jorgensen & van de Ark, 2017).

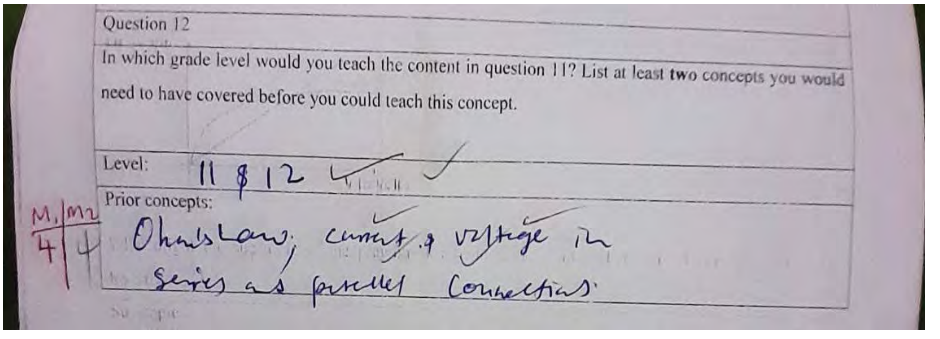
The data reported in this study was the PCK of Physics teachers and therefore needed to minimize subjectivity by engaging a second rater. McHugh (2012) emphasizes the need for the training of the raters before they are engaged in rating the responses. In this study, this was met as the instrument for data collection had been discussed with the second rater. This implies that there was a shared understanding of the items in the PCK test. The rubric used for scoring was constructed by the first researcher and discussed with the second rater so as to agree on what to look for in the responses. Although the two raters discussed the PCK test items and the responses expected, there were cases of disagreement on the scores allocated. In such cases the two raters discussed the reasons behind the scores allocated. In some cases, the two raters agreed to allocate the same score, but in other cases where there was disagreement, the scores were left unchanged.

According to ten Hove, Jorgensen and van de Ark (2017), there are various coefficients that can be used to calculate inter-rater reliability, and this makes the justification for why a certain coefficient was used to be difficult. The inter-rater liability 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 at all; zero also shows no agreement while 1 represents perfect agreement (McHugh, 2012). de Ruiter and Smid (2007) argue that Cohen's Kappa is equivalent to the coefficient *iota*. This implies that the interpretation of the values of the two coefficients is similar. Coefficient *iota* is defined as a chance corrected reliability for multivariate data (de Ruiter & Smid, 2007). Coefficient *iota* was used to report the inter-rater reliability for this study, and it 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). This high level of agreement suggests minimal error introduced by the two independent raters, and therefore, the statistical power for succeeding in the analyses is not significantly affected. An example illustrating how one PCK test item on content knowledge was rated by the two raters, rater 1 with a red pen and rater 2 with a green pen, is portrayed in Figure 1.

https://doi.org/10.33225/jbse/24.23.240

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Figure 1
Illustration of the Rating of PCK Test Items



Note: M_1 and M_2 show rater1 and rater2, respectively, and the numbers 4 and 4 indicate the PCK rating level from the rubric. Each item was rated on a four-point rating scale of: (1 = undeveloped, 2 = limited, 3 = intermediate and 4 = developed). The PCK test rubric excerpt is given in Table 2.

Table 2
PCK Test Rubric Example

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 point: Undeveloped	2 points: Limited	3 points: 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

Analysis of the PCK test using the Extended Rasch Model

In the Extended Rasch Model, the Rating Scale Model was used to analyze data. Smith et al. (2008) assert that the Rating Scale Model analysis is used to analyze Likert-type data and portrays the probabilistic relationship between the item difficulty and the person's ability. The Rasch Model measures a single trait (Boone & Noltemeyer, 2017). In this study, a single trait was the Physics teachers' PCK. The theory underlying the Rasch Model is discussed by Boone and Noltemeyer (2017) as follows:

> [W]hen attempting to measure a single trait, test-takers are more likely to correctly answer easy items than difficult items; furthermore, all items are more likely to be correctly answered by people with high ability on the construct being assessed than by those with low ability. (Boone & Noltemeyer, 2017, p. 2)

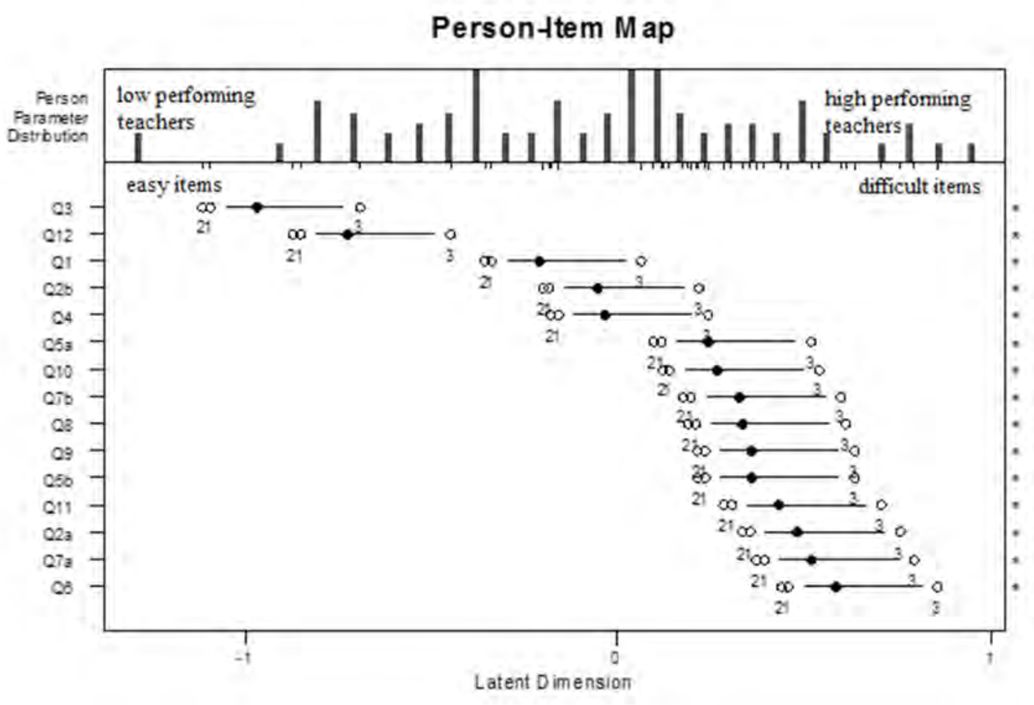
This means that teachers with high test scores would be considered to have a high PCK level, and vice versa.
Research Results

https://doi.org/10.33225/jbse/24.23.240

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

The PCK components discussed in this study are the knowledge bases in the Consensus Model (Gess-Newsome, 2015). Using the Extended Rasch Model and SPSS, the PCK test results were reported. Firstly, data were processed using the Extended Rasch Model version https://cran.r-project.org/package=eRm. Figure 2 shows the Wright Map.

Figure 2
Wright Map



Note: Figure 2: The Wright Map for PCK test. N = 87. The Wright Map illustrates the location of a person's abilities and item difficulties along the same latent dimension. The solid circles describe the locations of item difficulties while thresholds of adjacent category locations are indicated with open circles.

Figure 2 illustrates the distribution of Physics teachers' abilities and item difficulties on the same logit scale. The average item difficulty is set at zero. The more positive the value the more difficult the item and the more able the teacher. The more negative the value, the easier the item and the less able the teacher. The item difficulty is within the range of ± 1 logit intervals, meaning that the items were around an average level of difficulty. This average level of item difficulty is considered the most suitable level to evaluate the ability of the sample (Susac et al., 2018). Figure 2 also shows the relationship between the item locations and the person location on the latent scale. The easiest items are shown on the left and the most difficult items are located on the right side of the latent scale. In a similar manner, the participants with the lowest scores are located on the left and those with the highest scores are on the right of the latent scale. From Figure 2, the participant abilities ranged from -1.37 logits for the lowest scorer to 0.95 logits for the highest scorer. Teachers' ability has low positive values on the logit scale. Although Figure 2 shows that most of the items were roughly equal in level of difficulty, Q3 and Q12 stood out as easy. Q1, Q2b and Q4 were moderate while the rest of the items were difficult. Table 3 shows the level of difficulty of the PCK items in order from the easiest to the most difficult.

https://doi.org/10.33225/jbse/24.23.240

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Table 3
Level of Difficulty of PCK Test Items

Item	**Difficulty (logits)**	Threshold1	Threshold2	Threshold3
Q3	-0.968	-1.095	-1.115	-0.693
Q12	-0.724	-0.852	-0.872	-0.45
Q1	-0.212	-0.339	-0.359	0.063
Q2b	-0.057	-0.184	-0.204	0.218
Q4	-0.035	-0.162	-0.182	0.24
Q5a	0.243	0.116	0.096	0.518
Q10	0.266	0.139	0.119	0.541
Q7b	0.324	0.197	0.177	0.599
Q8	0.336	0.208	0.188	0.611
Q5b	0.359	0.232	0.212	0.634
Q9	0.359	0.232	0.212	0.634
Q11	0.432	0.304	0.284	0.706
Q2a	0.481	0.354	0.334	0.756
Q7a	0.519	0.392	0.372	0.794
Q6	0.584	0.457	0.437	0.859

Table 3 shows the items which participants found easy, moderate, and difficult. The greater the magnitude of a negative score, the easier the Extended Rasch Model considered the item. The items with a greater magnitude of positive scores were found to be difficult. For instance, Q3 was found easy as it had a difficulty level at -0.968 logits. Q6 was found most difficult with the difficulty at 0.584 logits. Table 4 shows the components in which the PCK test items belong and their level of difficulty.

Table 4
PCK Components and the Level of Difficulty of Their Composite Items

	Difficulty level of PCK test items		
PCK component	**Difficult**	Moderate	Easy
Assessment Knowledge	-	Q1, Q2b	-
Pedagogical Knowledge	-	Q4	Q3
Content Knowledge	Q5a, Q6, Q7a	-	-
Knowledge of Students	Q2a, Q5b, Q7b, Q8, Q9, Q10	-	-
Curriculum Knowledge	Q11	-	Q12

In Table 4, The PCK components and their composite items are arranged according to their levels of difficulty. The words difficult, moderate, and easy have been used to differentiate between difficulty levels. The participants had moderately developed skills in the components of Assessment Knowledge and Pedagogical Knowledge since there are no items in these components which were classified as difficult items. The Assessment Knowledge component has items Q1 and Q2b, which are both classified as moderate. These two items examined knowledge of dimensions of Science learning that are important to assess.

In the component of Pedagogical Knowledge, item Q4 tested a knowledge of instructional strategies and was classified as moderate while Q3 examined a knowledge of instructional strategies and their advantages. Item Q3 was classified as easy. The participants' skills show that they have better knowledge of instructional strategies. The component of content knowledge has items classified as difficult. The three items in this component, Q5a, Q6 and

https://doi.org/10.33225/jbse/24.23.240

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Q7a all examined the subject matter knowledge of the participants. Q5a explored a knowledge of the relationship between force, energy, and power. Q6 tested the knowledge of the distance-time graph in freefall. Q7a examined the knowledge of current behavior in circuit branches of parallel circuits. Among these items, Q6 was the most difficult having 0.584 logits.

The other component in which all items were classified as difficult is the component of Knowledge of Students. The component has 6 items: Q2a, Q5b, Q7b, Q8, Q9 and Q10. Q2a explored knowledge of misconceptions and students' difficulties. Q5b explored knowledge of students' difficulties. Q7b, Q8 and Q9 tested participants' knowledge of misconceptions. Q10 examined knowledge of students' understanding of Science. The component of Curriculum Knowledge had one item: Q11 was classified as difficult, and another, Q12, was classified as easy. Q11 tested the knowledge of the topics taught in the last two grades of secondary school, while Q12 tested the knowledge of the prior concepts needed for the topic being taught.

Although the Wright Map was able to show the item difficulty and to differentiate participants according to their abilities, the person measures and item measures were described in logits and could not easily be compared to the levels of PCK on the rating scale. The Extended Rasch Model provided information where the level of PCK was the underlying variable. This data could only be reported as a high, average, or low PCK level (Planinic et al., 2019). On the other hand, it would not be enough to be informed about a high or low level of PCK but to also describe how high or how low the PCK level is. It is in this regard that descriptive statistics were used to classify PCK components according to the levels of PCK on the rating scale.

The Extended Rasch Model revealed that the Physics teachers' PCK was rather low since the person measures ranked in the interval $-1.37 logits < PCK < +0.95 logits$. This is an indication that there were no teachers in the high ability measures. The item measures were found to be in the interval $-0.968 logits < difficulty < 0.584 logits$. This also reveals that there were neither too easy nor too difficult items in the PCK test, thus an indication that all the test items were within the average range. The items from this average region should have been able to discriminate between teachers who are more and less competent. Evidently, this means that there were no teachers with a high level of PCK.

Descriptive Statistics of the PCK Test

Descriptive statistics from SPSS were used to rate the PCK levels of the participants according to the levels portrayed on the rating scale. Table 5 shows the descriptive statistics of the PCK test looking at the PCK components. Descriptive statistics were used to rank the PCK components according to their means, which made it possible to rank the PCK components according to their level of difficulty and show the general PCK development of the participants. The difficulty of the PCK components is described according to the PCK test rating scales. To reiterate, the PCK levels of development range from 1 undeveloped, 2 limited, 3 intermediate to 4 developed. The interval used to place each of the PCK components is proposed by Pimentel and Pimentel (2019) who describe the following intervals for a unified interval 4-point Likert scale: 1(1.00 - 1.75), 2(1.76 – 2.51), 3(2.52 - 3.27) and 4(3.28 - 4.00). On this rating scale interval, the scale has a uniform difference of 0.75, except for the last interval where it is 0.72. Table 5 shows the PCK components and their ranks in order of their difficulty level.

Table 5
PCK Components Ranking Order and Levels

PCK Component	Pedagogical Knowledge	Curricular Knowledge	Assessment Knowledge	Knowledge of Students	Content Knowledge
Mean	2.91	2.59	2.57	2.07	2.00
PCK level	Intermediate	Intermediate	Intermediate	Limited	Limited

The outcomes of the descriptive statistics from SPSS complemented the Extended Rasch Model's findings. The Extended Rasch Model was unable to classify PCK components into the various stages of development. According to the descriptive results, PK, CuK, and AK are at an intermediate level while KS and CK are at a limited level. The results show that there were no PCK components at a developed level.

https://doi.org/10.33225/jbse/24.23.240

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Discussion

It is the goal of every government to have teachers with high levels of professional knowledge to effectively teach in schools. Teacher training institutions also train teachers to graduate having developed the knowledge of teaching in their different disciplines. Shulman (1987) emphasizes the importance of PCK as a professional knowledge base that helps the teacher transform subject matter into a teachable form. However, research examining the PCK of in-service qualified teachers is rare. This might be due to the assumption that in-service teachers have high levels of PCK gained from their training or from their teaching experience. This study adds to the literature that examines the PCK of qualified Physics teachers by engaging a paper-and-pencil PCK test that measures the domain-specific PCK for teaching physics. The paper-and-pencil test examines the episteme of teaching Physics as a discipline of Science to find out how much teachers know about the five components of PCK. Suffice to say, teaching is viewed as a complicated process that requires the formation of many PCK components for integration (Shulman, 1987), as well as a high PCK level. In as much as it has been argued that teachers with poor PCK exhibit low expertise in the teaching process (Barendsen & Henze, 2017; Qhobela & Moru, 2014), the low levels of CK and KS suggest that these components may not be adequately integrated into the teaching process, which may damage classroom practice. While some studies argue the importance of content knowledge in shaping the teachers' PCK (Oztay & Boz, 2022; Rollnick, 2017), others do not single out one component, but consider PCK to be more developed where all the components are developed and are integrated to produce PCK effective for classroom practice (Magnusson et al., 1999).

The PCK measure in this study was the PCK of qualified Physics teachers and the topics involved in the PCK test were topics from the LGCSE syllabus, which are taught by the sample for this study. The PCK components which were classified as limited are content knowledge and the knowledge of students. These results were startling since it is expected that a qualified teacher has developed subject matter around the taught discipline as Shulman (1987) and Oztay and Boz (2022) agree that the knowledge base for teachers is built from the teachers' knowledge of content from their training. Gess-Newsome (2015) also considers content knowledge to be academic knowledge, meaning it is the knowledge the teacher gains from school or university in a certain discipline. The low level of content knowledge reported in this study may begin to question the content knowledge transformed into the teachable form by the teachers where the paper-and-pencil test reveals the low levels of content knowledge. The lowest levels have also been recorded in the knowledge of students. This result is supported by Jacob, John and Gwany (2020), who provided examples of empirical studies showing that teachers with insufficient content knowledge led to the development of misconceptions and misunderstandings in classroom teaching. As much as the PCK measured in this study excludes the classroom context, the low level of the knowledge of students and content knowledge confirms that these two components are inseparable when the low level of one implies the low level of another.

Conclusions and Implications

The purpose of this study was to measure the domain-specific PCK of qualified Physics teachers. With less known about Physics teachers' domain-specific PCK due to scarcity of research in that line, especially in the context of Lesotho, this study fitted in well in contributing to the literature about Physics domain-specific PCK. It does this by giving insights about the level of development of PCK possessed by Physics teachers. The findings of this study show that the PCK of Physics teachers is rather low, with the component of content knowledge being the least developed. These findings suffice to be regarded as novel knowledge because they may be used to inform areas to be targeted by professional development for both novice and experienced teachers.

The findings of the PCK test, which included 87 competent Physics teachers, may not be generalizable, but they may provide an argument that having qualified teachers teaching a discipline does not necessarily mean that they have developed adequate PCK in the discipline, therefore calls for regular measurement of PCK in different disciplines. Documenting the PCK of Physics teachers does not indicate how this PCK may affect learners' performance in Physics; therefore, additional research that records the PCK of Physics teachers and a test that explores learners' performance may be conducted to provide insights into the relationship between PCK and learners' performance. The study focused on qualified teachers and discovered that some components of PCK are underdeveloped. This calls for further investigation into what the teacher training curriculum contains, whether the curriculum completely develops the components of PCK or not and whether the pedagogies used by teacher educators to train teachers have any influence on the lack of PCK demonstrated by practicing teachers.

https://doi.org/10.33225/jbse/24.23.240

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Declaration of interest

The authors declare no competing interest.

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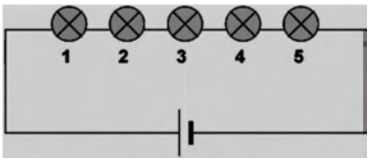
https://doi.org/10.33225/jbse/24.23.240

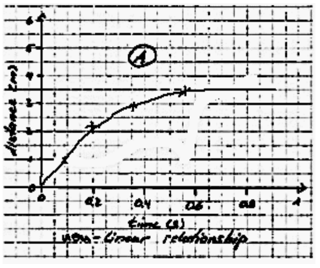
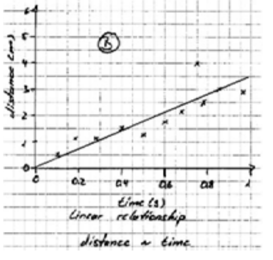
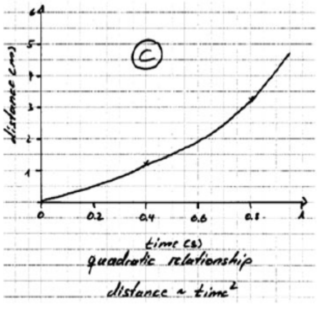
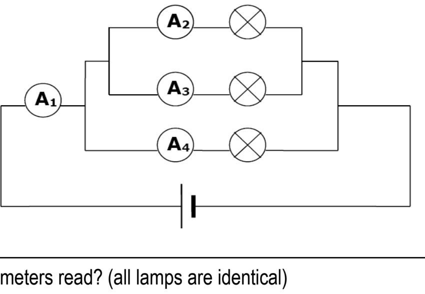
ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

APPENDIX A: DESCRIPTION OF THE PCK TEST ITEMS

Question		PCK Component	Adapted from
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.	Assessment knowledge: Knowledge of dimensions of science learning that are important to assess	Kirschner *et al.* (2016) Adapted
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 task above 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.	Knowledge of students: Knowledge of misconceptions and students' difficulty	Ergönenç, Neumann and Fischer (2018) Adapted
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 knowledge: Knowledge of dimensions of science learning that are important to assess	Kirschner *et al.* (2016) Adapted
3	Why do you use experiments in physics lessons? Please give at least three reasons.	Pedagogical Knowledge: Knowledge of instructional strategies and their advantages	Kirschner *et al.* (2016) Adopted
4	You would like to introduce the 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. 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. 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.	Pedagogical Knowledge: Knowledge of instructional strategies	Kirschner *et al.* (2016) Adopted
5	Force, Energy and Power are different, although related concepts		

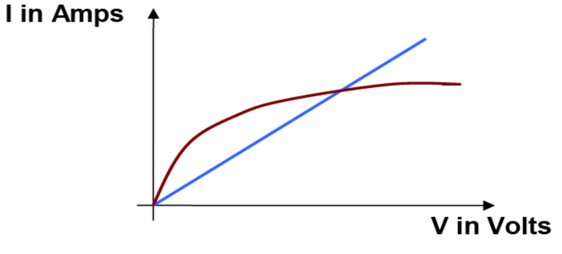
https://doi.org/10.33225/jbse/24.23.240

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Question		PCK Component	Adapted from
a)	Show the relationship between force and energy, force and power, power and energy. Use 100N and 100J, 100N and 100W and lastly 100J and 100W to provide examples which show these relationships.	Content Knowledge: Knowledge of subject matter	Kirschner *et al.* (2016) Adapted
b)	What makes it difficult for students to understand the concepts force, energy, and power? Explain giving at least three points.	Knowledge of students: Knowledge of students' difficulties	*Newly added*
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 relation 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.   	Content knowledge: Knowledge of subject matter	Kirschner *et al.* (2016) Adapted
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 A1 in the circuit below shows a current of 1.2 A. 		
a)	What do the other meters read? (all lamps are identical)	Content knowledge: Knowledge of the subject matter	Ergönenç, Neuman and Fischer (2018) *Adopted*

https://doi.org/10.33225/jbse/24.23.240

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Question		PCK Component	Adapted from
b)	One student gives the following answer: A2 reads 1.2A. A3 reads 1.2A. A4 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.	Knowledge of students: Knowledge of misconceptions	Ergönenç, Neuman and Fischer (2018) Adopted
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.	Knowledge of students: Knowledge of misconceptions	Kirschner *et al.* (2016) Adopted
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: Direction Force Calculations of speed and velocity	Knowledge of students: Knowledge of misconceptions	Kirschner *et al.* (2016) Adapted
10	What are the benefits of emphasizing units in physics lessons? Please explain, giving at least three points.	Knowledge of students: Knowledge of students' understanding of science	Kirschner *et al.* (2016) Adopted
11	When you enter one 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?	Curricular Knowledge: Knowledge of topics taught at a particular level.	Ergönenç, Neumann and Fischer (2018) Adopted
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.	Curricular knowledge: Knowledge of prior concepts.	Ergönenç, Neumann and Fischer (2014) Adapted

https://doi.org/10.33225/jbse/24.23.240

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

APPENDIX B:

PCK TEST RUBRIC
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 point: Undeveloped	2 points: Limited	3 points: 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 the bulbs.
- Resistance of bulb 1 is lower than the resistance of all other bulbs.
- Bulb 1 is near 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 point: Undeveloped	2 points: Limited	3 points: 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 point: Undeveloped	2 points: Limited	3 points: 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.

https://doi.org/10.33225/jbse/24.23.240

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

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
- 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 of data and data analysis
- Students practice handling of deviances/establish a relationship to 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 point: Undeveloped	2 points: Limited	3 points: 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 point: Undeveloped	2 points: Limited	3 points: 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 100N over a distance of 1m? Any example that would relate 100J and 100N 100J= 100N×1m Energy transfer of 100 J results when a force of 100 N is applied over a distance of 1m. 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 100W = $\frac{100N \times 1m}{1s}$ How much power would it take to lift a stone weighing 100N over a distance of 1m in 1 second? A force of 100N applied over a distance of 1m on an object for a period of 1 second produces 100W Or any example that can relate 100W to 100N.

Power and energy

Relationship Power = energy transferred per unit time When the rate of energy transfer is 100J/s, the power is 100W.	Example 100W = $\frac{100J}{1s}$ When Pule climbs up the hill, the energy transferred is 100J every second. Calculate Pule's power. Or any example relation 100W to 100J.

1 point: Undeveloped	2 points: Limited	3 points: 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.

https://doi.org/10.33225/jbse/24.23.240

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

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

Question 6

Expectations:

- Group: C

Group A, Incorrect because

- The graph shows that speed decreases as the object falls, which contradicts what actually happens, owtte.
- Group B, Incorrect because
- The graph shows the object moving with a constant speed, while in free fall the object accelerates, owtte.

1 point: Undeveloped	2 points: Limited	3 points: 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 point: Undeveloped	2 points: Limited	3 points: 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. owtte

Explanation

- Current is the same at all points of the circuit irrespective of the connection.
- The bulbs are identical and 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 point: Undeveloped	2 points: Limited	3 points: 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 point: Undeveloped	2 points: Limited	3 points: Intermediate	4 points: Developed
No answer or answers not related to lesson planning	One correct reason	Two correct reasons	Three correct reasons

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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*t
- Average speed and mean speed are the same

1 point: Undeveloped	2 points: Limited	3 points: 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 point: Undeveloped	2 points: Limited	3 points: 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 of current and voltage in ohmic and non-ohmic materials or
- Resistance of ohmic and non-ohmic materials
- V/I characteristic graphs for ohmic and non-ohmic materials

1 point: Undeveloped	2 points: Limited	3 points: Intermediate	4 points: Developed
No sub-topic given No content given Or Incorrect sub-topic and incorrect content	Sub-topic given and no content 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

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1 point: Undeveloped	2 points: Limited	3 points: 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

Received: *February 02, 2024* Revised: *February 23, 2024* Accepted: *March 18, 2024*

Cite as: Hlaela, N., & Jita, L. C. (2024). Examining physics teachers' domain-specific pedagogical content knowledge components in Lesotho secondary schools. *Journal of Baltic Science Education*, *23*(2), 240–259. https://doi.org/10.33225/jbse/24.23.240

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