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Prospective Elementary School Teachers' Science PCK: An Analysis of Perceptions and Implicit Knowledge

Atika Dwi Evitasari [1*], Insih Wilujeng [2], Entoh Tohani [3], Anita Dewi Astuti[4]
Merti Triyanti [5], Faridl Musyadad [6]

[1] *Doctoral Program in Elementary Education, Universitas Negeri Yogyakarta*, INDONESIA
[2] *Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta,* INDONESIA
[3] *Faculty of Education, Universitas Negeri Yogyakarta*, INDONESIA
[4] *Doctoral Program in Guidance and Counseling Education, Universitas Negeri Semarang,* INDONESIA
[5] *Doctoral Study Program in Mathematics and Natural Sciences Education, Universitas Jambi*, INDONESIA
[6] *Faculty of Education, IKIP PGRI Wates,* INDONESIA

***Corresponding Author:** atikadwi.2022@student.uny.ac.id

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ABSTRACT

PCK is crucial for prospective elementary school teachers to deliver effective science instruction. However, research on how they understand and implement PCK, especially in developing countries, remains limited. This qualitative study explored prospective teachers' perceptions and implementation of key PCK components in science instruction through in-depth interviews and narrative frameworks, followed by thematic analysis. The results showed a fairly comprehensive understanding of five core PCK elements: pedagogical orientation, student characteristics, curriculum content, instructional strategies, and assessment methods. Participants demonstrated awareness of inquiry-based and student-centered approaches, the need to diagnose students' prior knowledge, and the use of diverse instructional and assessment strategies. However, practice remained dominated by teacher-centered methods with limited hands-on science activities. Internal and external barriers hindered effective PCK implementation. This study highlights the need for holistic PCK development integrating content mastery, pedagogical skills, student understanding, and authentic assessment. Teacher education programs are encouraged to strengthen contextual teaching experiences through microteaching, inquiry-based field practice, and reflective supervision. Longitudinal research is recommended to track PCK development from university training to early teaching careers, as well as involving prospective teachers from non-science backgrounds to identify gaps in content knowledge and pedagogical approaches.

Keywords: descriptive phenomenology, inductive thematic, science PCK, teacher competence

INTRODUCTION

Strengthening Pedagogical Content Knowledge (PCK) is a critical concept in teacher education, particularly in elementary science teaching. Originating from Shulman (1986), PCK integrates pedagogical expertise with content knowledge, enabling educators to transform complex scientific ideas into simpler, more understandable concepts. The significance of PCK has continued to grow, as it is recognized as the foundation of effective teaching practice and a key component of teachers' professional competence (Deng, 2018). In science education, this is especially important due to the need to cultivate scientific thinking and inquiry skills from an early age (Lederman & Lederman, 2011; Osborne, 2007).

The strategic role of science education in elementary schooling is widely (Monteira & Jimenez-Aleixandre, 2015). Science learning fosters critical thinking, inquiry, and hands-on experiences for students (Levy & Mensah, 2021; Vieira & Tenreiro-Vieira, 2016). However, recent reports reveal a decline in Indonesian students' performance in science and mathematics (OECD, 2022). Furthermore, Worldtop20 (2024) data ranks Indonesia's education system 67th out of 203 countries. One contributing factor is the low level of teachers' pedagogical skills (UNICEF, 2020). In fact, the effectiveness of Indonesian teachers' instructional behaviors ranks among the lowest globally (André et al., 2020). These findings highlight an urgent need to strengthen PCK, particularly in elementary science education, to bridge the gap between curriculum expectations and student learning outcomes.

Science content presents unique challenges in teaching due to its abstract nature, which is often not directly observable (Demirdöğen et al., 2015; Zydney & Warner, 2016). Considering that elementary students are at the concrete operational stage of cognitive development (Santrock, 2018), they benefit more from hands-on, experience-based learning. This requires tailored teaching strategies that effectively contextualize abstract scientific phenomena into real-life experiences (Hwang et al., 2011). Despite its importance, science learning still faces issues such as limited exploration of scientific concepts (Blank, 2013), and a general lack of attention in the curriculum, necessitating well-planned strategies and strong teacher preparation to ensure high-quality science instruction (Marshall et al., 2024).

Teacher professionalism is increasingly linked to their capacity to integrate PCK into practice (Bullough, 2001). Developing science-related PCK is particularly complex, requiring more than just content mastery (Abd-El-Khalick, 2012). It demands teachers' understanding of instructional orientation, curriculum, students' conceptual understanding and misconceptions, assessment strategies, and effective teaching methods for science content (Magnusson et al., 1999; Demirdöğen et al., 2015 ; Deng, 2018). However, prospective teachers often lack an adequate understanding of student characteristics essential for science instruction (Hanuscin, 2013). Without such integration, even teachers with strong content knowledge may struggle to deliver meaningful science teaching.

Existing research has extensively explored Technological Pedagogical Content Knowledge (TPACK) (Fakhriyah et al., 2022; Shafie et al., 2019; Irmita & Atun, 2018; Pringle et al., 2015). However, specific investigations into elementary prospective teachers' perceptions of their science PCK remain limited. Previous studies have predominantly focused on in-service teachers (Luik et al., 2018; Koh et al., 2013), thereby overlooking insights from those still in the formative stages of teacher education. This study builds on the theoretical foundation by focusing on elementary prospective teachers enrolled in a STEM-based elementary science education course. These participants are likely to have a higher interest in science learning, offering valuable perspectives on the formation and application of science PCK, particularly regarding how they conceptualize and implement PCK. Their insights provide important feedback on the effectiveness of current teacher education programs. Previous studies have shown that despite having theoretical knowledge of teaching strategies, prospective teachers often lack a comprehensive understanding of student characteristics and their impact on science teaching (Hanuscin, 2013).

These limitations may hinder their ability to adapt their teaching to students' developmental stages and learning styles, which is crucial in science education. Therefore, this study aims to investigate the perceptions of elementary school teacher candidates regarding science PCK and its implementation. Specifically, this study explores two main questions: 1) how do the perceptions of prospective elementary school teachers regarding their pedagogical content knowledge (PCK) in science? 2) how do the perceptions of prospective elementary school teachers regarding the implementation of pedagogical content knowledge (PCK) in the context of science learning.

By answering these questions, this study seeks to fill a gap in the literature on early PCK development among elementary education students. It contributes to the broader discourse on teacher preparation by providing empirical evidence on how prospective teachers conceptualize and apply PCK in science contexts. The findings of this study are expected to inform improvements in teacher education curricula, particularly in the design of experiential and reflective learning opportunities that enhance PCK development. Ultimately, this work aims to support the development of competent and confident prospective teachers who can reflectively engage young learners in meaningful scientific inquiry.

LITERATURE REVIEW

Science is both a body of knowledge and a process (Lederman & Lederman, 2011; Krajcik & Czerniak, 2018). This means that science education not only emphasizes understanding scientific concepts but also focuses on how these concepts are developed through the scientific process. This is in line with Frost (2010), who stated that the main idea of science is the study of the natural and artificial environment, which helps us understand how events occur around us. In addition, science is a way of thinking about the world (Krajcik & Czerniak, 2018). When studying science, students are encouraged to think scientifically; therefore, teachers need to provide opportunities for students to achieve this competency (Osborne, 2007). One way to develop scientific thinking skills is to start with questions or problems that come from everyday life situations.

Current science education reforms emphasize the role of science in asking questions, solving problems, designing solutions, and generating concrete ideas (Bird et al., 2023). In science learning, students need hands-on experiences to construct scientific knowledge (Suryanti et al., 2024). As highlighted by Santos and Macena, when science subject matter is linked to its real-life applications, it can significantly enhance students' engagement and deepen their understanding (Diab et al., 2024).

Therefore, teachers' understanding of both science content mastery and effective instructional strategies is essential to ensure that students learn science in a holistic and comprehensive manner. This is especially important given research findings showing that teacher quality is one of the most influential factors in fostering student engagement in science learning (Osborne et al., 2003).

PCK is an integration of content mastery and the use of appropriate and effective teaching strategies. It emphasizes professional understanding of the subject matter to be taught and how to teach it effectively (Shulman, 1986). Aktaş dan Özmen (2020) describe PCK as a specific type of knowledge that includes understanding how to teach subject content while considering student characteristics. PCK reflects teachers' knowledge of how to teach various subjects (Koh et al., 2010). However, PCK is not uniform across all teachers; instead, it is an individual skill shaped and influenced by multiple factors (Loughran et al., 2012). As Ward et al. (2015) highlight, PCK is specialized knowledge that teachers use in making instructional decisions, taking into account teaching methods, students' learning approaches, student development and characteristics, as well as the learning environment.

PCK enables teachers to transform complex concepts into more accessible forms for students, thus enhancing learning effectiveness. Science-specific PCK (science PCK) serves as a critical framework that helps teachers convey complex science content in ways that are understandable to students with diverse ability levels. Science PCK encompasses an understanding of the curriculum, students, instruction, assessment, and teachers' orientation toward science teaching (Demirdöğen et al., 2015).

Previous research conceptualizes PCK as a multidimensional construct integrating teachers' orientations toward science teaching, curriculum knowledge, understanding of students' ideas, teaching strategies, and assessment practices (Magnusson et al., 1999; Demirdöğen et al., 2015; Deng, 2018) . However, empirical studies indicate that prospective teachers often exhibit discrepancies between their conceptual understanding of PCK and their ability to apply it in classroom practice, particularly in the context of science teaching (Hanuscin, 2013; Deng, 2018) Furthermore, research focusing on prospective elementary school teachers remains limited, particularly in developing country contexts, where science teaching is often constrained by curricular and pedagogical challenges.

In response to this gap, this study not only conceptualizes prospective elementary school teachers' science PCK but also how they understand its implementation in teaching practice. Therefore, this study addresses the following research questions: how do the perceptions of prospective elementary school teachers regarding their pedagogical content knowledge (PCK) in science? and how do the perceptions of prospective elementary school teachers regarding the implementation of pedagogical content knowledge (PCK) in the context of science learning?

METHODOLOGY

This study employed a descriptive phenomenological approach to explore the lived experiences of prospective elementary teachers regarding their understanding and implementation of Pedagogical Content Knowledge (PCK). Phenomenology, as emphasized by Creswell (2013), seeks to uncover the essence of participants' experiences by examining what they experienced and how they perceived the phenomenon. In this context, the phenomenon under investigation is science PCK within teacher education programs.

Participants and Sampling

The participants consisted of 15 prospective elementary teachers (11 females and 4 males) enrolled in a teacher education program at IKIP PGRI Wates. Participants were selected based on the following criteria: (1) prospective elementary teachers who had prior teaching experience in science education; and (2) students who had chosen the STEM-based Elementary Science Education elective course from among several elective courses offered by the program. Purposive sampling was employed to ensure that selected individuals had relevant experience and interests aligned with the research focus (Krishnaswamy et al., 2012).

Ethical Consideration and Data Collection

Ethical approval for this study was obtained from the Department of Elementary Teacher Education at IKIP PGRI Wates. All participants were informed about the nature and purpose of the research and were asked to provide written consent. They were assured of their right to withdraw from the study at any time. To protect anonymity, participants' names were replaced with pseudonyms, and any identifiable information was excluded from the reported data. In this study, data were generated through semi-structured interviews and narrative frameworks, which captured participants' articulated perceptions and pedagogical reasoning. Furthermore, research on survey- and interview-based data collection highlights that factors such as participants' motivation, perceived evaluation contexts, and interest in pedagogical discourse can influence the accuracy and consistency of self-reported responses (Lavidas, Petropoulou, et al., 2022), methodological factors also influence teacher survey responses in educational settings (Lavidas, Papadakis, et al., 2022). Consequently, the PCK implementation described in this study should be interpreted as perceived or intended practice rather than verified and enacted practice.

Data were collected using two primary qualitative instruments: semi-structured interviews and narrative frameworks. The interviews lasted between 60 and 90 minutes and included open-ended questions to elicit detailed responses. One guiding question was: "What steps do you take before starting a science lesson?" The narrative framework used in this study was adapted from Barkhuizen, (2014) and Ghiasvand dan Sharifpour (2024). This framework consisted of incomplete sentences with spaces provided for participants to describe their personal teaching experiences and reflections on science pedagogy. Clear instructions were given, and participants were allocated one week to complete the narrative framework.

Data Validity and Trustworthiness

To ensure the credibility of the findings, both methodological triangulation and researcher triangulation were employed (Noble & Heale, 2019). Multiple researchers with diverse academic backgrounds participated in the data analysis process to minimize individual bias and enhance interpretative rigor. Member checking was also conducted, how emerging themes and interpretations were verified with participants to ensure that they accurately reflected their experiences (Bonyadi, 2023). Although triangulation through interviews and a narrative framework enhances internal credibility, these methods do not fully eliminate the inherent limitations of self-report approaches in capturing complex teaching behaviors.

Although this study provides valuable insights into elementary prospective teachers' perceptions of PCK, the findings should be interpreted with caution. The reliance on self-reported data may have led participants to describe idealized or intended teaching practices rather than their actual classroom practices. This tendency may partially explain the gap identified in this study between participants' relatively strong conceptual understanding of science PCK and the dominant perceptions regarding the implementation of teacher-centered science instruction.

Future research should incorporate direct observational methods, such as classroom observations, video-based lesson analysis, teaching simulations, or analyses of lesson plans and instructional artifacts, to provide more robust and objective assessments of PCK enactment. Longitudinal designs that follow pre-service teachers from university coursework into the early stages of their teaching careers would also enable researchers to examine how conceptual PCK develops into enacted practice over time. Integrating self-reported perceptions with observational and performance-based data would strengthen the validity of the findings and contribute to a more comprehensive understanding of science PCK development among elementary prospective teachers.

Data Analysis

The data were analyzed using an inductive thematic analysis approach as proposed by Braun & Clarke (2006; 2021), following six key phases: (1) Familiarization with the data and reflective note-taking: The researchers thoroughly read all the data while making reflective notes as part of the familiarization process, followed by systematic coding across the entire dataset; (2) Systematic coding: Data segments were labeled based on recurring patterns and meaningful phrases; (3) Generating initial themes: Codes were grouped into preliminary themes representing core meanings; (4) Reviewing and refining themes: Themes were refined by checking for coherence and consistency across the entire dataset; (5) Defining and naming themes: Each theme was clearly defined, considering the relationship between codes, themes, and research questions; and (6) Producing the report: Themes were synthesized into a coherent narrative aligned with the research objectives.

This inductive approach allowed the researchers to ground findings in participants' lived experiences, providing nuanced insights into how prospective teachers conceptualize and implement science PCK. The combination of narrative and interview data enriched the analysis, offering triangulated insights that enhanced the study's depth and trustworthiness.

RESULT

Responding to Research Question 1

This section presents findings related to the first research question: "*How do the perceptions of prospective elementary school teachers regarding their pedagogical content knowledge (PCK) in science*?" Through inductive thematic analysis, five overarching themes were identified, each representing key dimensions of science PCK: science teaching orientation, understanding of students, science curriculum knowledge, science instructional strategies, and science assessment strategies.

Theme 1.1. Teaching Orientation

The findings show diverse understandings of science teaching orientation, which are categorized into three subthemes: inquiry orientation, learning activity orientation, and didactic orientation.

Subtheme 1.1.1. Inquiry Orientation

Inquiry-based activities in science teaching orientation begin with trigger questions related to the investigative activities carried out by the teacher. As conveyed by DKP participants.

> "*I ask trigger questions like, 'Why does ice melt?' Then, I invite students to investigate the phase changes of ice. I relate the material to everyday life, for example, when learning about forces, I can show how bicycle brakes work*." (DKP participants)

Subtheme 1.1.2. Learning Activity Orientation

Participants also highlighted strategies that actively involve students in building their knowledge.

> "*I start with apperception and Q&A session related to the topic to be taught. I encourage students to be active by asking some students to answer*". (MU participants)
>
> "*At the beginning of the lesson, I ask questions related to the topic and ask some students to write as many answers as possible on the board. For other students who do not come forward, I ask them to write their answers in their notebooks*." (MSS participants)

Subtheme 1.1.3. Didactic Orientation

On the other hand, some participants understood that certain science topics are abstract and cannot be observed directly. Therefore, they argued that:

> "*I deliver materials starting from everyday phenomena or real-world events using relevant, interesting, and concrete contexts, and I use videos to make it clearer*." (ADP participants)

These insights reflect a spectrum of pedagogical approaches, from student-centered to teacher-directed, with varying degrees of emphasis on experiential learning.

Theme 1.2. Student Understanding

This theme is supported by three subthemes: assessment of prior knowledge, identification of learning difficulties, and strategies to overcome challenges.

Subtheme 1.2.1. Assessment of Prior Knowledge

Identification of students' prior knowledge is carried out by carrying out the following actions:

> "*Conducting a pretest or diagnostic assessment is an effective way to find out students' prior knowledge before starting science learning*." (KSS Participants)
>
> "*… In addition, at the beginning of learning, students are expected to come forward and write on the board what they already know about the science topic…*" (DKP Participants)

Subtheme 1.2.2. Identification of Learning Difficulties

In addition to recognizing students' prior knowledge, teachers should also be aware of the difficulties that students face in learning science. As conveyed by KSS participants.

> "*… Class discussions and Q&A sessions can help teachers identify difficulties that students experience, such as difficult concepts or misunderstandings. Analyzing student assignments and daily tests also provides insight into areas of science content that require further clarification or deeper understanding*." (KSS Participant)

Subtheme 1.2.3. Strategies to Overcome Challenges

As prospective teachers, participants also explained several strategies to overcome students' difficulties in learning science, such as the presentation from DKP participants.

"*Usually, students find it difficult to learn topics such as force, circulatory system, ..., abstract and content-dense materials. So, I usually use videos for these topics. Sometimes, I also do simple demonstrations or experiments, such as when teaching the characteristics of light or changes in the state of matter* ". (DKP Participants)

This strategy suggests a proactive attitude among participants in adapting instructions to meet the various needs of students.

Theme 1.3. Understanding the Science Curriculum

Within this theme, the researcher identified this perspective through interviews and the narrative framework, which revealed two main sub-themes: understanding learning objectives and the science lesson content.

Subtheme 1.3.1. Understanding Learning Objectives

The teaching practice experiences undertaken by the student teachers seemed to provide them with valuable insights in formulating appropriate learning objectives.

> *"My approach to formulating precise and accurate science learning objectives to support student competency achievement is by using the ABCD formula (Audience, Behavior, Condition, Degree)."* (DKP Participants*)*

However, regarding the use of the ABCD formula, many students still tend to ignore it. This was seen during the interview, because many of them stated that they formulated learning objectives only based on student conditions.

> "... *I adjust to the cognitive development and characteristics of students, referring to Bloom's taxonomy*". (MSK Participants)

Subtheme 1.3.2. The Science Lesson Content

Development of sub-themes of science learning materials. Participants stated that they developed science content based on student needs, curriculum standards, and contextual factors. DKP and TEP participants explained:

> "*Developing integrated and thematic science materials by combining concepts from biology, physics, chemistry, and earth and space sciences. … Compiling materials based on students' needs and characteristics, … Utilizing concrete media and teaching aids that are greatly needed by early childhood learners who still rely heavily on concrete objects and direct experiences*". (DKP Participants)
>
> "*Before creating a teaching module (which functions as a Learning Plan), I first review the learning outcomes (CP) to determine the right material to be developed. However, I also adjust it to align with student characteristics and school context.*". (TEP Participants)

These findings indicate a developing but varied understanding of curriculum planning, influenced by theoretical models and practical considerations.

Theme 1.4. Understanding of Science Learning Strategies

Participants demonstrated awareness of effective science teaching methods, especially those related to the abstract nature of science. This theme includes two subthemes: general learning strategies and specific learning strategies.

Subtheme 1.4.1 General Learning Strategies

Although prospective elementary school teachers' general perceptions of science learning were positive, describing it as stimulating curiosity, challenging, and enjoyable, they also recognized that effective science learning requires careful preparation, including selecting appropriate learning models, media, and methods. As conveyed by KSS.

> "*Utilizing active and interactive learning methods, such as experiments, educational games, group discussions, and simulations. … Integrating technology and multimedia into the learning process, such as videos, animations, and interactive applications… Incorporating stories, analogies, and real-life examples, and presenting interesting challenges or projects for students …*". (KSS Participants)

Subtheme 1.4.2. Specific Learning Strategies

The complexity of certain topics, such as forces and the circulatory system, encourages participants to use analogies, visual aids, and real-life connections.

> "*Connecting abstract concepts to real-life situations… Using visuals and hands-on activities such as videos, animations, experiments, or teaching aids to enhance understanding… Implementing an inquiry-based and exploratory approach by allowing students to ask questions, conduct experiments, and discover answers independently …*". (KSS Participants)

"*Conveying abstract science concepts by relating them to everyday examples, using visual media or simulations, and conducting simple experiments…*". (EPS Participants)

Overall, participants demonstrated thoughtful consideration of how teaching methods can enhance science understanding.

Theme 1.5. Understanding of Science Assessment

In-depth interviews conducted by the researcher revealed that participants' assessment of science learning was categorized into three subthemes: cognitive assessment in science, psychomotor assessment (science process skills), and affective assessment (scientific attitudes).

"*Using written tests for science concepts, performance assessments for science process skills, and observations of scientific attitudes during practical activities or discussions… Applying authentic assessments and portfolio-based assessments…*" (KSS participants)

"*I assess science concepts through written assessments, scientific attitudes through observations, and process skills through observations during the learning process, especially during experimental*". (TEP participants)

These diverse assessment strategies reflect the student teachers' efforts to evaluate students holistically across cognitive, behavioral, and affective domains.

Responding to Research Question 2

Perceptions of science PCK among pre-service teachers regarding the second research question: "*How do the perceptions of prospective elementary school teachers regarding the implementation of pedagogical content knowledge (PCK) in the context of science learning?*" Four themes emerged from the data: characteristics of PCK understanding, realization in practice, implementation challenges, and development strategies.

Theme 2.1. Characteristic of PCK Understanding

Prospective teachers described the main components of effective science teaching, emphasizing the integration of student-centered pedagogy and content mastery.

"*In my opinion, one of the main characteristics of a strong understanding of pedagogy in elementary science teaching is the teacher's ability to understand the cognitive development of each student… In addition, teachers must be able to master and apply various interactive and effective learning models.*" (DKP participants).

"*A good teacher must be able to create a fun and relaxed learning environment. This is especially important for science subjects, which are often considered boring and difficult. Teachers must also help students understand the material more easily, for example by using learning media.*" (MU participants)

This perspective shows that participants recognize the multidimensional nature of PCK, which includes content knowledge, pedagogy, and student character.

Theme 2.2. Realization of PCK Understanding in Practice

Participants reported various experiences regarding the realization of PCK in science in real teaching contexts, categorized into positive and negative perceptions. Positive perspectives are illustrated in MSK statements.

"*… as seen in the teaching practice, teachers are able to use language that is appropriate to the age and level of cognitive development of students when explaining science concepts*". (MSK participants)

However, other participants expressed more critical views, concerns about the dominance of the lecture method and the lack of practical activities. As stated by IMA.

"*Teachers still use more lecture methods, which limits student engagement, and there are rarely any experiments or science activities that involve direct practice*". (IMA participants)

These different views illustrate the inconsistent application of PCK principles in science classes.

Theme 2.3. Challenges in PCK Implementation

Participants identified personal and external factors that hinder the effective implementation of PCK in science learning. These challenges are divided into two subthemes: personal (internal) challenges and external challenges.

Subtheme 2.3.1. Personal (Internal) Challenges

Many participants mentioned difficulties in selecting appropriate teaching strategies and aligning them with science content, as conveyed in interview excerpts from TEP participants.

"*The biggest challenge for me is how to align teaching methods with the characteristics of the material. For example, when I want to teach science material about the properties of light, I thought using the Problem Based Learning (PBL) model would be suitable, but it turned out not to be. Sometimes, I feel I am not capable enough*". (TEP participants).

Although the previous theme highlighted the ability to relate science material to everyday life, some prospective teachers still reported difficulties in making such connections or in implementing an interdisciplinary approach.

"*I sometimes find it difficult to provide everyday examples related to science topics or relate the content to other school subjects*". (DK participants).

Subtheme 2.3.2. External Challenges

In addition, prospective elementary school teachers also highlighted facing external obstacles that affect the implementation of PCK in science learning. One of these challenges is the heavy administrative workload, such as preparing teaching modules and learning materials, which tends to divert their focus from planning interesting and meaningful teaching strategies for students.

"*I spend too much time preparing lesson plans and documents rather than planning interesting learning.*" (MU Participants)

This finding reflects the need for personal career development and institutional support to enable effective implementation of science PCK.

Theme 2.4. Science PCK Development Strategies

In response to the challenges faced, researchers sought to explore their perspectives on strategies to improve their understanding of PCK in science. This resulted in the identification of several subthemes: direct teaching practice, higher education, professional development, and teacher collaboration.

Subtheme 2.4.1 Direct Teaching Practice

Participants emphasized the importance of direct teaching practice as a means to develop pedagogical competence, as conveyed by DK participants.

"*I think that direct teaching practice can significantly support the development of pedagogical skills. Through this experience, I faced unexpected situations that required me to think quickly and determine the right actions to take*". (DK Participants)

Subtheme 2.4.2. Higher Education

Some participants viewed pursuing advanced degrees as a way to deepen their understanding of science pedagogy and content.

"… *perhaps also by continuing higher studies, such as taking a master's degree*". (IMA Participants).

Subtheme 2.4.3. Professional Development and Teacher Collaboration

Participants also recognized the importance of workshops, mentoring, and structured training programs in strengthening PCK as well as the importance of peer interaction and collegial support.

"*Collaboration between teachers actually helps to improve this competency (PCK). This can also be improved through ongoing training, mentoring, and self-evaluation by the prospective teachers themselves.*". (DKP Participants)

Collectively, these strategies demonstrate prospective teachers' awareness of multiple pathways to improving science teaching competency. These findings illuminate the complex interplay between individual preparation and systemic support in shaping how PCK is understood and implemented by future elementary science educators. The following section discusses the implications and interpretations of these results based on the existing literature.

DISCUSSION

The first question: "How do the perceptions of prospective elementary school teachers regarding their pedagogical content knowledge (PCK) in science?"

Perceptions of science PCK indicate that student teachers have a basic understanding of science PCK, particularly in five main dimensions: pedagogical orientation, learner characteristics, curriculum, teaching strategies, and assessment strategies. This supports the multidimensional model proposed by Magnusson et al. (1999), which identified similar domains as important components of science PCK.

Pedagogical orientation is a central component of the PCK framework in supporting science education (Friedrichsen & Dana, 2005), with an emphasis on inquiry-based orientation that aligns with student-centered teaching practices (Pedaste et al., 2015). This orientation is an important element in science education (Strat et al., 2023). The activity-based orientation emphasizes active student engagement through strategies such as questioning, eliciting student responses, and involving students in class tasks, which distinguishes it from traditional lecture-based methods (Magnusson et al., 1999; Prince, 2004).

The reflects prospective teachers' awareness of the abstract nature of science content, which encourages the use of instructional media to bridge abstract concepts into more concrete representations appropriate for elementary school students' cognitive development (Demirdöğen et al., 2015; Magnusson et al., 1999). Understanding these orientations is critical to effective science teaching, influencing instructional design, assessment strategies, content selection, and textbook use (Faize & Alribdi, 2024). Participants recognized the importance of inquiry-based, student-centered, active learning approaches, and didactic orientation in developing their PCK, in line with Subramaniam (2021) findings on the significant impact of teaching orientation on PCK development.

Prospective teachers' understanding of student learning in science was reflected in two subthemes: recognizing students' prior knowledge and identifying learning difficulties. Most participants emphasized the importance of prior assessments, such as pre-tests, diagnostic assessments, and exploratory activities, to measure students' starting points. While they considered diagnostic tests effective for understanding prior knowledge, these assessments were primarily designed to identify students' learning difficulties (Huhta, 2008; Black, 1983). However, some misunderstandings about the role of pretesting suggest the need for deeper conceptual training in assessment theory. However, proactive instructional responses, such as simplifying content and contextualizing abstract concepts, demonstrate practical pedagogical reasoning that is aligned with developmentally appropriate science instruction (Santrock, 2018; Demirdöğen et al., 2015).

Participants' knowledge of the curriculum reflects a mix of formal and intuitive approaches. While some participants adopted structured models such as the ABCD framework (Ansyari & HUI, 2018), others relied on general pedagogical intuition based on student development. This variability highlights gaps in consistent curriculum training but also reflects an adaptive, student-centered planning mindset (Lee & Takahashi, 2011). Elementary prospective teachers demonstrated efforts to develop science teaching materials that were aligned not only with the curriculum and learning outcomes, but also with students' actual conditions, including cognitive levels, socio-cultural backgrounds, and learning needs. Their understanding of why science is taught in a particular way at the elementary school level is closely related to how they conceptualize science and how these concepts shape their classroom practices (Fitzgerald & Smith, 2016). The science education framework in the curriculum emphasized student-centered practices that aimed to foster creativity and problem-solving skills for everyday life (Aidoo, 2024).

Understanding of science teaching strategies, prospective teachers expressed the view that effective science content instruction involves the use of a variety of teaching models, multi-method approaches (especially experiments), and multimedia tools. These findings are in line with the goals of science education, which include understanding scientific concepts through hands-on activities (Y.-M. Huang et al., 2010) and encouraging student engagement in the problem-solving process (Levy & Mensah, 2021). Strategies for the characteristics of science content, prospective teachers believed that teaching strategies should include connecting lesson content to real-world events. Given that some science concepts cannot be directly observed (Zydney & Warner, 2016), underscores the continued need for targeted support in science-specific pedagogy. Prospective teacher students who choose to specialize in science are expected to be able to manage learning that is enjoyable and meaningful for students (Botes, 2024).

Although participants demonstrated awareness of inquiry-based and student-centered science approaches, their reported teaching practices were still dominated by teacher-centered methods, such as lectures and limited practical activities. This reflects a modernization gap in science education, where pedagogical understanding of contemporary approaches has not yet been fully translated into innovative learning practices. Recent literature suggests that student-centered learning is no longer limited to traditional inquiry but encompasses adaptive, technology-integrated, and personalized pedagogies. A study by Zourmpakis et al. (2024) demonstrated that adaptive gamification in science learning can go beyond traditional inquiry by dynamically adjusting learning challenges to suit student performance and motivation. Compared to these innovations, participants' practices demonstrated a procedural understanding of student-centeredness, likely influenced by limited exposure to innovative science teaching models and the complexity of implementing modern pedagogies that require the integration of PCK, technological pedagogical knowledge, instructional design skills, and institutional support.

The final theme, science learning assessment strategies, consists of two main subthemes: test-based and non-test-based assessments. For the cognitive domain, most participants reported using written tests to measure students' mastery of science concepts. In assessing science process skills (psychomotor domain), prospective teachers employed non-test approaches such as direct observation, performance assessment, authentic assessment, and portfolios, which are seen as effective tools for documenting both the process and outcomes of student learning (Sar et al., 2024). Portfolios, in particular, were valued for capturing students' scientific thinking throughout their learning experiences. For the affective domain, scientific attitudes were evaluated through observation-based discussions during experimental activities. Overall, the assessment strategies described by participants reflect an understanding aligned with the nature of science learning, encompassing science as product (concepts), process (skills), and way of thinking (scientific attitudes and values).

Second question: "How do the perceptions of prospective elementary school teachers regarding the implementation of pedagogical content knowledge (PCK) in the context of science learning?"

Qualitative data analysis revealed four main themes: (1) characteristics of PCK understanding in science education, (2) realization of PCK in teaching practice, (3) challenges in mastering PCK, and (4) strategies for developing PCK. Contextually, PCK is understood as professional knowledge that integrates effective science content teaching by considering students' needs, prior knowledge, and background (Aktaş & Özmen, 2020). The core dimensions of science-related PCK include five elements: science teaching orientation, understanding of curriculum and subject matter, knowledge of student characteristics, understanding of effective teaching strategies, and ability to design aligned assessments.

Prospective teachers who demonstrate competency in these five areas are considered to have a strong foundation in basic PCK competencies that are essential for success as elementary school science educators. This understanding supports the development of reflective and contextual teaching practices that integrate content and pedagogy (Fakhriyah dkk., 2022). The realization of PCK in classroom practice shows contrasting perspectives among participants: positive and negative. On the positive side, some prospective teachers observed that teachers adjusted their language to students' cognitive levels, which is in line with national standards (Ministry of Education Regulation No. 16/2022).

In contrast, negative perspectives highlighted the continued dominance of lecture-based instruction that limits student engagement and reduces hands-on science activities (Davis et al., 2006). This suggests that current teaching practices have not fully adopted the student-centered approach emphasized in the Merdeka Curriculum. Therefore, science teachers are encouraged to design learning experiences that actively engage students in exploratory activities, which promote conceptual understanding and real-life connections (Huang et al., 2010; Vieira & Tenreiro-Vieira, 2016).

Challenges in implementing PCK arise from internal (personal) and external factors. Internally, prospective teachers report difficulties in selecting pedagogical strategies that align with the characteristics of science content and integrating science with students' everyday experiences or other school subjects (Hanuscin, 2013; Hwang et al., 2011; Levy & Mensah, 2021). These challenges indicate limitations in pedagogical reasoning skills. Externally, administrative burdens, such as lesson planning documentation, limit their focus on designing engaging teaching strategies.

To address these challenges, prospective teachers identified four primary PCK development strategies: hands-on teaching practice, pursuing higher education, participating in professional training, and engaging in teacher collaboration. These strategies reflect their recognition of the importance of ongoing professional development (Bullough, 2001). Well-designed teacher training programs, particularly those that are intensive, contextually relevant, and include follow-up school visits, have been shown to be highly effective in improving teaching quality and student achievement (Kraft et al., 2018; Castro et al., 2019). In addition, teaching practice plays an important role in shaping prospective teachers' pedagogical understanding. Limited teaching experience has been shown to have a negative impact on the level of PCK mastery (Koh et al., 2010). Therefore, providing prospective teachers with authentic teaching opportunities through field practice, structured training, and professional collaboration is essential to strengthen their readiness to implement meaningful and contextual science learning in elementary classrooms. Furthermore, drama-based science lectures can be an alternative for professional development (C.-H. Huang et al., 2024).

These findings collectively indicate that fostering science PCK among prospective teachers requires a systemic approach, one that integrates reflective practice, contextual learning opportunities, professional collaboration, and supportive institutional structures. Only through such a comprehensive strategy can prospective teachers be empowered to deliver science instruction that is both theoretically robust and practically effective.

This study involved prospective teachers enrolled in a STEM-based elective course, who likely possessed higher interest and motivation in science than the average elementary prospective teacher. This characteristic may have contributed to the relatively comprehensive understanding of science PCK reported in the findings. However, the persistence of implementation challenges even within this group suggests that the gap between conceptual understanding and practice may be more pronounced among prospective teachers with lower science affinity.

CONCLUSION

This qualitative study revealed that elementary prospective teachers hold a relatively comprehensive perception of the key components of Pedagogical Content Knowledge (PCK) in science teaching. Their understanding covers five essential elements: pedagogical orientation, student characteristics, curriculum content, instructional strategies, and assessment methods. Participants demonstrated awareness of inquiry-based and student-centered approaches, the importance of diagnosing students' prior knowledge, the need for varied teaching strategies, and the use of appropriate assessment methods.

However, the implementation of this understanding in actual teaching practices remains inconsistent. While some prospective teachers acknowledged the need to adapt instructional strategies to students' cognitive development stages, teacher-centered approaches still dominate, and hands-on science activities remain limited. These findings highlight the need for a more holistic reinforcement of PCK that integrates content mastery, pedagogical knowledge, understanding of student characteristics, and relevant assessment practices.

These findings have significant implications for teacher education institutions. There is a pressing need to strengthen programs that provide real and reflective teaching experiences, ensuring that prospective teachers' understanding of PCK moves beyond theoretical knowledge. Contextualized microteaching programs, field-based teaching practice, and enhanced reflective supervision should be prioritized to support the development of practical and effective PCK.

This study recommends conducting longitudinal research to track the development of prospective teachers' PCK from their university studies through their first year of teaching practice. Such research would provide deeper insights into the dynamics of PCK formation and implementation in real classroom contexts. Furthermore, future studies should involve prospective teachers from non-science backgrounds to explore how PCK is perceived and developed among teacher candidates with diverse academic specializations. This is crucial for identifying potential gaps in content knowledge, pedagogical approaches, and teaching confidence in science education.

This study is limited by the characteristics of its participants, who were all elementary prospective teachers enrolled in a STEM-based science education course. This may have introduced bias in interest and content mastery, potentially enhancing the depth of their PCK perceptions in science teaching. Given that elementary teachers are expected to teach multiple core subjects, including science, regardless of their academic specialization, these findings cannot be generalized to all elementary prospective teachers. Further research involving a more diverse participant pool is needed to gain a more comprehensive understanding of the PCK profiles of elementary prospective teachers in Indonesia.

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Ethical Statement

Ethical approval for this study was obtained from the Research Ethics Committee of IKIP PGRI Wates (Approval Number: 013/KEP-M/IPW/IV/2024) regarding the ethical feasibility of research involving human participants. All participants voluntarily took part in the study and provided informed consent prior to data collection.

Competing Interests

The authors declare that they have no competing interests.

Author Contributions

The author's contribution is as follows 1) Atika Dwi Evitasari: research concept and design, collection and/or assembly of data, data analysis and interpretation, writing the article, and final approval of the article; 2) Insih

Wilujeng: data analysis and interpretation, and critical revision of the article; 3) Entoh Tohani: research concept and design, and final approval of the article; 4) Anita Dewi Astuti: collection and/or assembly of data, data analysis and interpretation, writing the article, final approval of the article; 5) Merti Triyanti: research concept and design, collection and/or assembly of data, data analysis and interpretation, and writing the article; 6) Faridl Musyadad: research concept and design, data analysis and interpretation, and critical revision of the article.

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