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Exploring pedagogical content knowledge of the concept of heat among Indonesian primary school teachers

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Abstract

This study aims to understand the gap in the development of practical pedagogical content knowledge (PCK) in science teaching between private and public elementary school teachers in Indonesia. Specifically, teachers' PCK development in science learning is focused on heat. The research design adopted a qualitative approach using a case study, where data were collected through content representation, semi-structured interviews, and classroom observations. This study found that the gap between private and public primary school teachers in developing PCK on heat learning materials was due to two important things. First, private primary schools have more adequate resources to support teachers' PCK development compared to the resources owned by public primary schools. Second, teachers in private primary schools are more likely to apply inquiry-based strategies, while teachers in public schools rely more on traditional methods in learning the topic of heat. Based on these findings, this study recommends the importance of professional development programs tailored to the needs of teachers in various school contexts, which focus on improving teachers' PCK in science learning, especially in learning the topic of heat. In addition, this study makes a significant contribution to existing literature by revealing novelty in understanding variations in PCK and school contextual influences on heat topic learning practices at the primary school level, which were previously less well identified.

Keywords: pedagogical content knowledge, experienced teacher, elementary school, science learning

INTRODUCTION

Effective science learning in primary schools demands a synergy between deep content mastery and superior pedagogical skills, with an emphasis on active learning. The concept of pedagogical content knowledge (PCK) introduced by Shulman (1987) is a strong foundation in integrating these two aspects. PCK allows teachers to transform material understanding into effective teaching strategies, accommodating the diversity of student backgrounds. Empirical evidence shows the significance of PCK in improving the quality of science learning. The results of research conducted by Kleickmann et al. (2013), for example, confirmed PCK as a strong predictor of learning success and student academic achievement. Other studies prove the direct impact of PCK on teaching quality, learning outcomes, and academic achievement (Mansor et al., 2010; Sadler et al., 2013), as well as improved student performance and interest in science (Fauth et al., 2019).

Although the importance of PCK in science learning has been recognized, research on primary school teachers' PCK in science learning is still minimal and generally general (Schneider & Plasman, 2011). Existing studies reveal that elementary school teachers' PCK understanding is often limited to general concepts without specific deepening for science teaching (Akerson, 2005; Appleton, 2003; Berry et al., 2015; Palmer, 2002). This impacts the inadequate quality of science teaching at the primary school level. In light of this, this study aims to fill the existing gap by focusing on developing PCK for specific topics in science learning in elementary schools. Specifically, this study targets the exploration of PCK in the context of "heat" learning at

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Contribution to the literature

- The findings of this study make an important contribution to the development of primary school teachers' PCK literature, especially in learning the topic of heat.
- This study reveals a new correlation between educational institutions and teachers' PCK. Private primary school teachers more often apply inquiry-based learning. In contrast, public school teachers tend to rely on traditional learning methods.
- This study recommends a contextualized training program to support professional development and improve teaching quality.

the primary school level, an area that remains under-researched. This gap highlights the need for a more in-depth exploration of PCK to support more effective science teaching at the primary level.

This study explores the PCK of experienced primary school teachers in the context of "heat" learning using the PCK framework developed by Magnusson et al. (2002). The focus on heat was chosen due to the limited previous research at the primary school level, making it a crucial area to explore, particularly in Indonesia. By investigating teachers' PCK at the specific concept level, this study aims to uncover in-depth strengths and weaknesses in teachers' pedagogical knowledge and skills (Mazibe et al., 2020). This approach is expected to significantly contribute to the PCK literature in science learning at the primary level and provide valuable insights for teachers' professional development. Related to this, this study poses a question; what is the PCK of experienced primary school teachers in teaching the topic of heat in various school contexts?

LITERATURE REVIEW

Pedagogical Content Knowledge

PCK is a unique type of knowledge possessed by teachers, which is the result of a combination of pedagogical knowledge (teaching skills) and content knowledge (mastery of materials) possessed by teachers (Shulman, 1986). PCK thus reflects how teachers can integrate and translate knowledge about teaching and knowledge about what is taught to create effective understanding for students.

Since its introduction by Shulman (1986), the concept of PCK has undergone significant development. Researchers have expanded and refined the concept, identifying various key components contributing to teaching effectiveness (Berry et al., 2008; Schneider & Plasman, 2011). Those components include curriculum knowledge, student understanding, learning strategies, and assessment, each of which plays an important role in successful teaching (Magnusson et al., 2002; Park & Oliver, 2008). The development of this concept of PCK has enriched our understanding of the complexity of knowledge that teachers need to teach effectively in a variety of educational contexts.

In an attempt to conceptualize PCK more comprehensively, several models have been developed by researchers. As the model developed by Magnusson et al. (2002), PCK is defined as a hierarchical interaction between orientation components in science teaching, including science curriculum knowledge, student understanding, learning strategies, and assessment. Schneider and Plasman (2011) define PCK as an integration of five interrelated components. The model developed by Park and Oliver (2008) emphasizes the reciprocal interactions between PCK components, highlighting the dynamic nature of this construct. Further developments in the conceptualization of PCK also include the addition of non-cognitive components, such as teacher beliefs, which expand the understanding of the complexity of PCK (Schneider & Plasman, 2011). This diversity of models reflects the evolution of understanding of PCK and underscores the importance of considering multiple perspectives in examining teachers' professional knowledge.

Although this diversity of models reflects the evolution of the understanding of PCK, research on PCK at the primary school level, particularly in science learning, is still relatively limited compared to studies at the secondary school level. Most of the existing PCK research focuses on prospective teachers (Barenthien et al., 2023; Bertram, 2014; Davis, 2004; Davis & Petish, 2005; Hanuscin, 2013; Johnston & Ahtee, 2006; Lewis, 2019; Nelson & Davis, 2012; Nilsson, 2008a, 2008b; Nilsson & Loughran, 2012; Nilsson & Van Driel, 2010; Schneider & Plasman, 2011; Timostsuk, 2015; Parker, 2006; Subramaniam, 2022; Zembal-Saul et al., 2000), or teacher professional development programs (Appleton, 2008; Fauth et al., 2019). Although there are several studies involving experienced teachers (Alkis Küçükaydin & Uluçinar Sagir, 2016; Anderson & Clark, 2012; Appleton, 2008; Attorps & Kellner, 2017; Aydin & Mihladiz Turhan, 2023; Chordnork & Yuenyong, 2014; Fauth et al., 2019; Hanuscin et al., 2018; Kang et al., 2018; Masters & Park Rogers, 2018; Mikeska et al., 2021; Oh & Kim, 2013; Soysal, 2018; Walan et al., 2017; Yang et al., 2018). Moreover, in comparative studies between experienced and pre-service teachers (Meschede et al., 2017; Nilsson & Van Driel, 2010), there are still significant gaps in primary school teachers' understanding of PCK, especially in science learning.

These limitations suggest the need for further research to comprehensively understand how PCK develops and is applied at the primary education level, given the importance of this phase in forming the basis of students' science understanding.

Furthermore, studies investigating all PCK components in interaction with science learning in elementary schools are still minimal (Soysal, 2018). Existing PCK research has only focused on one PCK component, such as understanding students and learning strategies (Alkis Küçükaydin & Uluçinar Sagir, 2016; Mikeska et al., 2021), student difficulties (Johnston & Ahtee, 2006), or curriculum components (Davis & Petish, 2005; Hamed et al., 2020). Existing findings show that primary school teachers' PCK still has many weaknesses, including a lack of knowledge of the material, students' level of understanding, and ability to evaluate science learning (Alkis Kokradi & Uluçinar Sagir, 2016). Primary school teachers also often struggle to identify science topics (Hanuscin et al., 2018) and have weak knowledge in assessment and curriculum (Aydin & Mihladiz Turhan, 2023). These limitations underline the importance of providing support to primary school teachers to develop strong PCK related to science subject matter (Davis, 2004), as well as the need for further comprehensive research to understand how PCK develops and is applied at the primary education level, given the importance of this phase in forming the basis of students' science understanding.

In addition to the limitations in the scope of PCK components studied, studies of elementary school teachers' PCK related to specific science content topics are still limited. Although some research has touched on specific themes such as global warming (Schneider & Plasman, 2011), our body (Alkis Küçükaydin & Uluçinar Sagir, 2016), water (Walan et al., 2017), water cycle and floating sinking (Blevins et al., 2020; Meschede et al., 2017), outer space (Bertram, 2014), density and buoyancy force (Fauth et al., 2019), force (Johnston & Ahtee, 2006), photosynthesis (Attorps & Kellner, 2017), air (Nilsson & Loughran, 2012), matter and its interactions (Mikeska et al., 2021), properties of matter (Masters & Park Rogers, 2018), light (Parker, 2006), biodiversity (Ottogalli & Bermudez, 2024). It should be noted, most of the studies above are from the European and American regions. While in Southeast Asia, especially Indonesia, PCK research in science learning is still relatively minimal.

These limitations, both in terms of the scope of PCK components and the specific topics studied, underscore the importance of providing support to primary school teachers to develop strong PCK related to science subject matter. These limitations also highlight the urgency for more comprehensive and geographically diverse research. In response to this need, this study took a different and more specific approach than previous studies. The focus is exploring the PCK of experienced primary school teachers in the context of "heat" learning. As explained earlier, the selection of the topic of "heat" as the focus of the research is based on the lack of previous studies at the primary school level, particularly in Indonesia, thus making it a critical area to explore.

METHOD

Research Method

This research adopts a qualitative approach with a case study design, focusing on primary schools in Medan City, the capital city of North Sumatra Province, Indonesia. The selection of the case study method is based on two main arguments. *First*, its ability to investigate phenomena in depth in real-life contexts, especially when the boundaries between phenomena and context are not clear. This method is considered suitable for answering "how" or "why" questions (Yin, 2018), which is very relevant in investigating how teachers' PCK is applied in science learning. *Second*, this method allows the analysis and synthesis of similarities, differences, and patterns from two or more cases (Goodrick, 2014), which is suitable for understanding the PCK framework that teachers have when teaching science materials in elementary schools, especially in inquiry-based learning practices.

Using a case study approach, this research can contextually explore how teachers apply PCK in learning activities and how these interactions influence learners' understanding and engagement in learning. This allows an in-depth exploration of the various dimensions of PCK, including teachers' knowledge of the curriculum, understanding of learner characteristics, knowledge of strategies, and evaluation knowledge. This approach allows researchers to holistically observe and analyze how these components of PCK interact with each other and are applied in authentic learning situations, providing rich and deep insights into science teaching practices at the primary school level.

Participants

This study involved two main participants: primary school teachers from two different types of schools, one from a private primary school and the other from a public primary school. These two participants were selected based on several important criteria relevant to this study. *Firstly*, in terms of teaching experience, both participants have substantial teaching experience, ranging from 10 to 12 years, which provides a strong basis for the analysis of their teaching practices. *Secondly*, about educational background, both were graduates of the faculty of natural sciences from a university of education with 4 years of study, indicating equality in the content knowledge base. *The third is* related to professional qualifications, where the participants have a bachelor's degree and have been certified as professional teachers to ensure equal standards of

Table 1. Demographic characteristics of participants

Name	Education qualification school	Type teaching	Experience teaching class	Teaching class
Amira	Bachelor of science education	Private primary school	12 years	Grade 5
Debora	Bachelor of science education	Public primary school	10 years	Grade 5

competence. The *fourth* is related to teaching specialization. Both teachers had similar experiences in teaching science, particularly in teaching heat in grade 5, allowing for a more accurate comparison of their teaching practices.

To maintain confidentiality and research ethics, the names of the participants in this study are pseudonyms. This selection of participants with similar characteristics allows for a more in-depth comparative analysis of how PCK is applied in different primary school contexts. **Table 1** presents the background information of each participating teacher.

Data Collection

Data mining in this study refers to the scheme developed by Creswell (2013), which states that observation, interviews, and documentation are effective methods for qualitative data collection. To explore teachers' PCK in more depth, this study also combined using content representation (CoRe) analysis developed by Loughran et al. (2004). In this context, CoRe plays an important role as a tool specifically designed to collect teachers' knowledge of content, learning methods on heat topics, and written reflections on their learning process.

Data mining of teachers' PCK using the CoRe instrument was conducted in five systematic stages. *First*, design a CoRe table with important ideas about heat material at the top of each column. *Second*, using CoRe to plan and teach the topic. *Third*, collecting data through interviews and observations, *Fourth*, analyzing the collected data. Finally, presenting the findings to the research team for discussion and interpretation. By utilizing the CoRe instrument, this study was able to gain an in-depth understanding of the development of teachers' PCK on specific heat topics at the primary school level.

Complementing the data obtained through CoRe, data collection was also carried out through interviews, which were conducted sequentially, following the quality standards of the questions prepared by the PCK indicators. Interviews were conducted before and after observations of learning practices to gain a more holistic understanding of the participants. The interview design was directed to enable reflection, critical analysis, and conceptual answers regarding PCK in the context of inquiry-based learning practices. Meanwhile, observation data was obtained by observing and investigating the learning process carried out by the teacher, especially in teaching the content of heat. This observation focused on pedagogical actions carried out by teachers in the classroom to identify and analyze the pedagogical practices used. Combining these methods enabled this study to gain a more comprehensive and validated perspective on teachers' PCK in the context of learning heat science in primary schools.

Data Analysis

The PCK data in this research focuses on four main components: knowledge of curriculum, knowledge of learners, knowledge of learning strategies, and knowledge of assessment. To measure PCK obtained from teachers' CoRe data, this study used assessment rubric developed by Hanuscin et al. (2018). Data collected from interviews, CoRe, and observations were analyzed using a five-stage cyclical model, following the framework of Yin (2016). This analysis process included five stages:

(1) data compilation,

(2) data disassembly,

(3) data reassembly,

(4) data interpretation, and

(5) conclusion drawing.

With this approach, the analysis is expected to provide an in-depth understanding of teachers' PCK and its implications for classroom learning practices.

FINDINGS

This section presents the PCK findings of two participants who taught the concept of heat. The findings are analyzed using the theoretical framework developed by Magnusson et al. (2002), which includes four main components of PCK: curriculum knowledge, knowledge of teaching strategies, knowledge of student understanding, and knowledge of assessment. To ensure the accuracy of teachers' PCK data, this study also included the analysis of interview results, observations, and field data from both participants.

Although both participants followed the Indonesian primary school science curriculum and chose the topic of heat, their interpretations of the three ideas of the heat concept varied. This variation indicates a difference in their understanding of PCK content, highlighting the importance of developing PCK that suits each teacher's needs, as seen in **Table 2**.

Table 2 guides the analysis of the findings of implementing PCK components obtained from the CoRe data, interviews, and observations. This analysis identifies similarities and differences in the two teachers' approaches in integrating the four PCK aspects of

Table 2. *Concept overview on science content based on answers on teachers' CoRe,* interviews, and observations

Teacher	Class	Topic	The big idea	Components
Amira	5	Caloric	1. Temperature and heat 2. Heat transfer 3. The effect of heat on life	1. Curriculum knowledge 2. Knowledge of teaching strategies 3. Student comprehension knowledge 4. Knowledge of assessment
Deborah	5	Caloric	1. Temperature and heat 2. Heat transfer around us 3. Heat energy source	1. Curriculum knowledge 2. Knowledge of teaching strategies 3. Student comprehension knowledge 4. Knowledge of assessment

curriculum knowledge, teaching strategy knowledge, student understanding knowledge, and assessment knowledge into lesson planning. The findings of this study are then described in detail for each participant.

Amira Case Study

Curriculum knowledge

In the interview regarding knowledge of the curriculum, Amira clearly understood what she wanted to teach students. The established curriculum guides her and integrates it with her annual and semester programs. This reflects Amira's strong understanding of the structure and hierarchy of the curriculum and the importance of alignment in lesson planning and implementation. Amira also recognizes that the determination of concepts has limitations but still leaves room for modifications according to the themes in the curriculum. This demonstrates Amira's ability to adapt and innovate within the curriculum context while maintaining the integrity and relevance of the learning materials. Amira replied;

> "… I determine the concept of the heated topic referring to the curriculum from the Education Office. Adjusting the topic content of the curriculum contained in the annual and semester programs. In determining the concept I cannot determine myself. However, I can add a little according to the theme in the curriculum ..."

Here, Amira tends to be pragmatic, focusing on the tested material and ignoring other important aspects of learning the topic of heat, such as conceptual development, science process skills and applications in everyday life. This approach makes learning more focused on exam results, reducing the opportunity for students to understand concepts deeply and developing a holistic understanding of heat. Amira's answer;

> "... another consideration in determining the concepts to be taught, usually we will stick to the tested material. So we focus more on topics that are often tested ..."

The CoRe data showed that Amira knew the curriculum and heat concepts well and could formulate structured and comprehensive learning objectives. The three big ideas she outlined reflect a strong understanding of the structure and hierarchy of heat learning at the primary school level and connections to practical applications in everyday life. Amira also recognizes the importance of utilizing curriculum materials to maximize their content and pedagogical value. Despite a good understanding of the concept of heat, there are weaknesses in the delivery of learning materials, including:

1. Lack of curricular continuity, where Amira did not connect the material to the previous or next grade level, indicating a lack of understanding of the learning flow and cognitive development of students.
2. Undelivered concept boundaries, where three complex concepts (longitudinal expansion of metals, heat calculation, and semi-conductors) were understood by Amira but not explained to students.

The lesson observation data is in line with the CoRe data, showing that Amira has in-depth knowledge of the topic of heat and its transfer and the skills to convey it effectively to students. Amira has a strong command of CK, one of the important components of teacher PCK. She explains concepts in detail and accurately, provides relevant examples, and connects them to natural phenomena and daily life. Amira also focuses on key concepts that are important for student understanding. She uses easy-to-understand language, demonstrating her understanding of how students learn. These strategies help minimize the possibility of misconceptions and build a strong foundation of understanding. Amira demonstrates good curriculum knowledge based on interviews, CoRe, and lesson observation data.

Knowledge of strategy

The results of learning observations on heat transfer material show that Amira effectively applies the inquiry learning strategy to prove the concepts of conduction, convection and radiation. She directs learners to conduct investigations, discuss the results, and present their findings. When there are errors in understanding, Amira asks questions that encourage learners to propose correct arguments and conclusions. In addition, she guides learners with questions on the worksheets so that they are more focused on recording observations during the inquiry process. This observation data indicates that Amira has a strong understanding of the inquiry learning strategy and the ability to implement it, thus demonstrating good PCK.

In the post-learning interview, Amira explained that the strength of learning on heat transfer lies in using readily available materials and clear work procedures. She adapts the learning strategy to the availability of resources and school conditions. Amira also noted that explaining concepts before practice helps students understand the material deeply and connect theoretical knowledge with synchronized practice. Amira's answer on learning implementation:

> "… Suppose I think about what I try to get from practical materials that are easy to obtain. In that case, it is already in the book if it is related to work procedures. However, before practical activities, I give the concept first, learn the concept first and then do the practice. I do it like because I think students understand better, understand better to synchronize the concept with the practice ..."

Referring to the CoRe data, Amira identified factors to be considered in learning the topic of heat transfer, such as learning style, readiness, students' understanding of previous concepts, and time allocation. She used specific strategies that fit the students' characteristics and could describe the support for learning the heat concept in general. Data analysis shows that Amira understands inquiry-based science learning strategies well. However, there are weaknesses in its implementation in the classroom. Although she can direct students to draw conclusions based on the evidence of the investigation, Amira still needs to develop the ability to formulate in-depth questions and help students explain phenomena and make meaning from data. This shows that Amira has the potential to be an effective teacher in implementing inquiry learning strategies but needs improvement in certain aspects of the conceptual domain.

Student Comprehension Knowledge

Related to knowledge about students, the interview data provided information that Amira realized that some learners had difficulty distinguishing the concepts of conduction and convection from the topic of heat transfer. Amira identified the cause of learners' difficulties in understanding the concepts of conduction and convection. Both terms are scientific, so cognitively, learners find it difficult to distinguish. Amira said some students were confused about the difference between intermediary substances and substances that reacted in the conduction and convection processes. Amira mentioned that this was a misconception of some students. The following is Amira's interview answer;

> "... But synchronizing it is confusing; this is conduction heat transfer; why is it like this? Concluding or reflecting in their own words is difficult. Conduction and convection are scientific languages, so some students are confused about the difference. They are confused about which is the intermediary substance and which reacts. You could say misconceptions, too, I guess ..."

Amira found another misconception among students related to the concept of radiation. She realized that students tend to associate radiation with heat transfer through propagation when, in fact, radiation is the process of emitting electromagnetic waves. Amira also revealed that students had difficulty understanding the difference between "conducting" and "emitting" heat. These findings suggest that Amira is sensitive to the conceptual difficulties students face and has knowledge of strategies that can be used to address these misconceptions. Amira's interview answers;

> "... They mentioned radiation by propagating, whereas radiation is by emission. So, I corrected their wrong concept that what conducts heat is often analogous to conduction. Radiation is more like emission. With difficult language, language that they do not pronounce often they hear, so so far "conducting" they think it is "carrying". So if the concept is confusing for them "conducting, radiating", children of their age think it is the same thing, but it is very different ..."

Knowledge of students' understanding of the prerequisite knowledge and skills indicators of the topic of heat transfer Amira mentioned that heat transfer is a new topic for students. At the previous grade level, students had never received any learning related to heat transfer. Likewise, the next level of learning is also not given learning about heat transfer. So, according to Amira, she considers no prerequisite concepts in teaching students.

> "… If I think the heat transfer material has never been studied, it was studied for the first time in grade five. So, there is no prerequisite material. I think the fourth grade has not been given heat material; the fourth grade discusses energy sources (motion energy, sound energy), so it does not discuss the specifics of heat. Only later in grade six, discussing electricity as a source of energy, not the concept of heat. So heat material is a new material for students ..."

Amira's answer shows a lack of understanding of the importance of prerequisite knowledge for learning the topic of heat. Some of the basic concepts that elementary school students need to have before learning heat transfer include:

(1) energy, students should understand the concept of energy in general, including kinetic, potential and heat energy,

(2) temperature, students should understand that temperature measures the hotness or coldness of an object, and be able to use a thermometer,

(3) changes in state of matter, students should understand processes such as melting, freezing, evaporation, and condensation, and how energy changes are involved, and

(4) examples of heat transfer in everyday life, students need to have experiences of how heat moves, such as heating water, drying clothes in the sun, and feeling the heat from a campfire.

CoRe data on learners' knowledge shows that Amira is aware of the difficulties students face in understanding the concept of heat transfer but has not been able to analyze the source of these difficulties. In addition, Amira had not evaluated students' prior knowledge and skills on this topic. Some of the misconceptions found include:

(1) students often mistakenly assume that temperature and heat are the same concepts, even though they are different;

(2) after the practicum, some students still misunderstand that conduction moves through radiance while conduction occurs through conductance, while radiation is the transfer of heat through radiance.

Thus, Amira demonstrated awareness and knowledge of students' misconceptions about heat transfer.

Observation data showed that Amira understood the difficulties and misconceptions faced by students in learning the concept of heat transfer and was able to implement appropriate intervention strategies. Although she did not thoroughly analyze the source of the difficulties, Amira provided concrete explanations that helped students connect abstract concepts with real-life experiences. She also directed students to seek additional information and re-explain misunderstood concepts, which supported the development of critical thinking skills and a deep understanding of heat transfer. After students re-explained the concept, Amira emphasized the correct concept to strengthen their understanding and reduce the possibility of recurring misconceptions. Based on interviews, CoRe, and observations analysis, Amira has a good knowledge of learners' understanding. Her good category is evident from her awareness of misconceptions and difficulties that students may face, as well as her identification of the source of misconceptions caused by the use of scientific terms that are difficult to understand. Amira recognizes that these misconceptions can disrupt learning and is committed to correcting these errors as a teacher.

Knowledge of assessment

Amira's interview data shows a good understanding of the principles of assessment in the curriculum context and her ability to implement them in learning practices. Teachers understand that assessment should be conducted comprehensively, covering cognitive, psychomotor and affective aspects, by the learning objectives stated in the curriculum. Here is Amira's explanation about assessment;

> "... The assessment uses three aspects of the curriculum. We conduct cognitive, psychomotor and attitudinal assessments. In the learner's learning report there is an assessment of attitude, skills and knowledge ..."

The discrepancies between CoRe and interview data suggest that Amira needs to improve her knowledge of more varied assessment techniques and how to link them to broader learning objectives. She understands cognitive assessment, such as asking students to make a comparison table of temperature and heat and classifying the concepts of conduction, convection and radiation. However, the CoRe data does not explain how Amira assesses students' affective aspects. She needs to develop effective assessment strategies, such as observing students' active participation in discussions or their courage to ask questions. Despite the focus on cognitive and psychomotor assessment, it is not clear how Amira assesses students' skills in experimentation. She should develop strategies to assess students' practical skills, for example, through observation during experiments. In addition, Amira needs to ensure that assessment tasks cover all aspects of the learning objectives, not just conceptual understanding.

In line with the CoRe data, the observation results show that Amira conducts assessments through tests, practice, and oral questions when students present their research results. She also gives homework in the form of questions. She does not skip assessments for various purposes, both formative and summative. Analysis of interview, CoRe and observation data indicates that Amira is knowledgeable about assessment and understands the importance of assessing all learning domains and aligning assessment with curriculum objectives. By improving assessment knowledge and skills, Amira can improve the quality of learning and provide helpful feedback to students.

Debora Case Study

Knowledge of the curriculum

The interview data shows that Debora understands the importance of adjusting the material to the learners' abilities and identifying the limits of the concepts that can be provided. Debora also showed awareness of being guided by essential competencies and textbooks when determining topics. The following is an excerpt from an interview with Debora regarding her knowledge of the curriculum;

> "... I identify the limits of concepts that can be given or not yet given by considering students' ability. In determining the topic, I still look at the basic competencies in the curriculum and textbook ..."

CoRe data indicated that Debora understood the curriculum materials well, comprehensive learning objectives and a strong pedagogical value base. She identified some concepts not taught at the primary school level, such as the temperature and heat formula and the heat transfer formula. However, there were errors in identifying the concept of electrical energy, which had already been introduced at the primary level. In addition, the indicators showed weaknesses in linking new concepts to students' prior knowledge, which was reflected in the sequencing of the lesson content that did not consider previous learning experiences.

Observation data in line with the CoRe showed that Debora had a good command of the topic of heat and the ability to explain concepts effectively. However, errors in identifying concepts appropriate for the elementary school level indicated weaknesses in her in-depth understanding of the curriculum and its suitability for students' cognitive development. In conclusion, although Debora has sufficient curriculum knowledge, efforts are still needed to improve her understanding and implementation. Professional development that focuses on analyzing the curriculum, understanding students' cognitive development, and mastering effective learning strategies to improve students' conceptual understanding could be an appropriate solution to overcome these weaknesses.

Knowledge of strategy

The interview data revealed that Debora's learning strategy focuses on students' initial understanding through reading and teacher explanation. This approach is based on the belief that direct explanations can confuse students. Debora admits that limited facilities and the condition of public schools are obstacles to implementing active and inquiry-based learning. As a result, the lecture method with simple language is more often used to facilitate students' understanding. The following is the transcript of Debora's interview about learning the topic of heat.

> "... I start the learning process by asking students to read; after they read, I explain. If we explain things directly, they will be confused. The concept is given at the beginning. In elementary school, practice takes much time, and students are trained to be quiet and in groups, so we usually do lecture learning. Because this is a public school, there are difficulties related to the facilities available. Also, the condition of students from the lower class means that their interest in learning is less ..."

Observation of learning on the topic of heat revealed that Debora's method was not entirely in line with the orientation of modern science learning. Learning is still teacher-centered, highly reliant on textbooks, and lacking in student worksheets. This results in learning that tends to be passive, where students simply follow instructions without the opportunity to actively discuss, question or solve problems. The CoRe data reinforces this finding, showing learning procedures dominated by reading activities, scrutinizing textbooks, and structured discussions and Q&A. Despite attempts to engage students, the lack of independent exploration and data analysis activities limited the development of deep conceptual understanding. In conclusion, Debora's learning strategy, influenced by public schools' limited facilities and conditions, has not fully facilitated student-centered, active, inquiry-based science learning. Further efforts are needed to design more interactive learning activities, prioritize exploration, and encourage students' active role in building knowledge through scientific inquiry.

Knowledge of learners

The interview data shows that Debora has limited knowledge about students, particularly about identifying and addressing students' learning difficulties. Debora's answers from the interview showed a lack of awareness and effort to identify misconceptions that students may have. Debora acknowledged students' difficulties in learning the topic of heat. However, Debora did not understand the importance of prerequisite knowledge in learning the topic of heat. The following is Ms. Debora's answer;

> "... Did not find students with misconceptions. Students have difficulty in understanding the concept of heat. Prerequisite knowledge: Learning in elementary school is still basic, so it does not require prerequisite knowledge. If there are difficulties, I give a re-explanation ..."

The CoRe data revealed that Debora had a limited understanding of students' prerequisite knowledge and misconceptions on the topic of heat. While she recognized students' understanding of heat energy sources, Debora did not identify common misconceptions, such as confusion between temperature and heat or difficulty understanding the concept of heat transfer. This suggests a lack of deepening knowledge about students in the context of heat learning.

Lesson observations reinforced these findings, showing Debora's limited focus on delivering concepts without paying attention to factors that influence students' learning. The absence of attempts to identify misconceptions prior to learning and the lack of appropriate responses to students' questions, which indicate comprehension difficulties, indicate Debora's limited knowledge of how students learn. In conclusion, Debora showed limitations in understanding knowledge about students, especially related to misconceptions and learning difficulties. The inability to conduct adequate diagnostic assessments hinders the preparation of appropriate learning strategies. This underscores the importance of improving teachers' understanding of student learning and the factors influencing it to create more effective learning.

Knowledge of assessment

Interview data revealed that Deborah applies assessments that mainly focus on students' factual knowledge and conceptual understanding individually without considering other aspects of science learning. The assessment methods consist of oral questions, homework, and questions students must answer. The following is Mrs. Debora's explanation regarding the assessment;

> "... The assessment I do is giving oral questions and asking students to explain what they have learned. Giving homework and questions that students must answer. I do an individual assessment ..."

CoRe data on the assessment of learning the topic of heat showed that Debora only mentioned repeating material and practice activities, indicating her limited understanding of the broader dimensions of assessment, including knowledge, attitude, process skills and product skills. In addition, Debora did not indicate any specific assessments for learning the topic of heat, reflecting a lack of awareness of the importance of tailoring assessments to the material being taught. She also did not express an understanding of the function of assessment in learning, which should be used to assess learners' abilities and improve subsequent learning processes.

Observation data shows that Debora has limitations in implementing effective and comprehensive assessment strategies, relying only on oral questions and homework assignments from the textbook at the end of the lesson. This method is not able to measure all dimensions of students' abilities. Overall, the observations show that Debora needs to expand her knowledge of various assessment techniques and adapt them to the learning objectives. The analysis of the interviews, CoRe and observations highlighted that Debora has a limited understanding of the broader assessment dimensions. This lack of variety in assessment techniques indicates her inability to assess important aspects such as science process skills and student attitudes. Therefore, Debora must develop knowledge and skills in diverse assessment techniques and link them to science learning objectives and student characteristics.

From the four PCK components described above, it can be concluded that Amira and Debora showed differences in their understanding and implementation of PCK despite both having good curriculum knowledge. Amira showed a stronger understanding of teaching strategies, particularly in applying inquiry learning. She was more sensitive to students' misconceptions but less likely to connect the material to students' prerequisite knowledge. Amira also had a more comprehensive understanding of assessment, although her implementation could still be improved. In contrast, Debora showed limitations in understanding teaching strategies, tended to use a lecture approach, and had a limited understanding of students' prerequisite knowledge and misconceptions. Debora's assessment knowledge was also limited, especially in diverse and comprehensive assessment techniques. Overall, Amira implemented PCK better than Debora. However, both have room for further development in various aspects of PCK.

DISCUSSION

This study reveals the diversity and complexity of PCK in elementary school teachers, even in the context of learning the same heat topic. The findings show significant variations in teaching strategies, knowledge about students, and assessment methods between the two teachers studied, in line with findings by Lee and Luft (2008) on the individualized and complex nature of primary school science teachers' PCK. Furthermore, these variations were influenced by the nature of the heat concept itself and the teachers' level of content knowledge, which supports the findings of Mazibe et al. (2023), on the possibility of teachers having different forms of PCK simultaneously. The results of this study reinforce the understanding that primary school science teachers' PCK is a complex and dynamic construct, formed from the interaction between individual teacher characteristics, the nature of the concepts taught, and the specific learning context.

Specific Differences in PCK Components

Knowledge of the curriculum

Discussing textbooks in the context of curriculum knowledge is important because textbooks are often the main reference and primary source of content to be taught. Textbooks represent the authors' and publishers' interpretation of the official curriculum and are often a significant guide for teachers in planning and implementing lessons. Therefore, an analysis of how teachers use and interpret textbooks provides important insights into how they implement the curriculum

From the research findings, it can be analyzed that the implementation of the curriculum shows a significant reliance on textbooks by Amira and Debora, as the main guide in planning and implementing lessons. This reliance, unaccompanied by critical reflection and the development of independent understanding, indicates a lack of in-depth understanding of the topic of heat and a lack of creativity in designing learning activities, as shown by previous research (Friedrichsen et al., 2011). This can be seen in the tendency to select frequently tested concepts without considering scientific relevance, meaningfulness for students, or functionality in everyday contexts (Hamed et al., 2020).

Furthermore, this study revealed both participants' difficulties in elaborating the concepts of the selected topics, which is in line with previous findings regarding the lack of subject matter knowledge in primary school teachers as a weakness of PCK (Alkis Kokradi & Uluçinar Sagir, 2016; Nkundabakura et al., 2024). This lack of material knowledge results in misunderstandings of scientific concepts that are not dissimilar to students' conceptions (Burgoon et al., 2010; Papageorgiou et al., 2010), thus reducing students' depth of understanding. Although Amira integrated the curriculum with annual and semester planning and was able to identify curriculum boundaries and innovate, her pragmatic and test-focused approach neglected aspects of conceptual development, science process skills and practical applications and showed weaknesses in curriculum continuity and concept explanation. In the case of Debora, despite understanding the conceptual boundaries for the primary school level, there were errors in the identification of some concepts and the sequencing of materials that did not consider students' previous learning experiences. Limited school facilities also limit the implementation of active learning. Nonetheless, Debora demonstrated effective mastery of the material and ability to explain concepts, showing efforts to adapt the material to students' abilities. Overall, both teachers' understanding and implementation of the curriculum showed a reliance on textbooks and a lack of critical reflection that could hinder students' deep understanding and creativity in learning, as emphasized by previous research on the relationship between teachers' knowledge of the curriculum and the implementation of effective learning strategies (Cohen & Yarden, 2009).

Knowledge of students

This section will explain the analysis of students' understanding of the concept of heat, with an emphasis on identifying and explaining misconceptions that arise during the learning process. The analysis of students' understanding of the concept of heat shows significant misconceptions, especially regarding heat transfer (conduction, convection and radiation). This was caused by two main interrelated factors. *First*, students' prerequisite knowledge in understanding the concepts of matter and its state, temperature and its measurement, and energy. These three concepts are important as the foundation for understanding heat, but were not fully anticipated by the two participants, Amira and Debora. *Second*, and more crucial, is the lack of PCK of both participants, especially in terms of identifying and addressing student misconceptions. Amira, although aware of some misconceptions, did not fully analyze the root of the problem. In contrast, Debora showed a lack of understanding of students' difficulties and misconceptions in general.

The lack of PCK is exacerbated by a less thorough teaching approach; Amira focuses on exam material, while limited resources prevent Debora from providing optimal learning. As a result, students' understanding is shallow and prone to misconceptions. This finding is in line with research showing that teachers' understanding of students' misconceptions is a key factor in planning, implementing and assessing learning (Park & Oliver, 2008). Misconceptions, which often hinder student understanding, should be anticipated and addressed through effective initial assessments to uncover student understanding. Teachers' lack of content understanding leads to difficulties in interpreting and responding to students' ideas and is associated with scientifically incorrect concept understanding (Halim & Meerah, 2002; Käpylä et al., 2009). Teachers who lack conceptual understanding are less likely to understand students' level of comprehension (Alkis Küçükaydin & Uluçinar Sagir, 2016), and limited content knowledge reduces teachers' ability to identify common misconceptions (Daehler & Shinohara, 2001). Although research shows that a deep understanding of science PCK is important for improving teaching practices (Van Driel et al., 2002), and experienced teachers generally have more PCK and understanding of student difficulties (Hogan et al., 2003), this research shows that teaching experience alone does not guarantee teachers' knowledge of students' alternative conceptions (Gomez-Zwiep, 2008; Halim & Meerah, 2002). Ultimately, the student misconceptions found in this study are rooted in the participants' lack of prerequisite knowledge and PCK, particularly the ability to identify and address misconceptions. Therefore, improving teachers' PCK becomes very important to improve the quality of learning and minimize students' misconceptions.

Knowledge of strategy

This section describes the research findings on the learning strategies applied by the two teachers, Amira and Debora, and analyzes the effect of these strategies on improving students' understanding of the concept of heat. This study revealed significant differences in knowledge of learning strategies between Amira and Debora, which had a direct impact on improving students' understanding of the concept of heat. Amira, with better access to resources, demonstrated more extensive PCK by applying inquiry-based learning strategies, using multiple representations (illustrations, examples, and analogies), and involving students in experiments and active discussions. This is in line with Rosenkränzer et al.'s (2017) findings which states that teachers with extensive PCK tend to utilize multiple forms of representation, including analogies and demonstrations.

Amira's approach, although it still has room for improvement, especially in formulating analytical questions, proved to be more effective in improving students' conceptual understanding and critical thinking skills. exactly what was stated by Ireland who emphasized that ideally, teachers should ask open-ended questions that encourage students to ask themselves and conduct investigations (Ireland et al., 2012). The same thing was also expressed by Capps et al. (2016) who emphasized the importance of involving students in scientifically oriented questions, asking them to develop and present explanations. While García-Carmona et al. (2017) adds that this questioning dimension becomes an important element in hypothesis formulation that should be taught in the classroom

In contrast, Deborah, facing limited resources, relied on a more traditional approach to learning with a focus on textbook explanations and guided demonstrations. This strategy, while conveying basic information, was less effective in promoting deep understanding and active student engagement in the learning process. Research by Fauth et al. (2019) shows that active learning is more effective in increasing students' interest and understanding. These differences in strategies reflect variations in teachers' PCK and have a direct impact on the level of improvement in student understanding. Amira's students showed a more significant improvement in the understanding of the concept of heat and the application ability of the concept, while Debora's students, despite acquiring basic knowledge, showed limitations in deep understanding and analytical ability related to the concept of heat.

Knowledge of assessment

An important but often overlooked dimension in teachers' PCK development is the assessment of students' affective and psychomotor skills. This study revealed that both participants, Amira and Debora, rarely conducted comprehensive assessments that covered these aspects. This casuistry reflects a significant gap in science education evaluation practices, where the focus of assessment is often on cognitive aspects alone.

Although Amira and Debora understand the importance of comprehensive assessment that includes cognitive (knowledge), affective (attitude) and psychomotor (skills) aspects, their assessment practices, as seen in **Table 2**, are limited to cognitive assessment. The dominance of oral tests and textbook assignments indicates a lack of implementation of comprehensive effective and psychomotor assessments. These findings are consistent with Aydin and Mihladiz Turhan (2023) research which shows the weakness of experienced teachers in terms of assessment and curriculum knowledge, and also supports the recommendation for more holistic assessment in science education (Davis & Petish, 2005). Referring to the findings described in the previous section, it confirms that although both lesson plans include comprehensive assessments, their implementation in practice is still limited to cognitive aspects, potentially limiting a thorough understanding of students' abilities. In this regard, this study highlights the importance of developing teachers' assessment knowledge and practices to cover all cognitive, affective and psychomotor aspects.

The findings showing significant differences in PCK between Amira and Debora highlight the importance of individual teachers' understanding of the concepts being taught. Although both teachers had experience, their level of understanding of the curriculum, teaching strategies, and knowledge of students varied significantly. This suggests that teaching experience is not always directly proportional to the depth of pedagogical and content knowledge. Although a teacher may have years of experience, without a deep understanding of pedagogy and content, student learning outcomes can be hindered. Therefore, teachers need to be reminded that they have a responsibility to continuously improve themselves.

This study reminds us that improving PCK is a must. In the ever-evolving world of education, teachers must be committed to adapting to new teaching methods and more effective pedagogical approaches. This is in line with the demands of professionalism in education, where teachers are required to not only master content but also how to deliver that content in a way that is understandable and relevant to students.

School Contextual Influence on Teacher PCK

The difference in PCK between the two participants was influenced by the school context in which they taught. Amira, who taught in a private school with greater resources, was able to effectively implement inquiry-based learning strategies, improving conceptual understanding and student engagement. In contrast, Debora, in a public school with limited resources, relied more on traditional methods such as lectures. These different contexts highlight the challenges of teachers in resource-constrained environments and the importance of adequate support for PCK improvement

The differences in PCK of the two participants from different school types reinforce the findings of Ramnarain et al. (2016), which proved that school type and contextual circumstances influence teachers' pedagogical choices. This suggests that PCK is context-specific and shows variation influenced by various factors, including teacher experience and contextual limitations (Shulman, 1987). Teaching experience is an important factor influencing the development of PCK (Halim & Meerah, 2002; Magnusson et al., 2002). Amira's longer teaching experience provided her with more opportunities for reflection, professional development, and observation of other teaching practices, which contributed to stronger PCK. Although experience plays an important role, this study shows that it is not guarantee of strong PCK. Debora's limited experience may have contributed to her less comprehensive knowledge of content and pedagogical strategies.

Therefore, improving PCK requires an approach that considers the school context and available resources. The success of elementary school teachers in developing science learning practices is influenced by support from educational institutions. This study shows that PCK on heat topic learning of private school teachers is superior to public schools. Kind stated that a supportive atmosphere in the school context is needed for teachers to develop PCK (Kind, 2009). By providing access to resources, collaboration opportunities, and ongoing training, teachers can better develop their teaching practices and improve student learning outcomes.

Implications for Teacher Professional Development

The research findings point to the need for continuous professional development that meets the specific needs of teachers at different stages of their careers. Professional development programs should:

(1) increase access to and support in comprehensive teacher professional development programs, including training on inquiry-based learning strategies, classroom management techniques, and effective assessment practices (Lee & Luft, 2008),

(2) facilitate collaborative learning opportunities through peer observation, mentorship programs, collaborative lesson planning, and reflection on instructional practices (Li et al., 2024; Mapulanga et al., 2024; Ottogalli & Bermudez, 2024), and

(3) Develop curricula that support inquiry-based learning and encourage active engagement, critical thinking, and deeper understanding of concepts.

Teacher professional development programs should be designed to support teachers in understanding and addressing student misconceptions and developing teaching methods that place students at the center of the learning process.

CONCLUSION AND RECOMMENDATION

This study highlights the importance of PCK in science teaching, particularly the topic of heat in primary schools, by highlighting the differences in implementation between two participants, Amira and Debora. Amira demonstrated a stronger understanding of inquiry-based teaching strategies and more comprehensive assessments, although she still needed development in linking concepts to students' prerequisite knowledge. Debora faced the limitations of more traditional teaching and assessment strategies, influenced by limited resources in a public school context. This suggests the need for support to overcome contextual constraints.

This study highlights how school context and teaching experience influence PCK. Amira, with better experience and access to resources, was able to implement more effective strategies than Debora. This study emphasizes the need for professional development programs that focus on improving PCK, including training on active learning strategies and comprehensive assessment, as well as support that enhances collaboration between teachers and strengthens supportive learning environments. Further research is recommended to explore other contextual factors that influence PCK, such as socioeconomic influences, school culture and leadership support. This may provide greater insight into how to improve teachers' PCK in various environments. Overall, although this study focused on two teachers in different contexts and the findings cannot be widely generalized, the results provide important insights into the crucial role of PCK in improving the quality of science learning. The findings support the need for continuous efforts in teacher professional development to achieve more effective and student-centered teaching practices.

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