Primary: Jurnal Pendidikan Guru Sekolah Dasar
journal homepage: https://primary.ejournal.unri.ac.id/
contents lists available at SINTA and DOAJ

Vol. 15 No. 3 (2026): June
https://doi.org/10.33578/jpfkip.v15i3.641-652

Beyond the surface: a narrative inquiry into the transformation of prospective teachers' pedagogical content knowledge for early numeracy

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Article info

Keywords:
early numeracy,
narrative inquiry,
pedagogical content knowledge,
prospective teachers.

Abstract

This study explores how prospective teachers' Pedagogical Content Knowledge (PCK) for early numeracy is articulated and reconstructed across different stages of teacher education. While prior research has examined PCK development, limited attention has been given to how prospective teachers at varying stages conceptualize and integrate numeracy knowledge within practice. Addressing this gap, the study aims to compare narrative representations of PCK among prospective teachers at early, intermediate, and final stages of their preparation. Adopting a qualitative narrative inquiry approach, data were collected from six participants through in-depth interviews and classroom observations within a single semester. Rather than tracking the same individuals over time, the study contrasts developmental perspectives across stages. Data were analyzed using thematic-narrative analysis to identify patterns in how PCK is understood and enacted.The findings reveal three interconnected trajectories: (1) From Abstraction to Awareness, reflecting a shift from procedural to more conceptual understandings of numeracy; (2) Awakening the Need for Concreteness, indicating increasing recognition of the role of representations and manipulatives; and (3) Pedagogical Integration in Action, illustrating emerging alignment between content knowledge and instructional strategies. These trajectories are synthesized into a meta-narrative that highlights the role of reflection, field experiences, and dialogic engagement in shaping PCK. The study contributes to the literature by offering a stage-based narrative perspective on PCK in early numeracy, providing insights for structuring teacher education programs. However, findings are limited to a small sample within a specific institutional context and should be interpreted accordingly. Implications highlight the importance of integrating reflective practice and field-based experiences to support prospective teachers' pedagogical development.

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DOI: https://doi.org/10.33578/jpfkip.v15i3.641-652
Received 16 February 2026; Received in revised form 22 April 2026; Accepted 24 May 2026
Available online 30 June 2026
e-ISSN 2598-5949 | p-ISSN 2303-1514 © The Authors.

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1. Introduction

Early numeracy constitutes a fundamental foundation for long-term success in mathematics learning at the primary education level. Early numeracy encompasses foundational understandings of numbers, basic operations, patterns, and measurement, which serve as the basis for more advanced mathematical reasoning (Nanda & Rani, 2025; Bezuidenhout, 2022). Empirical studies indicate that mastery of early numeracy is strongly associated with later mathematical achievement and students' readiness to engage with more complex academic challenges (Liu et al., 2025). Conversely, difficulties in early numeracy may hinder cognitive development in mathematics and contribute to the emergence of mathematics anxiety, with effects that can persist into adulthood (Skagerlund et al., 2019). These findings underscore the importance of strengthening early numeracy instruction in primary education.

In this context, primary school teachers play a crucial role in mediating students' mathematical understanding (Afrillia & Purnomo, 2025). Effective instruction requires not only strong Content Knowledge (CK) but also the ability to transform such knowledge into meaningful learning experiences that are developmentally appropriate for students. This integration is conceptualized as Pedagogical Content Knowledge (PCK), a construct that emphasizes how teachers represent and adapt subject matter to facilitate student understanding (Shulman, 1986; Ahmed & Shogbesan, 2023). Particularly in early numeracy, abstract concepts must be translated into concrete representations, highlighting the critical importance of well-developed teacher PCK.

However, despite its recognized importance, a growing body of research consistently shows that prospective teachers often struggle to integrate content knowledge with appropriate pedagogical strategies. Studies have found that although prospective teachers may demonstrate procedural understanding of mathematical concepts, they often fail to provide conceptually meaningful explanations aligned with students' thinking (Stovner & Klette, 2022). Similarly, other research indicates that prospective teachers tend to approach mathematics instruction in abstract ways, limiting their capacity to design engaging and comprehensible learning experiences (Geraghty, 2021). In addition, limitations in diagnosing students' misconceptions and the underutilization of visual or concrete representations remain evident in early numeracy instruction (Kurudirek et al., 2025).

These challenges reflect a persistent gap between theoretical knowledge and practical application in teacher education. In many programs, content knowledge and pedagogical knowledge are still treated as separate domains, thereby constraining prospective teachers' opportunities to develop integrated and practice-oriented PCK. Although previous studies have examined PCK in teacher education, most have focused on static descriptions of knowledge profiles or the effects of specific interventions such as microteaching (Appova & Taylor, 2020; Gultom & Mampouw, 2019; Ningsih & Juandi, 2020). Such approaches often overlook how PCK is conceptually constructed and reinterpreted across different stages of teacher preparation.

Based on this review, three key gaps can be identified. First, there is a lack of studies that explicitly compare how early numeracy PCK is conceptualized across different stages of primary teacher education. Second, the existing literature is largely dominated by static or cross-sectional approaches that do not adequately capture the dynamic and interpretive nature of PCK development. Third, limited attention has been given to the use of narrative inquiry as a methodological approach to explore how prospective teachers make sense of their pedagogical experiences over time.

To address these gaps, this study adopts a narrative inquiry approach to examine how prospective primary teachers at different stages of their preparation articulate and reconstruct

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[e-**ISSN 2598-5949** | p-**ISSN 2303-1514**]

their PCK for early numeracy. Narrative inquiry is particularly well-suited to this purpose, as it enables an in-depth exploration of lived experiences, reflections, and meaning-making processes that shape the development of professional knowledge. Through this approach, the study identifies three thematic trajectories of PCK development—From Abstraction to Awareness, Awakening the Need for Concreteness, and Pedagogical Integration in Action—which collectively illustrate how prospective teachers interpret and integrate content and pedagogy in their teaching practices.

This study makes three main contributions. Conceptually, it offers a narrative perspective on early numeracy PCK, extending the existing literature that predominantly relies on static representations. Methodologically, it demonstrates the value of narrative inquiry in capturing the complexity of teacher knowledge development. Practically, the findings provide insights for designing teacher education programs that more effectively integrate theoretical learning with reflective and field-based experiences.

Accordingly, this study is guided by the following research questions: 1) How do prospective primary teachers at different stages of their education conceptualize Pedagogical Content Knowledge for early numeracy? 2) What patterns of development can be identified in their narratives of learning and teaching experiences? 3) How do experiences and reflections contribute to the development of their PCK?

2. Method

This study employed a qualitative narrative inquiry approach to explore how prospective primary teachers at various stages of their education construct and interpret their pedagogical content knowledge (PCK) for early numeracy. This approach was selected because it enables an in-depth examination of lived experiences, personal meaning-making, and reflective processes that shape professional knowledge. Through narrative accounts, researchers can capture how individuals interpret their experiences and reconstruct professional understanding over time (Caine et al., 2019; Scheffelaar et al., 2021). In the context of teacher education, narrative inquiry is particularly useful for examining how prospective teachers reflect on learning experiences and how these reflections contribute to pedagogical reasoning and professional knowledge (Korthagen, 2017; Forsler et al., 2024).

Rather than adopting a longitudinal design, this study utilized a cross-stage comparative design. Participants were drawn from different stages of teacher preparation—early, intermediate, and advanced—within a single academic semester. This design enabled the study to identify patterns in the development of PCK, as represented in the participants' narratives, without tracking the same individuals over extended periods. By comparing the narratives of participants at different stages of their training, the study aimed to reveal how conceptions of early numeracy teaching evolve as prospective teachers progress through their professional preparation. The research was conducted within a primary teacher education program at a public university in Indonesia. The program integrates coursework in mathematics content, pedagogical theory, and field-based teaching practice. Prospective teachers in the program engage in various forms of teaching preparation, including microteaching sessions and school-based practicum experiences that allow them to apply theoretical knowledge in practical instructional settings. This context provided a suitable environment for examining how prospective teachers connect their mathematical content knowledge with pedagogical strategies in the teaching of early numeracy.

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The participants consisted of six prospective teachers selected using a maximum variation sampling strategy to represent different stages of teacher preparation. Two participants were first-year students, representing the early stage of teacher education; two were second-year students, representing the intermediate stage; and two were final-year students, representing the advanced stage. Inclusion criteria required that participants be actively enrolled in the teacher education program, have completed at least one mathematics education course, and be willing to participate in both interviews and classroom observations. This sampling strategy aimed to capture diverse perspectives and allow comparisons across stages of preparation regarding how PCK for early numeracy is articulated and enacted.

Data were collected over one academic semester using three primary sources: in-depth interviews, classroom observations, and teaching artifacts. Each participant completed two in-depth interview sessions, each lasting approximately 60–90 minutes. The interviews focused on the participants' experiences in learning and teaching mathematics, their beliefs about early numeracy instruction, the challenges they encountered, and their reflections on their teaching practices. Open-ended questions were used to encourage narrative responses, allowing participants to describe meaningful learning experiences and turning points in their understanding of mathematics teaching. For example, participants were asked to describe moments when their understanding of how to teach mathematics changed or when they recognized the importance of certain instructional strategies.

Classroom observations were conducted during microteaching sessions and teaching practicum activities, with one to two observations for each participant. Field notes were taken to document instructional strategies, the use of visual or concrete representations, student engagement, and the extent to which participants aligned mathematical content with pedagogical approaches. In addition to interviews and observations, teaching artifacts were collected to provide further insight into the participants' pedagogical reasoning. These artifacts included lesson plans, student worksheets, and instructional media designed by the participants. Collecting these materials allowed the researcher to examine how prospective teachers translated their conceptual understanding of early numeracy into concrete instructional designs.

The use of multiple data sources enabled triangulation across narrated experiences, observed teaching practices, and documented instructional materials. This triangulation strengthened the credibility of the findings by allowing comparisons among participants' interview reports, observations of teaching activities, and the ways instructional intentions were reflected in their teaching documents.

Data analysis followed a thematic-narrative approach involving several iterative steps. First, narrative reconstruction or restorying was conducted. Data from interviews, observations, and teaching artifacts for each participant were organized chronologically and reconstructed into coherent narrative accounts. This process helped highlight key experiences, turning points, and shifts in pedagogical understanding related to early numeracy instruction.

Second, thematic coding was conducted to identify recurring patterns across participants' narratives. The coding process was inductive and focused on themes related to the development of PCK, including awareness of students' thinking, the use of representations in teaching, and the integration of mathematical content with pedagogical strategies. Through repeated reading and comparison of narratives, emerging themes were refined and categorized to represent patterns in participants' experiences.

Third, cross-stage comparisons were conducted to examine how themes varied among participants at the early, intermediate, and advanced stages of teacher preparation. This

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comparative analysis enabled the identification of developmental tendencies in how PCK for early numeracy was conceptualized and enacted. Finally, the interpretations generated through thematic analysis were validated through member checking and peer debriefing. Narrative summaries were shared with participants to confirm the accuracy of interpretations and provide opportunities for clarification. In addition, peer discussions with colleagues in mathematics education were conducted to review coding decisions and strengthen the credibility of thematic interpretations.

Several strategies were employed to ensure the study's trustworthiness. Triangulation was implemented by integrating data from interviews, classroom observations, and teaching artifacts. Member checking was used to validate the authenticity of participants' narratives, while thick descriptions were provided to capture the contextual details of participants' experiences. Peer debriefing further reduced interpretive bias by enabling external review of analytical decisions.

The researcher's positionality was also acknowledged as part of the research process. As a lecturer in mathematics education, the researcher possessed professional familiarity with the context of teacher preparation, which provided insight into participants' experiences but also posed the possibility of interpretive bias. To address this issue, reflective memos were maintained throughout the research process in order to critically examine assumptions and interpretations during both data collection and analysis.

Ethical considerations were carefully addressed in conducting the study. Ethical approval was obtained from the Research Ethics Committee of the Faculty of Education at the affiliated university. All participants provided informed consent prior to participation in the study. Confidentiality and anonymity were ensured through the use of pseudonyms and secure data storage procedures. Participants were also informed of their right to withdraw from the study at any point without any consequences.

3. Results

This section presents the findings through three interrelated themes that represent how prospective teachers at different stages of their education conceptualize and enact Pedagogical Content Knowledge (PCK) for early numeracy. The findings are based on triangulated data from interviews, classroom observations, and teaching artifacts. To provide an integrated overview, Table 1 summarizes how each theme is reflected across the three data sources and across stages (early, intermediate, and advanced). The table highlights the alignment between participants' narratives (what they say), observed practices (what they do), and lesson plans (what they design).

Table 1. Integrated summary of PCK across data sources

Theme	Stage	Narrative Insight (Interview)	Observed Practice	Lesson Plan Evidence
From Abstraction to Awareness	Early to Intermediate	Participants described number teaching as procedural and abstract, often neglecting how students conceptualize numbers. One shared, "I just explained without thinking about using concrete objects," while another admitted, "I used	Both participants relied on verbal explanations with little to no visual aids or manipulatives. Lessons were delivered in a teacher-centered manner.	Lesson plans emphasized symbolic computation, omitted student-centered tasks, and lacked visual or concrete materials.

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Theme	Stage	Narrative Insight (Interview)	Observed Practice	Lesson Plan Evidence
		formulas but never thought about how students actually see the numbers."		
Awakening the Need for Concreteness	Intermediate to Final	Participants became aware of the need for tactile and visual aids. One noted, "Bottle caps made place value easier," while another reflected, "Students understood more when I used drawings and real items."	Lessons included drawings, bottle caps, and contextual tools to aid comprehension; student engagement was more evident.	Revised plans integrated manipulatives and real-world scenarios to bridge abstract concepts with student experience.
Pedagogical Integration in Action	Final Stage	Participants showed reflective instructional planning. One stated, "I think first about what students already understand," and another added, "I try to connect numbers with real-life situations."	Observations revealed adaptive sequencing, anticipation of misconceptions, and integration of student responses into teaching. However, peer collaboration and emotional sensitivity were less evident.	Lesson plans aligned learning goals with prior knowledge, incorporated scaffolding, and used flexible instructional strategies.

Following Table 1, the findings are elaborated narratively to illustrate each theme with representative evidence.

Theme 1: From Abstraction to Awareness

At the early stage, participants predominantly described teaching numeracy in procedural and abstract terms, with limited attention to students' thinking processes. Interview data revealed that teaching was often perceived as delivering correct steps rather than facilitating understanding. For instance, one participant stated, *"I usually just explain the steps as I remember them. I did not think about using objects or how students understand the numbers."* This perspective was consistent with classroom observations. During microteaching sessions, participants relied heavily on verbal explanations and symbolic representations written on the board, with minimal use of visual or concrete supports. Students' responses were rarely explored beyond correctness. Teaching artifacts further supported this pattern. Lesson plans emphasized computational procedures and lacked activities that engaged students conceptually. Tasks were generally teacher-centered, with limited opportunities for exploration or interaction.

However, across participants, there were early indications of emerging awareness. Some began to question the effectiveness of purely procedural instruction. As one participant reflected:

"I realized that even if I explain clearly, students may still not understand in the same way."

This shift marks the initial movement from surface-level teaching toward an awareness of the importance of students' conceptual understanding.

Theme 2: Awakening the Need for Concreteness

At the intermediate stage, participants demonstrated a growing recognition of the importance of concrete and visual representations in supporting students' understanding. Their narratives reflected a shift toward more student-centered thinking. One participant explained:

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"When I used bottle caps to teach place value, students understood more easily. They could see and count directly." Another added: *"Using pictures and real objects helped me explain ideas that were difficult before."*

Observational data confirmed this shift. Participants began incorporating manipulatives, drawings, and contextual examples into their teaching. Lessons showed increased student engagement, with more opportunities for interaction and questioning. Participants also demonstrated responsiveness to students' confusion, adjusting explanations during instruction. Teaching artifacts at this stage showed corresponding changes. Lesson plans included activities using concrete materials and real-life contexts. Tasks were more varied and began to reflect an effort to connect abstract concepts with students' experiences.

This theme represents a pedagogical awakening, in which participants not only recognize but also begin to enact the need for multimodal instructional strategies. However, their application was sometimes inconsistent, indicating that this phase involves experimentation rather than full integration.

Theme 3: Pedagogical Integration in Action

At the advanced stage, participants demonstrated a more integrated form of PCK, combining content understanding with pedagogical reasoning. Their narratives reflected deliberate instructional planning and consideration of students' prior knowledge. One participant stated:

"Now, before teaching, I think about what students already understand and how I can build from that." Another explained: *"I try to connect numbers with real-life situations so students can relate to them."*

Classroom observations supported these claims. Participants demonstrated adaptive teaching practices, including anticipating misconceptions, carefully sequencing instruction, and using formative feedback to guide learning. Concrete representations were meaningfully embedded in lessons rather than used as isolated tools.

Teaching artifacts further illustrated this integration. Lesson plans aligned learning objectives with instructional strategies and included scaffolding techniques. Activities were designed to progressively support student understanding, indicating a more sophisticated level of pedagogical reasoning. Despite these strengths, evidence related to collaboration and affective sensitivity was limited. While some observational notes suggested individual responsiveness to students, there was insufficient consistent data to draw strong conclusions about these aspects. Therefore, any interpretation regarding these domains should be considered tentative and requires further investigation.

Cross-Theme Synthesis

Across the three themes, the findings suggest a progressive but nonlinear pattern in how PCK is articulated and enacted. Rather than a fixed sequence, participants' development reflects iterative movement between understanding, experimentation, and integration. The triangulated data demonstrate coherence between what participants expressed, what they enacted in practice, and what they designed in their lesson plans. Narrative inquiry enabled the identification of these patterns by capturing how participants interpret their experiences and reconstruct their pedagogical understanding. Overall, the findings highlight that the development

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of PCK for early numeracy is shaped by the interaction between coursework, teaching practice, and reflective processes, rather than by a single instructional intervention.

4. Discussion

This study provides a stage-based narrative perspective on how prospective primary teachers conceptualize and reconstruct Pedagogical Content Knowledge (PCK) for early numeracy. Rather than merely confirming existing findings, the results extend prior research by illustrating how PCK is not only possessed but interpreted, negotiated, and enacted differently across stages of teacher preparation.

The first theme, From Abstraction to Awareness, confirms previous research indicating that early-stage prospective teachers often rely on procedural knowledge while paying limited attention to students' conceptual understanding (Dewi et al., 2021). However, the present study adds nuance to this finding by suggesting that such a tendency should not be viewed merely as a deficit. Rather, it represents an initial interpretive framework in which teaching is understood primarily as the transmission of knowledge (Özpınar & Arslan, 2022).

Through narrative reflections, participants gradually began to question this orientation, indicating that awareness of prospective teachers' thinking did not emerge automatically but developed through reflective engagement with teaching experiences. This finding aligns with studies emphasizing the role of reflection in teacher learning (Schön, 2017; Korthagen, 2017). In this sense, the study extends existing literature by highlighting reflection as a catalyst for conceptual awareness, rather than portraying PCK development as a purely linear accumulation of knowledge.

The second theme, Awakening the Need for Concreteness, aligns with research emphasizing the importance of representations and manipulatives in early numeracy learning (Sikhwari & Feza, 2024). However, beyond confirming their effectiveness, this study demonstrates that prospective teachers gradually internalize the pedagogical value of concreteness through practice, rather than merely through theoretical instruction. The shift observed across stages suggests that exposure to teaching contexts enables prospective teachers to reinterpret abstract mathematical knowledge into more accessible forms. This supports the view that PCK development is situated and experience-dependent, reinforcing the importance of integrating field-based learning into teacher education (Afrillia & Purnomo, 2025).

The third theme, Pedagogical Integration in Action, reflects a more advanced stage in which prospective teachers begin to integrate content knowledge, pedagogical reasoning, and knowledge of learners. This finding is consistent with Shulman's (1986) conceptualization of PCK as the transformation of subject matter into teachable forms. However, the present study further contributes by showing that such integration is not merely a cognitive achievement but also a reflective, context-sensitive process, shaped by ongoing interaction among planning, teaching, and reflection (Alghifari et al., 2023). In this sense, the findings extend prior work by illustrating how PCK is enacted as a dynamic practice, rather than a stable body of knowledge.

Importantly, this study highlights that PCK development across stages is progressive but nonlinear (Banjo, 2019). Participants' narratives indicate that movement between abstraction, experimentation, and integration occurs iteratively rather than sequentially. This challenges simplified developmental models and suggests that teacher education programs should not assume uniform progression, but rather provide continuous opportunities for reflection, practice, and feedback (Tangkin, 2022).

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In relation to existing literature, the key contribution of this study lies in its methodological approach. While previous studies on PCK in teacher education have largely relied on quantitative measures or static descriptions, this study uses narrative inquiry to reveal how prospective teachers make sense of their experiences and reconstruct their pedagogical understanding over time. This approach enables the identification of developmental patterns that may not be visible through conventional assessments, particularly the shifts in meaning, awareness, and instructional reasoning that underpin PCK growth.

Nevertheless, the findings should be interpreted with certain limitations in mind. The study involved a small number of participants within a single institutional context, which limits the generalizability of the results. In addition, the cross-stage design captures differences across groups rather than tracking individual development over time. Therefore, the identified trajectories should be understood as representative patterns rather than definitive developmental sequences.

From a practical perspective, the findings suggest that teacher education programs should move beyond separating content and pedagogy and instead design integrated learning experiences that connect theory, practice, and reflection. Structured opportunities such as microteaching, guided practicum, and reflective dialogue can support prospective teachers in developing more coherent and responsive PCK for early numeracy.

Future research could extend this work by examining more diverse contexts or by employing longitudinal designs to follow the same participants into their early years of teaching. Such studies would provide deeper insight into how PCK continues to evolve beyond initial teacher education and how narrative processes shape long-term professional learning.

5. Conclusion and implications

This study explored how prospective primary teachers at different stages of teacher education conceptualize and enact Pedagogical Content Knowledge (PCK) for early numeracy through a cross-stage narrative comparison. The findings reveal that PCK development is reflected in three interconnected patterns. Initially, prospective teachers tend to rely on procedural and abstract approaches when explaining mathematical concepts. As they progress through their teacher education program, they increasingly recognize the importance of using concrete representations to support students' conceptual understanding. At more advanced stages, their pedagogical reasoning becomes more integrated, demonstrating greater awareness of students' prior knowledge, learning difficulties, and instructional needs.

Importantly, the findings do not suggest a strictly linear or longitudinal transformation of PCK. Instead, the results indicate that these patterns represent developmental tendencies that emerge across different stages of teacher preparation. These tendencies appear to be shaped by the interaction between coursework, teaching practice, and reflective engagement with instructional experiences. By examining narratives from participants at different stages of preparation, the study provides a more nuanced understanding of how PCK is interpreted and enacted, highlighting that it evolves through ongoing interaction between theoretical knowledge and practical teaching experiences rather than being acquired as a fixed professional competence.

From a methodological perspective, this study demonstrates the value of narrative inquiry for investigating the development of teacher knowledge. Narrative approaches allow researchers to capture shifts in pedagogical reasoning that may remain invisible in conventional descriptive or quantitative studies. By focusing on lived experiences, reflections, and personal

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interpretations, narrative inquiry provides insight into how prospective teachers make sense of teaching early numeracy within specific instructional contexts. This methodological contribution highlights the potential of narrative-based research to deepen understanding of professional knowledge formation in teacher education.

Despite these contributions, several limitations should be acknowledged. First, the research employed a cross-sectional rather than a true longitudinal design, meaning that the same participants were not followed over time. Consequently, the findings should be interpreted as indicative patterns across stages rather than definitive evidence of developmental trajectories. Second, the number of participants was relatively small and limited to a single teacher education institution, which restricts the generalizability of the findings. Third, a substantial portion of the data was generated within microteaching and simulated classroom contexts. Although these settings provide valuable insights into instructional reasoning, they may not fully capture the complexity and unpredictability of authentic classroom environments.

In terms of practical implications, the findings suggest several directions for strengthening teacher education programs. First, teacher education curricula should more explicitly integrate mathematical content knowledge with pedagogical strategies, particularly in relation to early numeracy instruction. Second, structured opportunities for microteaching and guided practicum should be expanded to allow prospective teachers to experiment with instructional approaches and receive constructive feedback. Third, reflective activities should be systematically incorporated into coursework to foster pedagogical reasoning and professional awareness. Finally, learning experiences should emphasize concrete and contextual representations that help bridge abstract mathematical concepts with students' everyday experiences.

6. Limitation

This study has several limitations that should be considered when interpreting the findings. First, the study employed a cross-sectional rather than a longitudinal design, meaning it did not track the same participants over time. As a result, the findings reflect indicative developmental patterns rather than definitive trajectories of PCK development. Second, the number of participants was relatively small and limited to a single teacher education program.

Credit authorship contribution statement

First Author: Methodology, Formal analysis, Data curation, Conceptualization. **Second Author**: Resources, Project Administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request. Because the data include human participant information, they are not publicly available to protect participant privacy.

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Ethical Declaration

This study was conducted in accordance with the Declaration of Helsinki, and informed consent was obtained from all participants. Prior to enrollment, participants were fully informed about the study's purpose, procedures, and their right to withdraw at any time without consequence.

Declaration of AI statement

Portions of this manuscript were drafted, edited, or enhanced using ChatGPT-4 (OpenAI). The authors used this tool specifically to improve grammar and clarity in drafting an initial version of the Introduction section. All content generated by the AI was thoroughly reviewed, edited, and validated by the authors, who take full responsibility for the final content. The authors provided the prompts and edited the output to ensure accuracy and relevance.

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[e-**ISSN 2598-5949** | p-**ISSN 2303-1514**]