European Journal of Science and Mathematics Education, 2026, **14**(1), 68-84
ISSN: 2301-251X (Online)

OPEN ACCESS

**Research Article**

# Exploring science teachers' pedagogical content knowledge based on instructional approaches used to teach force concepts

**'Maphole Marake [1*]**
0000-0002-6230-0960

**Loyiso Jita [1]**
0000-0001-6871-6820

**Maria Tsakeni [1]**
0000-0003-3208-1362

[1] University of the Free State, Bloemfontein, SOUTH AFRICA
[*] Corresponding author: mmaphole7@gmail.com

**Citation:** Marake, M., Jita, L., & Tsakeni, M. (2026). Exploring science teachers' pedagogical content knowledge based on instructional approaches used to teach force concepts. *European Journal of Science and Mathematics Education, 14*(1), 68-84. https://doi.org/10.30935/scimath/17624

**ARTICLE INFO**

Received: 11 Apr 2025
Accepted: 4 Nov 2025

**ABSTRACT**

Teachers use personal pedagogical content knowledge to filter instructional approaches when teaching topics such as force concepts. Understanding teachers' approaches when teaching is important because it provides a window into teachers' knowledge base. This interpretive, qualitative multiple-case study aims to understand three physics teachers' pedagogical content knowledge by examining their approaches to teaching force concepts. Data were collected through classroom observations, analysis of lesson plan books and post-observation interviews revealed that the teachers explained concepts with illustrations; described experiments and made demonstrations and teacher-dominated whole-class discussions. Although teachers' lesson plans didn't reveal pedagogical approaches, they demonstrated knowledge of science curriculum; how students understand science including instructional and assessment strategies. These findings imply that teachers' lack of reflection-on practice may result in low-quality instruction and low students' performance. It was concluded that teaching experience mediates teachers' knowledge of relevant examples, questions to ask and activities to do.

**Keywords:** physics, science teachers, pedagogical content knowledge, instructional approaches

## INTRODUCTION

Teachers' abilities and competences are crucial resources for student learning (Omoruan & Osadebe, 2020). Physics teachers are no exception because students perceive physics as difficult to understand, particularly the concepts of force (Liu & Fang, 2016). Students encounter force concepts in their everyday lives, and the conceptions they develop are mostly unscientific. This calls for teachers to possess competences to assist students develop scientific understanding of force concepts (Kirya et al., 2022), particularly because force concepts are foundational for understanding most physics topics, including electricity (Fulmer et al., 2014; Geelan, 2020). Moreover, when students are not helped to change non-scientific conceptions early in their schooling, it becomes difficult for them to understand advanced physics, mainly Newtonian mechanics and other science topics (Spatz et al., 2020).

The competences that teachers need to assist students develop scientific understanding include knowing how to sequence topics and concepts logically and using representations that are easily understood by students. Teachers should give students opportunities to experience the content and to judge whether they are satisfied with their preconceptions (Vosniadou, 2019). Notably, teachers should be cautious of how they approach teaching; that is, how they promote students' understanding, and they must ensure they encourage knowledge construction, not transmission.

Teaching approaches that physics teachers should use to teach concepts of force so that they are comprehensible to students include relating the concepts to students' everyday experiences (Maharaj-Sharma & Sharma, 2017). In addition, physics teachers should use approaches that expose students' preconceptions, that challenge non-scientific views and create an environment that enable students to willingly change their views to scientific conceptions (Bryce & MacMillan, 2005). For teachers to succeed in this enterprise, literature emphasizes that they should use student-centered approaches, most of which involve inquiry. According to Crawford (2007, p. 618), one of the aspects of inquiry teaching approaches "involves asking and answering a question and comparing the answer with what scientists already know about the world". However, science classrooms in Lesotho, and elsewhere, do not generally apply approaches that are student-centered, or promote knowledge construction (Qhobela & Moru, 2014; Silm et al., 2017), despite the Lesotho basic education curriculum policy (LBECP) (Lesotho Ministry of Education and Training, 2021) being explicit about the approaches to science teaching that teachers should adopt. The LBECP stipulates that student-centered approaches acknowledge that students are different, thus instruction should be thoroughly prepared to cater for learners' differences and facilitate knowledge creation not transfer.

Although the LBECP is clear about how pedagogical approaches to be adopted in schools, physics education in high schools in Lesotho does not seem to be meeting this standard. Anecdotal evidence supported by a study done by Blom et al. (2017), reports that science classrooms are still dominated by teacher-centered strategies.

A few studies have been conducted in Lesotho on topic-specific approaches to teaching physics. These include examining the feasibility of students' success when argumentation is used in teaching the topic of force (Qhobela, 2012), and an investigation into the impact of the factory of ideas (FOI) teaching approach to students' understanding of energy (Koma et al., 2021). The two studies used specific topics–force and energy, respectively–as contexts to study how specific instructional strategies influenced learning. In this study, the authors explored physics teachers' approaches when teaching the concepts of force with the purpose of understanding teachers' pedagogical content knowledge (PCK).

Examining the approaches used to teach specific physics topics is important, because it gives a window into teachers' PCK, particularly their personal pedagogical content knowledge (pPCK). The study aims to explore physics teachers PCK based on the instructional approaches they use when teaching force concepts. This is because understanding and revealing teachers' PCK is one of the essential elements of science education research, because a good grasp of PCK is essential for high quality instruction (Chan & Hume, 2019; Irmer et al., 2023). Of utmost importance are the elements of teachers' PCK–enacted and personal–that come to the fore during teaching. It is important to know teachers enacted pedagogical content knowledge (ePCK) and pPCK, because teachers generally work independently.

## LITERATURE REVIEW

### Teachers' Pedagogical Content Knowledge

The five components of science teachers' PCK, as advanced by Magnusson et al. (1999), constitutes science teachers' knowledge of the science curriculum, how students understand science (KSU), instructional strategies (KIS), assessment strategies (KA), and teaching orientations (TO). The way teachers integrate the PCK components during planning and teaching reveals both their ePCK and pPCK. Particularly, pPCK is the entire knowledge a teacher possesses and developed through teaching experience, students they taught and discussions they had with colleagues (Irmer et al., 2023). When confronted with a particular situation, during either planning or enactment, teachers draw what makes sense at that moment from their pPCK. Consequently, the PCK that is evident from a teacher's plans and during teaching gives a snapshot of their entire PCK.

Teachers have professional knowledge from which they draw during planning, teaching and reflecting and which, thus, guides their teaching practices. PCK is that form of professional knowledge that guides teachers in sequencing topics and concepts, selecting examples and representations and formulating explanations (Azam, 2020; Sakaria et al., 2023). To teach physics concepts such as force, teachers should have developed PCK, from which they draw when planning how to sequence concepts, and when they select examples, representations and activities.

Studies that explored the interplay among PCK components show that teaching approaches that science teachers use are related to their PCK. Soysal (2017) indicates that an experienced elementary science teacher's knowledge of students' understanding is central when making decisions; that is, when stating the purpose of teaching elementary science, the teacher referred to knowledge, skills and competences that students need to develop, hence, insinuating activities and strategies to use to develop them. Similarly, Aydin et al. (2017), as well as Park and Chen (2012), report that teacher observations and interviews revealed connections between other PCK components and knowledge of instructional strategies. Different from reported research findings that beginning teachers lack integrated PCK for specific topics, Sæleset and Friedrichsen (2021) presented contrasting findings that six pre-service teachers integrated both KSU and KIS at topic level. Rice and Kitchel (2016) point out that teachers' knowledge of content and students greatly informed how they broke down content knowledge to help students understand. While Sæleset and Friedrichsen (2021) explained that specialized science courses, personal learning experiences, peers and mentor teachers contributed to their knowledge and integration of the PCK components. Teachers with KSU, including their preconceptions, were likely to know which activities, questions, and representations to give when explaining force concepts, thus revealing a connection between PCK components, knowledge of students' understanding of science, and instructional strategies.

Studies that focused on force concepts mainly portray teachers' PCK. Loughran et al. (2012) portrayed physics teachers' PCK by compiling content representations (CoRes) and pedagogical and professional experiences repertoires (PaP-eRs). The CoRes and PaP-eRs helped reveal teachers' PCK by eliciting their thinking and knowledge of the subject matter that had to be taught, what students knew about force, what strategies to use, and why they use them, so that force concepts could be plausible and comprehensible to students. Azam (2020) used teachers' narratives of how they teach force and motion concepts as a way of accessing their personal PCK. The two studies used teachers' self-reports, in the form of answers to questions asked about the CoRe, and narratives provided about their practice. Researchers used this information to profile the teachers' PaR-eRs.

## Implementing Inquiry-Based Instruction

Force is an abstract concept (Bryce & McMillan, 2005) because only its effects can be observed, not the concept itself; therefore, it is difficult for most students at different levels of education to comprehend it. Consequently, inquiry-based approaches are said to be effective for advancing students' understanding. Literature is replete with studies that recommend the implementation of inquiry-based instruction in different subjects (Mataka & Taibu, 2020). For instance, Akçay and Doymuş (2012), Gurcay and Ferah (2017), Mataka and Taibu (2020) and Subramaniam et al. (2017) studied the effectiveness of different inquiry-based approaches, such as predict, observe, experiment, and apply, and the 5E learning cycle that entails engage, explore, explain, elaborate and evaluate. However, Sæleset and Friedrichsen (2021) explored how a first-year Chemistry teacher demonstrated responsiveness to students while maintaining a TO of inquiry-based instruction. In Lesotho, Qhobela (2012) investigated the use of argumentation when teaching physics in high schools in Lesotho, while Koma et al. (2021) investigated the extent to which the FOI teaching approach impacted students' understanding of energy. The studies found the use of inquiry-based approaches to be effective for increasing students' understanding. Nonetheless, research indicates that teachers are still not teaching through inquiry (Papaevripidou et al., 2017; Silm et al., 2017).

Regarding concepts of force, Bryce and McMillan (2005) used bridging analogies as inquiry-based approaches to assist students understand action and reaction forces. Furwati et al. (2017) used multiple representations as a strategy to improve students' understanding of Newton's laws, and the influence of the quality of representations when solving Newton's laws of motion. In both cases, using inquiry-based approaches improved students' understanding. Thus, studies advance the notion that inquiry-based approaches are effective in promoting students' comprehension of force concepts.

Nonetheless, myriad factors seem to hinder the implementation of inquiry-based approaches. Particularly, inquiry-based learning requires both teachers and students to exert effort and training students to make them aware of the methodology (Khalaf & Zin, 2018). Teachers find training students about inquiry-based learning to be challenging, because teachers lack knowledge and understanding of the strategy (Papaevripidou et al., 2017). Furthermore, lack of resources and the teachers' personal choices to use teacher-centred approaches also exacerbate the neglect of inquiry-based approaches in science classrooms (Silm et al., 2017).

As evidenced in the ongoing discussion, research focusing on physics teachers approaches highlighted strategies such as bridging analogies (Bryce & McMillan, 2005) and multiple representations (Furwati et al., 2017). In Lesotho, argumentation (Qhobela, 2012) and FOI (Koma et al., 2021) were investigated. The reviewed literature shows that research is selective of strategies to focus on. On the contrary, this study aims to explore in entirety the approaches that physics teachers use when teaching force concepts. The rationale for this approach is to find out in total how teachers approach the topic so that a wholistic picture of their practices regarding the topic of fore concepts.

## RESEARCH AIMS AND RESEARCH QUESTIONS

This study examined the nature of physics teachers' approaches during teaching of the concepts of force, with the purpose of understanding their PCK. This study is significant because it focuses on teacher activities before and during instruction, therefore, providing insights into what informs their actions in class. The study, therefore, sought answers to the following questions:

1. What instructional approaches do teachers use to teach force concepts in grade 11 classrooms?
2. How do teachers use pPCK to teach force concepts in grade 11 classrooms?

## METHODOLOGY

### Research Design

The study was conducted in the context of three grade 11 physics classrooms in Lesotho during the teaching of the topic of forces. Qualitative multi-case study underpinned by the interpretive paradigm (Cohen et al., 2018) was used. Interpretive studies allow researchers to purposely and conveniently select participants, and the aim is to undertake in-depth analysis and make meaning out of textual data that is collected (Cohen et al., 2018). The research design enabled the researchers to conduct an in-depth study of three participants' instructional strategies, to gain understanding of their PCK.

### Participants

Three teachers, one with a Bachelor of Science in education (BSc Ed) (mathematics and physics), one with a Bachelor of Science (BSc) and a postgraduate diploma in education (mathematics, computer science, and physics) and one with a BSc in applied chemistry and physics, constitute the multiple case study. The teachers were located at different schools in Lesotho. The participants were purposely selected because they had majored in physics during tertiary education, and they were teaching grade 11 physics (Creswell, 2012). Convenience sampling was also used, because the researcher who was collecting data wanted to collect data at all the schools on the same day. The accessibility of the schools was important, because the topic, concepts of force, was taught at the same time at schools. Consequently, if the schools were located very far from each other, it would have been a challenge to conduct classroom observations. The participants gave consent to participate in the study and they were informed that they were free to cease participation at any stage should they feel no more comfortable. **Table 1** provides a summary of the demographic data of participants.

### Instruments and Data Collection

The teachers were observed five times each while teaching the topic, concepts of force. A semi-structured observation protocol was used to capture the teachers' and students' actions during the lessons, including how and what they did when introducing the lesson, how students' difficulties were addressed, concepts explained, and students' questions responded to, as well as the activities teachers assigned students.

**Table 1.** Demographic data of teachers

| Teacher | Gender | Qualification | Subjects majored in | Teaching experience | Class size | Teaching load/ periods per week |
|---|---|---|---|---|---|---|
| Mr. L | Male | BSc Ed | Mathematics and physics | 1 year | 50 | 35 |
| Mr. C | Male | BSc and postgraduate diploma in education | Mathematics, computer science, and physics | 10 years | 48 | 30 |
| Mr. M | Male | BSc in chemical technology | Applied chemistry and physics | 9 years | 25 | 32 |

**Table 2.** Lesson plan analysis protocol

| Aspects analyzed | Lesson plan |
|---|---|
| Objectives | Are they short, measurable, achievable, realistic and time bound? |
| Skills | Which skills are teachers planning to develop? |
| Activities | Which activities do teachers plan to give students? (hands-on, discussions, demonstrations, written, notes taking, etc.) |
| Assessment | What do teachers plan to assess? Which assessment methods are they planning to use? |

**Table 3.** Categories of teacher practices (adopted from Dancy & Henderson, 2007)

| Categories of teacher practices | Practices consistent with traditional instruction | Practices consistent with alternative instruction |
|---|---|---|
| Interactivity | One-sided discourse, passive | Conversation, active students |
| Instructional decisions | Decisions made by teacher | Decisions shared by teacher and students |
| Knowledge source | Students receive expert knowledge | Students develop own knowledge |

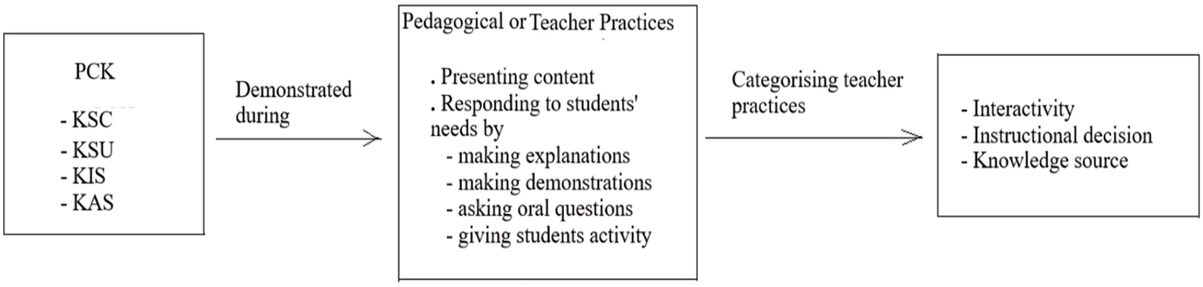


**Figure 1.** Summary of how teacher practices reflect levels of PCK (Source: Author's own conceptualization synthesized from literature review)

Document analysis was also used to collect data; before each lesson observation, the lesson plan was collected for analysis, to understand the knowledge bases, as shown in **Table 2**, that were referenced when teachers planned their lessons. After the lesson observations, the teachers were interviewed, to gain an understanding of their practice and rationales for the decisions they made. The classroom observations and interviews were audio recorded, and the researcher wrote notes during observations, to document teacher actions that could not be captured by audio.

## Data Analysis

After each classroom observation, the researcher listened to the audio recordings to get the whole picture of the lesson, after which the recordings were transcribed verbatim. The same was done with the interview recordings. The researcher read the transcripts of classroom observations for understanding, and to identify PCK episodes as defined by Park and Oliver (2008). The PCK episodes included incidents of teachers responding to students' difficulties, explaining concepts, and applying inquiry-based strategies, such as conducting experiments. For each PCK episode, the researcher asked the following questions: *What did the teacher do*? *Why did he do it*? *What does the teacher know*?

To categorize the teachers' practices, a framework for articulating practices suggested by Dancy and Henderson (2007) was used (**Table 3**). The framework has ten categories of practices; however, in this study, only the first three categories–interactivity, instructional decisions and knowledge sources–were used. **Figure 1** shows how the instructional approaches reflect teachers' PCK.

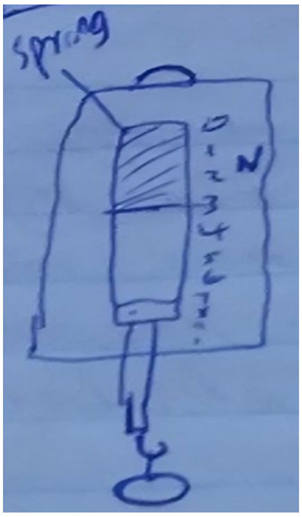


**Figure 2.** Illustration of spring balance by Mr. L (Source: Author's collected data)

## FINDINGS OF THE STUDY

The demographic data of the participating teachers is presented in **Table 1**. The three participants were, coincidentally, all males. Each one of them studied physics at BSc level and had teaching qualifications. The findings of the study are presented under three major themes, namely, pedagogical approach practices, evidence of pedagogical approaches in lesson plans, and the salient aspects of teachers' pPCK.

### Pedagogical Approach Practices

The pedagogical approaches that teachers used when teaching force concepts comprised teacher explanations that used illustrations, experiments and demonstrations done by the teacher, as well as questioning techniques that lead to discussions.

#### *Explanations using illustrations*

There were differences and similarities regarding how the teachers explained force concepts. Nonetheless, all three teachers explained with the aid of illustrations. Mr. C explained that frictional force is not applied only when there is motion, in this way:

> You specified that for force of friction to be applied, objects should be moving in opposite directions, so if we have frictional force between the box pushed across the desk that is stationary and the box is moving, do we have frictional force in that case? Ok let's do it when you have this book on the desk and you tilt this desk, will the book slide? (*teacher tilts the desk*).

Mr. M reinforced his explanation of air resistance by releasing a piece of paper from his hand, and saying,

> If I take this piece of paper and let it fall (*releases it*), did you observe it as it changed direction? Air particles collide with this paper. These air particles are resisting the downward motion of paper.

Mr. L clarified his explanations with illustrations, as evidenced in his explanation of resultant force:

> Let's say we have objects like this (*draws*) in which 20 N and 30 N forces are applied to the object in the same direction (*draws a small rectangle with two arrows of different lengths, shorter one 20 N longer one 30 N facing same direction*). What is the resultant force acting upon that block?

The excerpts indicate that all three teachers explained concepts verbally and reinforced their explanation with illustrations, in the form of either a demonstration, diagram, or mathematically. Analysis of Mr. L's lesson plans revealed that he had planned some of the illustrations he made to clarify his explanations. For instance, when planning to teach about weight, he had made a diagram in his lesson plan, illustrating how to measure weight with a spring balance as shown in **Figure 2**.

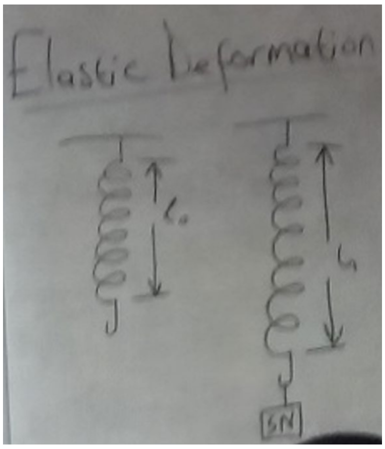


**Figure 3.** Illustration of extension of a spring (Source: Author's collected data)

Of importance to note is that the length and logic of the explanations of the three teachers differed. The excerpts report the explanations of the teachers:

> When you look at the surface area of contact of the duster and paper you will see that the paper has more surface area than the duster. But when you compare their weights, the paper is way too light. The surface area is small (duster) but the weight is large when you compare it with this one (paper). Since weight of paper is small, air resistance easily stops it from going down. Weight is small, as it falls through air, this is going to happen, right? (Mr. C).

> Inertia is the resistance of the object to change in motion, like that one of a car, when people are moving in a car, we said they gain the speed of the car. When the car suddenly stops, they resist the change in the motion, that is why they have that forward movement. So, inertia means resistance to change the state of motion (Mr. L).

> When rubber band is released, it returns to its original length. When elastic material is stretched or released the force that it returns with is called elastic force. For example, when you stretch a rubber band in a catapult, the rubber is going to push the stone. The force that the rubber is using to push the stone is called elastic force. But when that elastic material is stretched, it only possesses elastic potential energy, it has energy only (Mr. M).

Analysis of the excerpts indicate that Mr. C's explanation was more logical; he explained step by step why a duster will reach the ground before a sheet of paper released from the same height. In contrast, Mr. L and Mr. M gave brief explanations, and did not provide justification for the claims they made. Furthermore, Mr. M provided a great deal of information that may end up confusing the students. It can, therefore, be concluded that Mr. C was clearer and more logical than the other two.

### *Experiments and demonstrations*

Interestingly, all three teachers merely described how to perform experiments, even though materials that could be used to illustrate were available. When teaching about elastic deformation and, consequently, Hooke's law, Mr. C explained the experiment and demonstrated it with diagrams (**Figure 3**). This is what he said and did:

> We are supposed to do this in the lab, but unfortunately, we don't have the springs and the weights. We will just discuss whatever happens on the board (*draws a spring and labels it $l_o$*). So, we have this spring with its length as $l_o$, its normal length when there is no weight. The expectation is that if you hang an object on that spring, you are expecting it to extend.

Similarly, Mr. L described the experiment to illustrate elastic deformation this way:

> Mr. L: What happens to the spring when stretched? Maybe you fix the spring on one end and suspend a weight on the other end, what happens?
>
> Student: It stretches.
>
> Mr. L: What happens when you remove the weight?
>
> Student: It goes back to its original shape.
>
> Mr. L: When you hang a load from the spring (*draws a load at the end of the spring*), this is the length of the spring, before we hang a load.

Although the school science laboratory was equipped with springs and metal discs of different masses, Mr. M described how to perform the experiment to illustrate elastic deformation and, thereafter, asked students to perform the experiment. This is what transpired in the lesson:

> We are going to determine the extension caused by different forces applied on an elastic material; we are going to use a spring. We are going to attach a spring on a fixed point, a retort stand in our case, then hang the spring on the stand (*shows with a diagram*). Measure the original length of the spring. We measure the part of the spring which extends, not the hanger (*demonstrates with a diagram*), this is our original length. Afterwards I will supply you with objects of different masses which you are going to hang on the spring ...

As the excerpt shows, the teacher described how to perform the experiment. Mr. M did not have written lesson plan for this lesson, as a result, it could not be established whether he had planned for it to proceed in this way.

After explaining how to conduct the experiment, Mr. M gave students the opportunity to conduct the experiment. However, he provided the procedure and the materials to be used.

> OK, a simple demonstration (*suspends a spring on the retort stand and suspends a mass*). So, this object pulls the spring and increases its lengths, the weight of this object hanging on the spring is the force which pulls the spring...after hanging this we measure the new length of the spring, then you increase the mass, say to 100 g, and then measure the length of the spring. So, this is the table on which you are going to record your results (*draws the table*). So, this is our table here you write these masses that I am going to give you, that is, 50 g, 100 g, 200 g, 300 g, 400, 750 g.

Analysis of the excerpt reveals that Mr. M provided students with the procedure, explanations of why the spring stretches, and the variables to measure. In short, students' task was to remember what the teacher told them and reproduce it by following the steps provided.

### *Questioning techniques leading to class discussions*

All three teachers initiated whole-class discussions by asking questions–mostly low-order. For instance, Mr. C asked, "w*hat is force*?" and "*what are the things that affect air resistance?*" while Mr. M asked, "*does force have any effect on the motion of object?*" In contrast to Mr. M, Mr. C occasionally followed up with questions requiring deeper thinking, such as, "*Is it in all cases that we have a push or pull when force is applied*?", after which he probed students' answers and did demonstrations to clarify his questions. Mr. C, therefore, attempted to help students reach the level of thinking that he wanted them to attain. Similarly, Mr. L made deliberate efforts to ask thought-provoking questions, such as "*What do you think causes people in the car moving at very high speed to move forward when the car suddenly stops*?"

The discussions in Mr. L's class followed the following pattern:

> Mr. L: We are going to talk about the effects of force on an object (*writes on the chalkboard*). How do you think force can affect the object?

Student 1: I think it can change the speed of an object.

Mr. L: Give me examples where force can change the speed of an object.

Student 1: When the box is pushed across the room, frictional force is going to change the speed of that object.

Mr. L: Very good, force of friction can change the speed of an object by decreasing it … How can force change the speed of an object? You said it can change the speed of an object; how else can it affect it?

Analysis of the flow of Mr. L's discussion reveals that he accepted a student's response without giving others the opportunity to express themselves. He concluded the discussion by evaluating the correctness of the student's responses.

The pattern of Mr. M's discussion resembles that of Mr. L, as shown by the following excerpt.

Mr. M: What about direction, you need to explain how direction is an effect?

Student 1: It changes direction of moving objects.

Mr. M: Force changes the direction of moving object, even stationary object, it can still change direction. Since we are concentrating on motion, we say it can change the direction of motion of a moving object. Let us suppose that someone is kicking a soccer ball. That ball is in motion, it is moving towards me. As it moves towards me, I kick it in a different direction (*demonstrates with a duster*).

Mr. M channeled the discussion as if he did not want students to come up with responses outside what he anticipated, by saying, for instance, "*force has different effects on objects, but here we have to concentrate on motion*." When students grasped the direction they had to take, he then accepted one-word answers, and then provided the explanation.

In contrast to his counterparts, whose discussions resembled a recitation of facts, there were many occasions when Mr. C's students asked questions to seek clarification, such as, "*when riding on a donkey my feet are not in contact with the floor, does inertia apply there?"*. In addition, he created an environment for students to voice their views regarding what they were discussing. When they were distinguishing between mass and weight, one student asked, "S*ir, I don't understand, in hospitals, they usually say go and measure weight. That is why I was saying it [bathroom scale] measures weight*".

Mr. C's class discussions seemed to involve a mix of teacher-dominated and student-dominated discussions. He engaged his students in arguments during discussions of concepts they had learned previously, such as when he revised types of force. This was evident when he assisted students to construct a conceptual understanding of force. After students had claimed that the word "twist" should be included in the definition, he asked them to justify why that should be so:

Mr. C: Should we add that force is a push, a pull and a twist, or those two are enough?

Student 1: I think a twist is one type of force.

Mr. C: Let's get this straight, will this twist add to these two or is it on its own?

Student 1: Sir, I think we should add twist because when we twist we apply force, that is when we twist the shape of the object is going to change because when we apply force on the object, shape changes so when we twist the shape of the object will change.

Student 2: I think twist is still a push because by twisting you are pushing two parts of the same object in opposite directions.

**Table 4.** Sample of Mr. L's lesson plan

| Teacher activities | Student activities | Assessment criteria (what to assess) | Assessment method (how to assess) |
|---|---|---|---|
| 1. Ask learners what elastic and plastic materials are | Give their opinions to the teacher's question | Elastic and plastic material | Discussion |

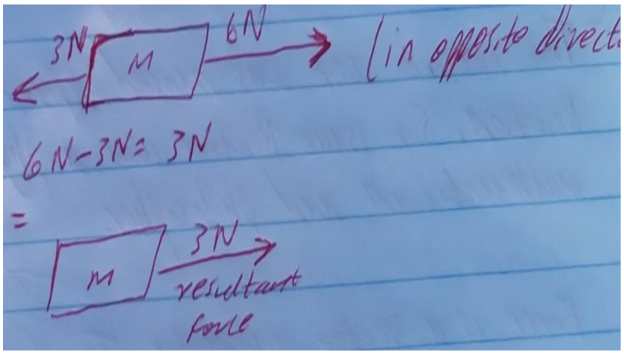


**Figure 4.** Illustration of resultant force by Mr. L (Source: Author's collected data)

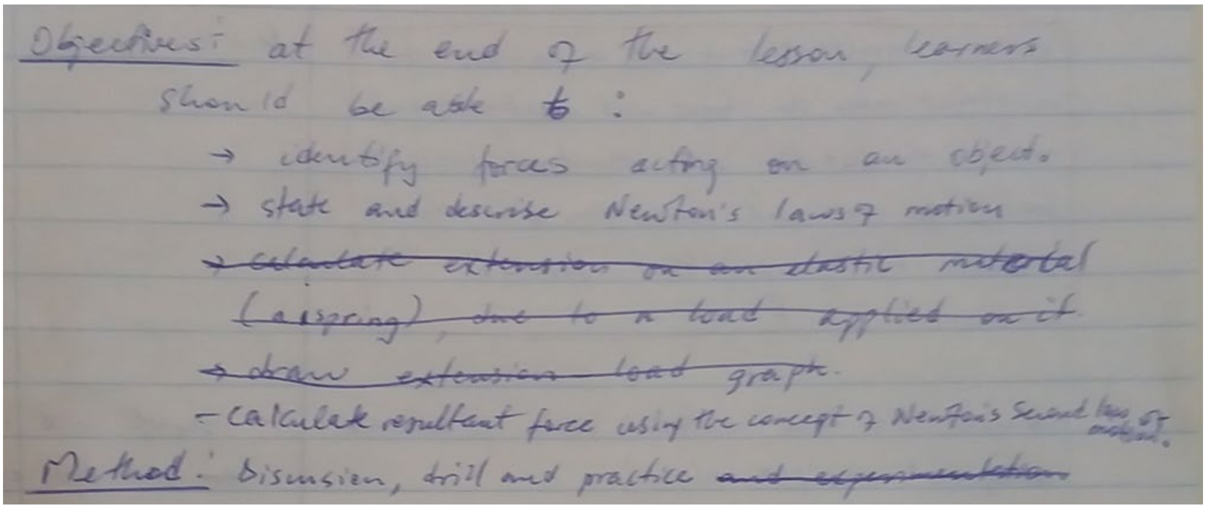


**Figure 5.** Extract of Mr. M's lesson plan (Source: Author's collected data)

## Evidence of Pedagogical Approaches in Lesson Plans

Only two teachers, Mr. L and Mr. M, had written lesson plans. However, both did not have lesson plans for all lessons. In some cases teachers had notes and diagrams. **Table 4** is an example of Mr. L's lesson plan, and **Figure 4** is an extract of Mr. M's lesson plan.

A closer look at **Table 4** shows that Mr. L planned the classroom activities and the assessment before going to class. The pedagogical approach that he seemed to plan, albeit not explicit, is discussion. He stated that he planned to ask students to differentiate between two concepts, without listing the actual questions he would use. Furthermore, Mr. L's lesson plan book had areas where he had prepared notes. It was where he had prepared how to illustrate resultant forces.

**Figure 5** shows an extract of Mr. M's lesson plan. The extract shows that Mr. M planned to use discussion, drill, and practice. However, Mr. M's lesson plan was sketchy, and lacked a professional appearance, as there were cancelling and unfilled sections.

In contrast to his counterparts, Mr. C did not have written lesson plans. When asked to explain how he planned, this is what he said:

> Preparing for classes, reflecting after class, I have done them and I have seen that it is very important for me to go to class knowing what I am going to do. But I don't do preparations, the written ones. I plan I just don't write this plan down. I read.

Mr. C agreed that it is important to have lesson plans before presenting the lesson. Nonetheless, he acknowledged that, as his career progressed, he stopped writing the plans down. He reported that his planning constituted reading through the subject matter he intended his students to learn. It is worth noting that Mr. C recognized the importance of planning, and that he admitted that it gave him the opportunity to reflect on previous lessons.

## Salient Aspects of Teachers' pPCK

This section presents the reservoir of the components of the knowledge bases teachers seemed to draw from when teaching. These make up four categories, which are knowledge of the curriculum, knowledge of learners, knowledge of instructional strategies, and knowledge of assessment. The study design did not include data on teacher content knowledge.

### *Knowledge of the science curriculum*

Knowing the goals and purposes of teaching in the school science curriculum is an aspect of science teachers' PCK, particularly their pPCK. The following are what the teachers said about the purposes of teaching force to grade 11 students.

> Mr. C: Students should know about friction and air resistance. When they see a parachute, they should know what is happening. We are teaching them to be pilots. They should know why the plane is like that, why it is designed that way.

> Mr. L: … most of the things that happen around us is because of force, like walking. So, when students know this, they are able to explain why we are able to walk.

> Mr. M: … to help students develop the concept of force which can help them even in tertiary education, even as they pursue science related careers, they need to have the foundation.

The three teachers seemed to pursue the same purpose in teaching concepts of force, which was to help students understand natural phenomena. Additionally, Mr. M's purpose was to help students acquire knowledge they will need when they continue with their education. In all cases, the teachers' purposes seemed to align with the purposes of the physical science syllabus (Examinations Council of Lesotho, 2020, p. 4), which is to enable candidates to acquire sufficient understanding and knowledge to

(1) become confident citizens in a technological world and to take or develop an informed interest in scientific matters

(2) be suitably prepared for studies beyond the LGCSE level in pure sciences or in science-dependent vocational courses.

During teaching, an alignment was observed between the teachers' purposes and their teaching, thus, revealing that they drew from their pPCK. This was evidenced when teachers referred to real-life examples and when providing explanations.

### *Knowledge of how students understand science*

Teachers' knowledge of the difficulties that students experience when learning concepts, such as force concepts, is indicative of teachers' pPCK. The three teachers explained that students encounter difficulties in understanding force concepts. Mr. C said,

> "problem is with terminal velocity because when saying it is when the air resistance balances with the weight it's not easy for them…"

Mr. L highlighted that

> "most people believe that for force to occur, objects must be in contact physically,"

similarly, Mr. M explained that

> "most of the learners have problems identifying the forces."

The excerpts indicate that, although all three teachers were informed by the knowledge of how students understand force concepts, each of them had their own personal understanding of what students found difficult, hence, they had different pPCK. The teachers, therefore, drew from their pPCK and explained force by referring to real-life examples: *behavior of passengers in a moving vehicle when it suddenly stops; the feel of upward force when one pushes hand in water.* In this way, they assisted students to relate what they were learning to what they already knew. Moreover, teachers used different representations, such as *diagrams, demonstrations, numbers and gestures*. This was taken as an indication that the teachers knew that students differed intellectually. Moreover, Mr. L's objectives reported that knowledge of students' differences informed his planning.

### *Knowledge of instructional and assessment strategies*

Knowledge of pedagogy itself, particularly knowledge of content-specific instructional and KA, is indicative of teachers' pPCK. Mr. M's lesson plans and notes, as well as the teaching and learning in the classrooms of all three teachers, revealed that they know representations of force concepts. The teachers' knowledge of instructional strategies was evident in their various representations and demonstrations and their ways of describing experiments and concretizing abstract concepts. Moreover, they varied their pedagogical approaches, such as whole-class discussions, lecturing, questioning and experimentation. They coupled the different strategies with thought-provoking questions, as was the case in Mr. C's classroom.

## DISCUSSION

This study examined the nature of physics teachers' approaches when teaching concepts of force, with the purpose of understanding their PCK. Unlike most studies that examine science teachers' instructional approaches that focus on a particular approach (Hoffenberg & Saxton, 2015; Koma et al, 2021; Qhobela, 2012), this study explored, in totality, the approaches that physics teachers use when teaching concepts of force. Specifically, the study was guided by two research questions: what instructional approaches do teachers use when teaching force concepts in grade 11? and how do teachers use their personal PCK to teach force concepts in grade 11? It was found that teachers used a variety of pedagogical approaches such as providing explanations with illustrations as well as demonstrations and experiments and asking questions that led to class discussions. The results led to promising results which advance related literature. The key findings are discussed based on the two research questions.

### What Instructional Approaches Do Teachers Use to Teach Force Concepts in Grade 11 Classrooms?

The results show that all three teachers constructed explanations as a strategy to teach force concepts. The teachers helped students understand the concepts of force by constructing verbal explanations and reinforced them with illustrations in the form of diagrams and demonstrations. Constructing explanations is a scientific knowledge and skill that all students learning science should develop. However, the teachers did not teach students how to construct explanations. Teaching students to construct explanations comprises teachers; defining; making the rationale for scientific explanations; and modelling and connecting them to every-day explanations (McNeill & Krajcik, 2008). Given that there were no incidents where teachers explicitly taught students how to make explanations mean that they held traditional beliefs about physics and teaching. This is because Mulhall and Gunstone (2008) emphasize that teachers who hold traditional beliefs about physics focus on explanations using formulas while paying little or no attention to students' conceptual understanding. While those who held conceptual views encourage students to make their reasoning explicit and create situations where students improve with input from other students' not from teacher. Therefore, the three teachers in this study could be viewed as holding traditional beliefs, although they may not be on the same point on the continuum.

Moreover, the nature of the explanations was consistent with the features of explanations as presented by Geelan (2020). Similarly to the findings of Cabello et al. (2019), the teachers' explanations were clarified by demonstrations with readily available materials such as pieces of paper, duster and students' desks. To further make the concepts more explicit, teachers referred to students' real-life experiences such as riding in a speeding car. The results support those of Irmak and Yılmaz Ergül (2024) who reviewed literature about instructional approaches used by physics teachers and found hands-on activities, think-pair-share, practical reasoning explanations and discussion as dominant instructional approaches to teaching physics. However, in this study, teachers were the ones who did most of the hands-on activities through demonstrations and illustrations with either pictures or mathematically. This suggests that teachers had limitations regarding how to actively engage students in constructing own understanding.

All but one teacher did not do experiments. The teacher whose students did an experiment told students what to investigate, provided the materials they had to use, and told them how to conduct the experiment, and what variables to measure and manipulate. Thus, the experiment was meant to confirm what students had been taught (Tsakeni, 2019). Perhaps the unavailability or limited number of laboratory materials, as well as time constraints, could be the reason why the teachers' pedagogical practices were not fully inquiry-based (Silm et al., 2017).

Furthermore, the teacher never engaged his students in inquiry-based learning when constructing explanations, it can be concluded that the teacher's PCK to implement inquiry was very limited. As explained by Tsakeni (2019), it is not fair to expect teachers who have not experienced inquiry to be able to teach through inquiry. To address this challenge, in-service science teachers should participate in professional development activities aimed at helping them teach through inquiry. To avert problems related to the availability of science materials and equipment, teachers should use technology, such as simulation, as a means of enhancing inquiry learning.

Although all three teachers used similar strategies, there were differences in how they enacted them. The approaches represented the entire spectrum of practice, from traditional lecture-driven lessons to open-ended inquiry (Clores & España, 2023; Crawford, 2007). In general, the teachers' approaches can be characterized as inquiry, however, two of the three teachers used the strategies in a more traditional and lecture-driven manner. In agreement with Döş et al. (2016), two teachers mostly asked closed-ended questions that did not provoke thinking and to give detailed explanations to promote students' understanding. As a result, the teachers were the ones who provided most of the information during explanations, instead of their students.

### How Do Teachers Use pPCK to Teach Force Concepts in Grade 11 Classrooms?

Although the strategies that all three teachers used could be categorized as inquiry, the way teachers enacted them did not have aspects of inquiry. This is because in most of the activities, students were not actively engaged. They contributed minimally when developing explanations, designing and performing experiments as well as performing demonstrations. Teachers were more active than the students as they did almost all activities. That the teachers involved students minimally could be due to various factors, such as limited PCK to enact inquiry-based strategies, beliefs about teaching and learning science, personal choice, or limitations on time (Papaevripidou et al., 2017). This is because inquiry-based instruction requires teachers to design activities where students connect observations and theory (Wagner et al., 2020).

Moreover, the teachers did not write lesson plans before teaching. One teacher explained that he planned by deciding on the concepts and/or subject matter to teach, and how to sequence it. The other teacher had written lesson plans for some of the lessons, although they were sketchy and did not reflect pedagogical reasoning they engaged in. The last teacher had notes and representations in the form of illustrations in the book that he referred to as lesson plan book. It was therefore concluded that the teachers did not plan the activities they did during the lessons, as there was no evidence of planning in the lesson plan books. Rather, what teachers did were a result of in-the-moment actions or responses to address classroom situations, an indication of well-established PCK (Carpendale & Hume, 2019). This was an interesting finding, because, on the one hand, it could mean that the teachers had rich PCK and pPCK because they were able to respond to students' needs by easily drawing from a repertoire of demonstrations and examples without having had to plan what might be difficult for students and, thus, how they would help students should the problem come up during the lesson (Morris, 2024). But the teachers' responsiveness to students' needs was high yet enactment of strategies did not seem to indicate that they know how students learn is a point for concern.

Absence of lesson plans could mean that the teachers' lesson planning competency level was low (Süral, 2019); that is, the teachers lacked the skills and knowledge to develop lesson plans that incorporated important aspects of learning. When teachers do not take the time to reflect on instruction during lesson planning, they deprive themselves and students of opportunities to design interesting and thought-provoking activities that have the potential to advance learning and PCK. Furthermore, lack of planning of instructional activities may result in giving students activities that do not necessarily address the intended purpose thus resulting in students developing misconceptions (Lestari et al., 2019).

As explained that the teachers' lesson plans were not informative, it was not easy to approximate teachers' pPCK for planning. During teaching, teachers drew from their pPCK and enacted it in response to classroom events (Carlson & Daehler, 2019). This finding suggests that by failing to allot time to plan, which is an opportunity for reflection-on the lesson and thus improve teaching, the teachers were deprived of the opportunity to develop pPCK. Carlson and Daehler (2019) explain that, during planning, teachers contextualize the collective PCK to align with their school, classroom and students' contexts.

## CONCLUSION AND IMPLICATIONS/RECOMMENDATIONS

This paper explored the pedagogical approaches that three physics teachers used when planning for and during teaching force concepts, to understand their pPCK. The paper reports that lesson plans did not provide information regarding knowledge bases that the teachers drew from, including their pPCK. However, during teaching, the teachers' pedagogical approaches seemed to reveal some elements of inquiry-based teaching. Of importance to note is that, on the inquiry-based spectrum, their approaches were inclined more towards traditional lectures. It can, therefore, be concluded that teachers did not afford themselves opportunities to develop their pPCK, by not dedicating enough time and effort to reflect on teaching during the planning phase of professional practice. Consequently, even the teacher who seemed capable of enacting inquiry-based approaches did not do so, because he did not dedicate time and effort to thinking about the pedagogical approaches to use; instead, he focused on the content he had to deliver. For teachers to develop pPCK, they should reflect on their teaching practice by participating in completing research-based tools, such as CoRes, and engage in professional development activities, such as lesson study. Since writing lesson plans seems to be a daunting job for teachers, we, therefore, recommend that

(1) future studies should ask teachers to articulate how they plan and map their pPCK and

(2) that opportunities be created for teachers at different schools to interact, with the purpose of enabling knowledge transfer and developing pPCK.

This study has potential limitations; however, the main one is the small sample size. The number of physical science teachers was very small as only three teachers participated in the study. Three teachers are not representative of the whole population of physical science teachers in Lesotho; therefore, the findings of this study cannot be generalized to other physical science teachers although they may apply to them. It is therefore recommended that a large study be done to establish if these results are applicable to the population of physical science teachers.

**Author contributions: MM:** conceptualization, writing – original draft, data curation, formal analysis; **LJ & MT:** conceptualization, writing – review & editing. All authors approved the final version of the article.

**Funding:** The authors received no financial support for the research and/or authorship of this article.

**Acknowledgments:** The authors would like to thank the SANRAL Chair. The authors would also like to thank the Ministry of Education and Training, school principals, and teachers who generously allowed them into their schools and classrooms and gave us time and insights.

**Ethics declaration:** This study is extracted from a PhD thesis which was approved by the ethics committee (UFS-HSD2018/1115) at the University of the Free State on 23 August 2018. All participants were informed about the research aim and the permission for data collection were requested and granted by the Ministry of Education and Training. To ensure participants' anonymity, pseudonyms were used. All data were placed in a safe place where they were accessed only by the authors.

**Declaration of interest:** The authors declared no competing interest.

**Data availability:** Data generated or analyzed during this study are available from the authors on request.

## REFERENCES

Akçay, N. O., & Doymuş K. (2012). The effects of group investigation and cooperative learning techniques applied in teaching force and motion subjects on students' academic achievements. *Journal of Educational Science Research, 2*(1), 109-123.

Aydin, S., Demirdöğen, B., Akin, F. N., Uzuntiryaki-Kondakci, E., & Tarkin, A. (2017). The nature and development of interaction among components of pedagogical content knowledge in practicum. *Teaching and Teacher Education, 46*, 37-50. https://doi.org/10.1016/j.tate.2014.10.008

Azam, S. (2000). Locating personal pedagogical content knowledge of science teachers within stories of teaching force and motion. *Eurasia Journal of Mathematics Science and Technology Education, 16*(12), Article em1907. https://doi.org/10.29333/ejmste/8941

Blom, A., Cao, X., Rasolonjatovo, A. H. D, & Kola-Edun, J. T. (2017). Job-ready graduates of secondary education in Botswana, Lesotho and Zambia: Reforming instruction, curriculum, assessment, and structure to teach vocational and 21st century skills: Conference version. *World Bank Group*. http://documents.worldbank.org/curated/en/297731506359700310/

Bryce, T., & MacMillan, K. 2005). Encouraging conceptual change: The use of bridging analogies in the teaching of action-reaction forces and the "at rest" condition in physics. *International Journal of Science Education, 27*(6), 737-763. https://doi.org/10.1080/09500690500038132

Cabello, V. M., Real, C., & Impedovo, M. A. (2019). Explanations in STEM areas: An analysis of representations through language in teacher education. *Research in Science Education, 49*, 1087-1106. https://doi.org/10.1007/s11165-019-9856-6

Carlson, J. K., & Daehler, R. (2019). The refined consensus model of pedagogical content knowledge in science education. In A. Hume, R. Cooper, & A. Borowski (Eds.), *Repositioning PCK in teachers' professional knowledge* (pp. 77-92). Springer. https://doi.org/10.1007/978-981-13-5898-2_2

Carpendale, J., & Hume, A. (2019). Investigating practising science teachers' pPCK and ePCK development as a result of collaborative CoRe design. In A. Hume, R. Cooper, & A. Borowski (Eds.), *Repositioning PCK in teachers' professional knowledge* (pp. 77-92). Springer. https://doi.org/10.1007/978-981-13-5898-2_10

Chan, K. K. H., & Hume, A. (2019). Towards a consensus model: Literature review of how science teachers' pedagogical content knowledge is investigated. In A. Hume, R. Cooper, & A. Borowski (Eds.), *Repositioning PCK in teachers' professional knowledge* (pp. 3-76). Springer. https://doi.org/10.1007/978-981-13-5898-2_1

Clores, L. J., & España, R. C. N. (2023). Assessment of teachers' instructional practices: Towards proposing an innovative instructional model for teaching learning material in chemistry. *Journal of Practical Studies in Education, 4*(4), 1-19. https://doi.org/10.46809/jpse.v4i4.69

Cohen, L., Manion, L., & Morrison, K. (2007). *Research methods in education*. Routledge. https://doi.org/10.4324/9780203029053

Crawford, B. A. (2018). Learning to teach science as inquiry in the rough and tumble of practice. *Journal of Research in Science Teaching, 44*(4), 613-642. https://doi.org/10.1002/tea.20157

Creswell, J. W. (2012). *Educational research: Planning, conducting and evaluating quantitative and qualitative research*. Pearson.

Dancy, M., & Henderson, C. (2007). Framework for articulating instructional practices and conceptions. *Physical Review Physics Education Research, 3*, Article 010103. https://doi.org/10.1103/PhysRevSTPER.3.010103

Döş, B., Bay, B., Aslansoy, C., Tiryaki, B., Çetin, N., & Cevahir, D. (2019). An analysis of teachers' questioning strategies. *Educational Research and Reviews, 11*(12), 2065-2078. https://doi.org/10.5897/ERR2016.3014

Examinations Council of Lesotho. (2020). Lesotho general certificate of secondary education syllabus physical science 0181. *Examinations Council of Lesotho*. https://web.examscouncil.org.ls/uploads/Physical_Science_Syllabus_c16c28a348.pdf

Fulmer, G. W., Liang, L. L., & Liu, X. (2017). Applying a force and motion learning progression over an extended time span using the force concept inventory. *International Journal of Science Education, 36*(17), 2918-2936. https://doi.org/10.1080/09500693.2014.939120

Furwati, S., Sutopo, & Zubaidah, S. (2017). Conceptual understanding and representation quality on Newton's laws through multi-representation learning. *Jurnal Pendidikan Sains, 5*(3), 80-88.

Geelan, D. (2020). Physical science teacher skills in a conceptual explanation. *Education Sciences, 10*(1), Article 23. https://doi.org/10.3390/educsci10010023

Gurcay, D., & Ferah, H. O. (2017). The effects of multiple intelligences based instruction on students' physics achievement and attitudes. *Journal of Baltic Science Education, 16*(5), 666-677. https://doi.org/10.33225/jbse/17.16.666

Hoffenberg, R., & Saxton, E. (2015). Scientific explanations: A comparative case study of teacher practice and student performance. *Electronic Journal of Science Education, 19*(5).

Irmak, Ş., & Yılmaz Ergül, D. (2024). Instructional strategies in science education: A dual approach combining systematic review and secondary qualitative data analysis. *e-Kafkas Journal of Educational Research, 11*(4), 597-616. https://doi.org/10.30900/kafkasegt.1503657

Irmer, M., Traub, D., Böhm, M., Förtsch, C., & Neuhaus, B. J. (2023). Using video-based simulations to foster pPCK/ePCK–New thoughts on the refined consensus model of PCK. *Education Sciences, 13*(3), Article 261. https://doi.org/10.3390/educsci13030261

Khalaf, B. K., & Zin, Z. B. M. (2018). Traditional and inquiry-based learning pedagogy: A systematic critical review. *International Journal of Instruction, 11*(4), 545-564. https://doi.org/10.12973/iji.2018.11434a

Kirya, K. R., Nuru, T. S., & Yadav, L. L. (2022). Conceptual understanding of force concepts in the Ugandan context: A thread assessing performance and misconceptions. *Journal of Mathematics and Science Teacher, 2*(1), Article em008. https://doi.org//10.29333/mathsciteacher/12049

Koma, S., Mokuku, T., Makatjane, T. J., Black, C., & Sermeus, J. (2021). The effectiveness of teaching energy in secondary school using the "factory of ideas" teaching approach. *African Journal of Research in Mathematics, Science and Technology Education, 25*(1), 27-37. https://doi.org/10.1080/18117295.2021.1893006

Lesotho Ministry of Education and Training. (2021). Lesotho basic education curriculum policy: Education for individual and social development. *Ministry of Education and Training Leshoto*. http://www.education.gov.ls/img/lesotho%20basic%20education%20curriculum%20policy.pdf

Lestari, F., Saryantono, B., Syazali, M., Saregar, A., Madiyo, M., Jauhariyah, D., & Umam, R. (2019). Cooperative learning application with the method of network tree concept map: Based on Japanese learning system approach. *Journal for the Education of Gifted Young Scientists, 7*(1), 15-32. https://doi.org/10.17478/jegys.471466

Liu, G., & Fang, N. (2016). Student misconceptions about force and acceleration in physics and engineering mechanics education. *International Journal of Engineering Education, 32*(1), 19-29.

Loughran, J., Berry, M., & Mulhall, P. (2012). *Understanding and developing science teachers' pedagogical content knowledge*. Sense Publishers. https://doi.org/10.1007/978-94-6091-821-6

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome, & M. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 95-132). Kluwer Academic Publishers. https://doi.org/10.1007/0-306-47217-1_4

Maharaj-Sharma, R., & Sharma, A. (2017). Analogies in physics teaching: Experiences of Trinidadian physics teachers. *The Electronic Journal of Science & Mathematics Education, 21*(4), 65-81.

Mataka, L., & Taibu, R. (2020). A multistep inquiry approach to improve pre-service elementary teachers' conceptual understanding. *International Journal of Research in Education and Science, 6*(1), 86-99. https://doi.org/10.46328/ijres.v6i1.677

McNeill, K. L., & Krajcik, J. (2008). Inquiry and scientific explanations: Helping students use evidence and reasoning. In J. Luft, R. L. Bell, & J. Gess-Newsome (Eds.), *Science as inquiry in the secondary setting* (pp. 121-134). National Science Teaching Association.

Morris, D. L. (2024). Reflections of a first-year chemistry teacher: Intersecting PCK, responsiveness, and inquiry instruction. *Education Sciences, 14*(1), Article 93. https://doi.org/10.3390/educsci14010093

Mulhall, P., & Gunstone, R. (2008). Views about physics held by physics teachers with differing approaches to teaching physics. *Research in Science Education, 38*, 435-462. https://doi.org/10.1007/s11165-007-9057-6

Omoruan, B. P., & Osadebe, P. U. (2020). Examining the influence of computer literacy and mathematics competency on pre-service teachers in Nigeria. *International Journal of Education and Practice, 8*(3), 511-517. https://doi.org/10.18488/journal.61.2020.83.511.517

Papaevripidou, M., Irakleous, M., & Zacharia, Z. C. (2017). Using teachers' inquiry-oriented curriculum materials as a means to examine their pedagogical design capacity and pedagogical content knowledge for inquiry-based learning. *Science Education International, 28*(4), 271-292.

Park, S., & Chen, Y. C. (2012). Mapping out the integration of the components of pedagogical content knowledge (PCK): Examples from high school biology classrooms. *Journal of Research in Science Education, 49*(7), 922-941. https://doi.org/10.1002/tea.21022

Park, S., & Oliver, J. S. (2008). Revisiting the conceptualisation of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in Science Education, 38*, 261-284. https://doi.org/10.1007/s11165-007-9049-6

Qhobela, M. (2012). Using argumentation as a strategy of promotion of talking science in a physics classroom: What are some of the challenges? *US-China Education Review B 2*, 163-172.

Qhobela, M., & Moru, E. K. (2014). Examining secondary school physics teachers' beliefs about teaching and classroom practices in Lesotho as a foundation for professional development. *International Journal of Science and Mathematics Education, 12*, 1367-1392. https://doi.org/10.1007/s10763-013-9445-5

Rice, A. H., & Kitchel, T. (2016). Influence of knowledge of content and students on beginning agriculture teachers' approaches to teaching content. *Journal of Agricultural Education, 57*(4), 86-100. https://doi.org/10.5032/jae.2016.04086

Sæleset, J., & Friedrichsen, P. (2021). Pre-service science teachers' pedagogical content knowledge: Integration of students' understanding in science and instructional strategies. *Eurasia Journal of Mathematics, Science and Technology Education, 17*(5), Article em1965. https://doi.org/10.29333/ejmste/10859

Sakaria, D.A., Maat, S. M. B., & Matore, M. E. E. (2023). Factors influencing mathematics teachers' pedagogical content knowledge (PCK): A systematic review. *Pegem Journal of Education and Instruction, 13*(2), 1-14. https://doi.org/10.47750/pegegog.13.02.01

Silm, G., Tiitsaar, K., Pedaste, M., Zacharia, Z. C., & Papaevripidou, M. (2017). Teachers' readiness to use inquiry-based learning: An investigation of teachers' sense of efficacy and attitudes toward inquiry-based learning. *Science Education International, 28*(4), 315-325.

Soysal, Y. (2017). An exploration of the interactions among the components of an experienced elementary science teacher's pedagogical content knowledge. *Educational Studies, 44*(1), 1-25. https://doi.org/10.1080/03055698.2017.1331839

Spatz, V., Hopf, M., Wilhelm, T., Waltner, C., & Wiesner, H. (2020). Introduction to Newtonian mechanics via two-dimensional dynamics–The effects of a newly developed content structure on German middle school students. *European Journal of Science and Mathematics Education, 8*(2), 76-91. https://doi.org/10.30935/scimath/9548

Subramaniam, K., Kirby, B., Harrel, P., & Long, C. (2017). Using concept maps to reveal prospective elementary teachers' knowledge of buoyancy. *Electronic Journal of Science Education, 23*(2), 1-18.

Süral, S. (2019). An examination of pre-service teachers' competencies in lesson planning. *Journal of Education and Training Studies, 7*(3), 1-13. https://doi.org/10.11114/jets.v7i3.3902

Tsakeni, M. (2019). *Pre-service science teachers' perceptions of how they learn to facilitate inquiry-based practical work* [Paper presentation]. The European Science Education Research Association 13th Conference.

Vosniadou, S. (2019). The development of students' understanding of science. *Frontiers in Education, 4*. https://doi.org/10.3389/feduc.2019.00032

Wagner, S., Kok, K., & Prieme, B. (2020). Measuring characteristics of explanations with element maps. Education Sciences, 10(2), Article 36. https://doi.org/10.3390/educsci10020036

◆❖◆