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Research Article

Pedagogical Content Knowledge and Human–Computer Interaction in Digital Early Mathematics Education: Fostering Mathematical Literacy among Pre-service Primary Grade Teachers

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ABSTRACT

This study looked at the relationship between Pedagogical Content Knowledge (PCK) and the academic performance of pre-service primary grade teachers in the class Teaching Mathematics in the Primary Grades and how these elements foster a mathematical literacy. The study adopted a mixed methods research strategy that included a quantitative descriptive-correlational survey and a systematic evaluation of international empirical works on Human–Computer Interaction (HCI) in mathematics education. Eighty-five third year bachelor of elementary education students of western mindanao state university were chosen using simple random sampling. PCK was tested by a modified 10-item Likert-scale instrument and academic performance was determined by official course grades. Descriptive analysis revealed a High level of PCK (M = 3.79, SD = 0.58), with adapting explanations to learners' needs receiving the highest rating (M = 4.00, SD = 0.55) and addressing student misconceptions the lowest (M = 3.51, SD = 0.85). Academic achievement was evaluated as Very Good (M = 1.79, SD = 0.33). The Pearson correlation analysis showed that there was a weak positive link between PCK and academic achievement although it was not significant (r =.128, p >.05). The systematic review highlights usability, adaptive feedback, learner engagement, cognitive scaffolding, multimedia support and intuitive interface design as key HCI concepts that facilitate mathematics learning and literacy. The results indicate that the use of evidence-based HCI techniques and pedagogical instruction may enhance instructional competence and mathematical literacy of prospective primary grade teachers.

Keywords: Pedagogical Content Knowledge, Human–Computer Interaction, Mathematical Literacy, Academic Performance, Early Mathematics Education, Pre-service Primary Grade Teachers

INTRODUCTION

Mathematics remains a foundational subject in primary education, serving as the bedrock for developing students' comprehension of advanced mathematical concepts and fostering essential skills like computational abilities, confidence, curiosity, and a constructive attitude toward problem-solving. Beyond the mechanical acquisition of numerical algorithms, contemporary educational paradigms place a significant premium on mathematical literacy—the capacity to identify, understand, and engage with mathematics to make well-founded judgments and decisions required of constructive, concerned, and reflective citizens. In early education, fostering mathematical literacy is deeply reliant on how effectively teacher education programs prepare pre-service teachers to translate theoretical concepts into developmental, interactive, and highly engaging lessons.The teacher's role is paramount in shaping students' mathematical experiences. Effective instruction in primary mathematics hinges heavily on a teacher's Pedagogical Content Knowledge (PCK)—their capacity to transform content into teachable and meaningful lessons. First conceptualized by Lee Shulman (1986), PCK represents the unique intersection of content knowledge and pedagogical knowledge. For pre-service teachers, this is a formative stage where theoretical knowledge is integrated with practical application. Studies emphasize that effective mathematics teaching goes beyond knowing the content; it requires the specific ability to explain, represent, and adapt instruction based on learners' developmental needs (DepEd, 2020).

Professional-development research demonstrates that when teachers engage in focused training around basic algebra and quantitative reasoning, their PCK improves, directly enhancing their confidence and effectiveness in teaching algebraic and arithmetic concepts clearly (Rupasinghe et al., 2023). However, pre-service teacher preparation programs often face challenges. While many pre-service teachers possess adequate content knowledge, their actual teaching performance and instructional quality vary widely based on their confidence and skill in applying pedagogical strategies (Abenoja et al., 2024). Furthermore, deficiencies in PCK can severely limit a teacher's ability to diagnose and address early learning difficulties, leading to a direct drop in the quality of mathematical literacy instruction in the primary classroom (Depaepe et al., 2013; Gönen & Kocakaya, 2016; Tokmak et al., 2019).

While the theoretical importance of PCK in supporting mathematical literacy is widely acknowledged, there remains a notable gap in research specifically examining how pre-service teachers' PCK directly correlates with their ratings of academic performance within specialized pedagogy courses. Specialized courses such as 'Teaching Mathematics in the Primary Grades' are critical for training future educators in lesson delivery, active learning strategies, and addressing learner misconceptions. By establishing whether PCK significantly correlates with academic performance, this research provides vital empirical evidence to inform and strengthen curriculum design, field exposure, and instructional training within teacher education programs.

STATEMENT OF THE PROBLEM

This study aimed to examine the level of pedagogical content knowledge (PCK) and the academic performance of pre-service mathematics teachers, as well as determine the relationship between these two variables in the context of fostering mathematical literacy in early childhood education. Specifically, it sought to answer the following questions:

1. What is the level of pedagogical content knowledge of pre-service mathematics teachers in teaching mathematics?

2. What is the academic performance of pre-service mathematics teachers in the subject course 'Teaching Mathematics in the Primary Grades'?

3. Is there a significant relationship between the pedagogical content knowledge of pre-service mathematics teachers and their academic performance?

4. What Human–Computer Interaction design principles are consistently identified across empirical studies to enhance mathematics learning among pre-service primary grade teachers?

Hypothesis

To guide the inferential analysis, the following null hypothesis was formulated:

H_0: There is no significant relationship between the pedagogical content knowledge (PCK) of pre-service mathematics teachers and their academic performance as reflected in their grades in the course 'Teaching Mathematics in the Primary Grades.

Significance of the Study

The results of this study are envisioned to provide valuable insights and practical benefits to the following stakeholders:

Pre-service Teachers — Helping them identify areas of strengths and weaknesses in their PCK, particularly regarding student misconceptions and lesson delivery, thereby improving their overall instructional skills and preparation for the classroom.

Teacher Education Institutions (TEIs) — Informing curriculum development and encouraging the integration of more targeted instructional designs, laboratory experiences, and active training sessions to better develop pre-service teachers' PCK.

School Administrators & Policy Makers — Providing empirical evidence to support policy decisions on teacher standards, professional development planning, and resource allocation aimed at improving the overall quality of mathematics and literacy instruction.

Mathematics Educators / Instructors — Empowering instructors to enhance their pedagogical approaches, identify specific areas of PCK needing stronger emphasis, and design better interventions for pre-service teachers.

Future Researchers — Serving as a robust theoretical and empirical baseline for subsequent investigations into the dynamic variables affecting pedagogical readiness, teacher performance, and student mathematical literacy.

Scope and Delimitation

This study was delimited to third-year Bachelor of Elementary Education (BEED) students enrolled at Western Mindanao State University (WMSU) during the academic year 2023-2024. Specifically, the respondents were those who had completed the course 'Teaching Mathematics in the Primary Grades' during the first semester. The assessment of PCK focused on the respondents' self-reported capability across content, pedagogical strategy, and learner-based instructional adjustments. Academic performance was delimited to the final grades obtained in the mathematics pedagogy course, which represents a composite metric of demonstration teaching performance, theoretical examinations, and course projects. Extraneous variables such as personal motivation, prior teaching experiences, socio-economic factors, and classroom environmental conditions were outside the scope of this study.

OPERATIONAL DEFINITION OF TERMS

Pedagogical Content Knowledge (PCK) — The specialized integration of mathematical content knowledge with appropriate pedagogical strategies. In this study, it was measured using the 10-item Likert scale questionnaire reflecting the respondents' capacity to explain concepts, adapt to struggling learners, and anticipate student misconceptions.

Academic Performance — The student's general weighted average (GWA) or final grade obtained in the course 'Teaching Mathematics in the Primary Grades.' This grade serves as an indicator of academic and theoretical readiness in primary mathematics instruction.

Pre-Service Teachers — Third-year students enrolled in the Bachelor of Elementary Education (BEED) program who are undergoing formal teacher preparation and have completed the mathematics pedagogy course.

Mathematical Literacy — The capacity of future educators to understand and apply mathematical concepts in real-world contexts, and their readiness to foster this foundational literacy among primary-grade learners through clear and responsive teaching practices.

REVIEW OF RELATED LITERATURE

Human–Computer Interaction (HCI) as a Strategy in Developing Mathematical Ability

Human–Computer Interaction (HCI) has been identified as a means of enhancing mathematics ability through the development of meaningful interaction between learners and digital learning systems. HCI is not merely about delivering instructional content; it is about the design of interactive systems that promote cognitive engagement, conceptual understanding, and problem-solving through intuitive interfaces, quick feedback, visualization, and adaptive learning support. Norman (2013) suggested that human-centered design allows learners to connect with technology more efficiently by removing usability barriers. Shneiderman et al. (2017) claimed that consistency, informative feedback and streamlined interaction increase the users' learning experiences.

In addition, Mayer (2005) noted that when designing multimedia learning environments based on cognitive principles, unnecessary cognitive burden is reduced and knowledge retention is improved. Similarly, Sweller, Ayres, and Kalyuga (2011) asserted that instructional technologies should reduce irrelevant cognitive processing, so that learners can concentrate on mathematical reasoning. Empirical evidence also points to the fact that interactive digital platforms based on HCI principles can greatly improve mathematical understanding by incorporating adaptive feedback, case-based learning, and scaffolded instruction to support learners' cognitive development and diagnostic skills in mathematics.

International research also recently prove more that HCI-based digital learning environments significantly affect mathematics ability through enhancing student motivation, engagement and higher order thinking skills . Kay (2020) observed that mathematics explanations' quality of pre-service teachers improved by visual supports, engagement strategies, and cognitive load reduction in interactive instructional videos. Similarly, dynamic mathematics learning objects have been demonstrated to increase learner's motivation and reduce cognitive load, which allows for more effective mathematical problem solving and conceptual understanding. Similarly, recent study on adaptive gamification in metaverse-based mathematics learning environments obtained considerable improvement in motivation for mathematics, cognitive engagement, and performance in problem-solving by means of individualized interaction and adaptive feedback systems.

Furthermore, Walter et al. (2023) found that a human-centered digital learning platform integrating principles of mathematics education and computer science design, such as usability, consistency, adaptive feedback and multimedia learning principles, significantly enhanced pre-service teachers' diagnostic competence. Together, these findings indicate that Human-Computer Interaction is a useful pedagogical approach to improve mathematical competence through the design of learner-centered digital environments that encourage active participation, conceptual understanding, and growth of mathematical literacy.

METHODOLOGY

Research Design

The study used an Embedded Mixed Methods Research Design with a quantitative survey as the major research method and a systematic review of empirical studies as the complementary approach. In Creswell (2014), mixed methods research refers to the use of both quantitative and qualitative or secondary sources of data to create a more complete knowledge of a study problem than each of the two methodologies could alone. Specifically, an embedded mixed methods design is one in which one type of data is embedded within another dominating method to improve the understanding of the results (Creswell & Plano Clark, 2018). The quantitative part of this research was utilized to identify the levels of pedagogical topic knowledge and mathematical literacy of pre-service primary grade teachers using a standardized survey instrument. The systematic review, on the other hand, synthesized empirical evidence from peer-reviewed international journals to identify Human–Computer Interaction (HCI) design principles that support mathematics learning. The review follows a thorough and transparent procedure for finding, selecting, assessing and synthesising the relevant papers to make sure the evidence is credible and reliable (Page et al., 2021). The results of the survey together with the synthesized evidence from the systematic review gave a holistic view of the combined impact of pedagogical content knowledge and Human–Computer Interaction in fostering mathematical literacy in pre-service primary grade teachers.

Research Locale

The study was conducted at the College of Teacher Education (CTE) within Western Mindanao State University (WMSU), located in Zamboanga City, Philippines. WMSU is a premier public university in the region, recognized for its comprehensive teacher preparation programs. The CTE provides a highly structured environment where pre-service elementary teachers undergo theoretical coursework and field-based laboratory teaching experiences, making it an ideal setting for this investigation.

Respondents and Sampling Design

The target population comprised 108 third-year Bachelor of Elementary Education (BEED) students who completed the specialized course 'Teaching Mathematics in the Primary Grades.' Using Slovin's formula with a margin of error of 5% ($e = 0.05$), a representative sample size of 85 respondents was determined. Simple random

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sampling via the lottery technique was utilized to select participants proportionally from each of the three BEED sections (BEED A, B, and C), ensuring that all eligible students had an equal, independent chance of selection.

Section	Total Respondents Per Section	Percentage Distribution
BEED A	30	35.29%
BEED B	28	32.94%
BEED C	27	31.76%
Total (N)	**85**	**100.00%**

Research Instruments

To measure PCK, the researchers adapted and modified a standardized 10-item questionnaire based on the work of Alcher Arpilleda (2024). The items focused on pedagogical content knowledge in early mathematics (e.g., choice of representations, adjusting instruction, and addressing learner misconceptions). The scale utilized a 5-point Likert-type response format (1 = Strongly Disagree to 5 = Strongly Agree). The interpretation scale for the mean scores is presented below:

Mean Range	Descriptor	Interpretation
4.00 – 5.00	Very High PCK	Demonstrates comprehensive, flexible, and accurate understanding of teaching mathematics.
3.00 – 3.99	High PCK	Shows strong understanding; able to explain and apply concepts with minimal difficulty.
2.00 – 2.99	Moderate PCK	Possesses basic understanding but struggles with complex concepts and applications.
1.00 – 1.99	Low PCK	Demonstrates limited understanding; has difficulty explaining and applying concepts.
0.00 – 0.99	Very Low PCK	Lacks understanding of essential concepts; unable to apply teaching knowledge.

Journal of Information Systems Engineering and Management
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Validity and Reliability of the Instruments

Content validity was established through rigorous review by a panel of three educational experts in early mathematics and pedagogy from the Integrated Laboratory School (ILS) Elementary Department. Following content validation, a pilot test was conducted with 30 non-respondent third-year BEED students to evaluate the clarity and suitability of the items. Reliability analysis yielded a Cronbach's alpha coefficient of 0.72, exceeding the standard threshold of 0.70, confirming that the instrument was internally consistent and reliable for data collection.

Ethical Considerations

To ensure complete ethical compliance, the research protocol was officially reviewed and approved by the Western Mindanao State University Research Ethics Office (WMSU-REO), receiving clearance code-UG-0394 and a Certificate of Exemption. Written informed consent was obtained from all participants prior to data collection. Participation was completely voluntary, and respondents were explicitly informed of their right to withdraw at any point without academic repercussions. Data confidentiality and participant anonymity were strictly protected under the guidelines of the Philippine Data Privacy Act of 2012 (RA 10173).

Statistical Treatment of Data

The collected data were analyzed using both descriptive and inferential statistics. To answer research questions 1 and 2, weighted mean and standard deviation were computed. For research question 3, which explored the relationship between PCK and academic performance, the Pearson Product-Moment Correlation Coefficient (Pearson r) was computed at a 0.05 level of significance. All statistical analyses were executed using professional statistical software to ensure mathematical accuracy.

RESULTS AND DISCUSSION

Pedagogical Content Knowledge (PCK) of Pre-Service Teachers

The first objective of the study was to evaluate the levels of PCK among the pre-service mathematics teachers. Table 3 presents the detailed item-by-item means, standard deviations, and qualitative interpretations.

Indicators of PCK	Mean	SD	Interpretation
1. Use teaching strategies that best fit the math topic.	3.96	0.52	High
2. Anticipate students' misconceptions in mathematics.	3.51	0.64	High
3. Adjust explanations when students struggle to understand.	4.00	0.55	Very High
4. Choose examples that help students grasp difficult	3.92	0.62	High

Journal of Information Systems Engineering and Management
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Research Article

concepts.			
5. Modify activities to align with mathematical skills developed.	3.88	0.64	High
6. Explain why certain solution methods are more effective.	3.60	0.49	High
7. Integrate representations (e.g., diagrams, models).	3.77	0.64	High
8. Evaluate if teaching approaches support learning.	3.77	0.75	High
9. Select instructional approaches for challenging concepts.	3.96	0.59	High
10. Anticipate and address common misconceptions.	3.51	0.85	High
Overall Weighted Mean	**3.79**	**0.58**	**High**

Academic Performance of Pre-Service Teachers

The second research question aimed to establish the academic performance of the pre-service teachers in their specialized pedagogy course. Table 4 displays the descriptive findings for this variable.

Variable	Mean	Highest Grade	Lowest Grade	SD	Descriptor
Overall Academic Performance	1.7882	1.25	2.00	0.326	Very Good

Relationship Between PCK and Academic Performance

The final research question sought to establish whether a significant relationship exists between PCK and academic grades. The results of the Pearson r correlation analysis are shown in Table 5.

Journal of Information Systems Engineering and Management
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https://www.jisem-journal.com/
Research Article

Variables	Pearson r	N	Sig. (2-tailed)	Descriptor	Decision on Ho
PCK & Academic Performance	0.128	85	0.245	Weak Correlation	Accept Ho (Not Significant)

Interpretation of Findings and Association with Mathematical Literacy

The descriptive analysis indicates that the pre-service primary-grade teachers possess a High level of Pedagogical Content Knowledge (M = 3.79, SD = 0.58). This is an encouraging finding, suggesting that the College of Teacher Education has successfully equipped future teachers with foundational pedagogical strategies and mathematical knowledge bases. Most notably, the respondents demonstrated an exceptional capacity to adjust their instructional explanations when learners struggle to understand a lesson (M = 4.00, SD = 0.55). This adaptive capability is a crucial component of early mathematical literacy instruction, as young children regularly encounter cognitive blocks that require spontaneous, diverse, and developmentally appropriate analogies.

However, a critical area for improvement was highlighted by the lowest-performing indicator: anticipating and addressing student misconceptions in mathematics (M = 3.51, SD = 0.85). In early education, mathematics learning is cumulative; unaddressed misconceptions in basic number sense, place value, or operations quickly compounded into severe learning obstacles that hinder long-term quantitative literacy. This finding suggests that while pre-service teachers excel in general instructional adaptability, they require deeper training in early diagnostic pedagogy—specifically, learning how to anticipate specific, localized cognitive hurdles and addressing them with target-oriented interventions.

Regarding academic performance, the pre-service teachers obtained an overall grade mean of 1.7882 (SD = 0.326), representing a 'Very Good' performance. This demonstrates that they possess a robust grasp of the academic content, theories, and instructional methodologies presented in the curriculum. The narrow standard deviation suggests that academic standards and student achievement in the BEED program are relatively uniform and consistent.

The core finding of this study is the weak and statistically non-significant correlation between PCK and academic performance ($r = 0.128$, $p > 0.05$). Consequently, the null hypothesis was accepted. While surprising at first glance, this outcome is highly consistent with emerging educational literature (Pangan & Magno,; Santos & Rivera, 2024). It indicates that academic performance in a university course—which is typically measured by written exams, structured assignments, and controlled demonstrations—does not directly predict or represent the complex, multi-dimensional nature of Pedagogical Content Knowledge needed in actual classroom environments. Actual teaching requires a high degree of spontaneous communication, real-time classroom management, emotional intelligence, and immediate adaptation to learner needs. Therefore, a student may achieve an outstanding grade in a theoretical course while still struggling to effectively deploy PCK to foster mathematical literacy in a dynamic classroom setting.

On the Human–Computer Interaction Design Principles that are Consistently Identified Across Empirical Studies to Enhance Mathematics Learning among Pre-Service Primary Grade Teachers

Empirical studies have consistently highlighted that Human–Computer Interaction (HCI) design for effective digital mathematics learning is based on usability, consistency, cognitive load reduction, immediate feedback, scaffolding, and learner-centered interaction (Shneiderman et al., 2017; Norman, 2013). Human-centered interfaces allow pre-service primary grade instructors to focus on mathematical reasoning instead of the mechanics of complex system navigation, hence facilitating better conceptual comprehension and mathematical literacy. Shneiderman et al. (2017) found that interface consistency and predictable navigation reduce errors and enhance user performance.

Journal of Information Systems Engineering and Management
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Research Article

While Norman (2013) stressed visibility, feedback, restrictions, mapping, and affordances as key principles for intuitive interaction. Mayer (2005) also emphasized the necessity of reducing extraneous cognitive processing through coherent multimedia presentations grounded on the Cognitive Theory of Multimedia Learning, while Sweller, Ayres, and Kalyuga (2011) promoted instructional designs that lessen unnecessary mental effort during learning based on the Cognitive Load Theory. Applying these ideas, Walter et al. (2023) showed that digital learning platforms with consistent interfaces, less memory burden and learner-centered interaction greatly improved the diagnostic competencies of pre-service mathematics teachers. In line with this, Rezat, Malik, and Leifeld (2022) found that scaffolding strategies including structured reading assignments, instructional videos, and guided activities in digital environments improved students' understanding of mathematical concepts by engaging with instructional resources meaningfully rather than passively consuming information.

International empirical research also identify "interactive feedback, visualization, learner engagement, and adaptive instructional support" as key HCI design elements for effective mathematics learning environments. Kay (2020) pointed out that the employment of instructional films with visual clues, short explanations, and opportunities for feedback led to a significant enhancement in the quality of mathematical explanations generated by pre-service teachers. Similarly, Gün and Taş (2021) have shown that digital mathematical activities are more effective when they incorporate authentic problem-solving situations, take into account learners' past knowledge, offer various solution pathways, and predict students' misconceptions.

More recently, Arslan, Frankenberg and Kjällander (2023) have shown that digital teacher-support systems that depict children's arithmetic development enable tailored scaffolding and instructional decision-making based on children's learning trajectories. Taken together, these studies indicate that HCI in math education is not merely about the aesthetics of an interface, but also includes evidence-based design concepts that foster usability, engagement, cognitive efficiency, adaptive feedback, and instructional scaffolding (Kay, 2020; Walter et al., 2023). These ideas build interactive digital environments that enhance pedagogical decision-making and promote mathematics literacy for pre-service teachers in the elementary grades.

CONCLUSIONS

Based on the results of this study, the following conclusions are drawn:

1. Pre-service primary-grade teachers at Western Mindanao State University possess a high level of Pedagogical Content Knowledge, showing strong readiness to adapt instructions but requiring target-oriented training in identifying and diagnosing student misconceptions.
2. The respondents demonstrate a very good level of academic achievement, indicating strong academic preparation and theoretical understanding.

3. Pedagogical Content Knowledge does not significantly correlate with academic course grades. This suggests that academic grades alone are insufficient metrics to fully capture or guarantee actual instructional effectiveness in fostering primary-grade mathematical literacy.

RECOMMENDATIONS

To enhance teacher preparation and better support the development of primary-grade mathematical literacy, the following recommendations are offered:

1. **Curriculum Enrichment —** Teacher education programs should integrate specialized diagnostic modules into mathematics pedagogy courses, focusing specifically on identifying, anticipating, and correcting common early childhood mathematical misconceptions.
2. **Enhanced Laboratory & Clinical Experiences —** Pre-service teachers should be provided with earlier and more frequent opportunities for field-based practice, microteaching simulations, and reflective teaching clinics to bridge the gap between academic theory and classroom reality.

3. **Alternative Assessment Models —** TEIs should explore multi-faceted evaluation systems that incorporate peer evaluations, classroom simulations, and student portfolios to supplement traditional grading systems and better measure practical PCK development.

4. **Fostering Literacy-Centric Instruction —** Instructors should emphasize the development of early quantitative and mathematical literacy strategies, encouraging pre-service teachers to design lessons that connect abstract concepts to practical, real-world contexts for primary learners.

5. **Expanded Research Directions —** Future researchers should conduct larger-scale longitudinal studies incorporating additional variables—such as communication competence, teaching efficacy, mathematics anxiety, and actual student learning outcomes—to map a more comprehensive model of teacher effectiveness.

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