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Pre-service mathematics teachers' pedagogical reasoning in museum-based mathematics instruction through AI-mediated reflective dialogue

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Abstract

Mathematics learning is often presented in abstract and procedural forms, making it difficult for students to connect mathematical ideas with meaningful real-world experiences. Museums offer authentic opportunities for contextual mathematics learning. Although previous studies have highlighted the educational potential of museum-based learning, little is known about how pre-service mathematics teachers develop pedagogical reasoning for designing museum-based mathematics instruction through AI-mediated reflective dialogue. This study investigated how pre-service mathematics teachers conceptualized museum-based mathematics learning and how AI-mediated reflective dialogue supported the development of their pedagogical reasoning. Using a qualitative approach, seventeen pre-service mathematics teachers participated in structured reflective dialogue sessions through the AISI chatbot platform. Data were collected through written interaction transcripts, revised responses, and semi-structured interviews and analyzed thematically. Initial responses showed that participants viewed museum-based learning as engaging and contextual but lacked instructional specificity and assessment alignment. Through iterative reflective dialogue, participants developed more coherent pedagogical reasoning by clarifying learning objectives, anticipating students' thinking, refining instructional procedures, and proposing more aligned assessment approaches. This study provides new insights into AI as a reflective scaffold for preparing pre-service mathematics teachers to design contextual and culturally grounded mathematics instruction.

Keywords: AI-mediated reflection; museum-based mathematics learning; pedagogical reasoning; pre-service mathematics teachers; reflective dialogue

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Introduction

Contemporary mathematics education increasingly emphasizes the importance of contextual, meaningful, and experiential learning to address students' persistent difficulties in understanding abstract mathematical concepts. When mathematics is taught mainly through symbols, formulas, and routine procedures detached from meaningful situations, students often struggle to develop conceptual understanding and to perceive mathematics as relevant to their everyday lives (NCTM, 2014). Such instructional practices may limit students' ability to apply mathematical reasoning in authentic contexts and can contribute to negative attitudes toward mathematics.

This challenge is also evident in the Indonesian context. Despite ongoing curriculum reforms that encourage meaningful and contextual learning, mathematics instruction in many schools continues to emphasize procedural fluency and routine problem solving. As a result, students often experience difficulties in connecting mathematical concepts with real-life situations and cultural contexts. This issue is reflected in Indonesia's performance in international assessments, where students continue to demonstrate limited mathematical reasoning and problem-solving abilities in authentic contexts (Leton et al., 2025; Tanudjaya & Doorman, 2020). These conditions underscore the need for innovative learning environments that enable students to experience mathematics as meaningful, contextual, and culturally connected.

In response to these concerns, researchers have advocated for learning environments that position mathematics within meaningful experiences. From a constructivist perspective, learning occurs when learners actively construct understanding through interaction with experiences and social contexts rather than passively receiving information (Larsari & Abouabdelkader, 2024; Wetering et al., 2022). Experiential learning theory similarly highlights the importance of reflection and concrete experience in shaping conceptual understanding (Illeris, 2007; Yardley et al., 2012). Within mathematics education, contextual learning approaches have been associated with stronger conceptual understanding, improved problem-solving abilities, and greater knowledge transfer (Gravemeijer & Doorman, 1999).

Informal learning environments such as museums, science centers, and cultural heritage sites have therefore gained increasing attention as potential spaces for contextual mathematics learning. Museums may provide authentic opportunities for students to encounter mathematical ideas through artifacts, spatial structures, cultural patterns, and historical objects. Learning in museums emerges through the interaction of personal, sociocultural, and physical experiences, allowing museums to function as rich environments for meaning-making beyond traditional classrooms. Previous studies have shown that museum-based learning can foster inquiry, interdisciplinary connections, and reflective engagement when supported by purposeful instructional design (Cesário & Campos, 2024; Hansson & Öhman, 2022; Kim et al., 2024; Xu et al., 2023). In mathematics education, museums may support the exploration of geometry, symmetry, proportion, measurement, and pattern recognition embedded within cultural artifacts and architectural designs (Chatain et al., 2025; Marshall, 2023).

Despite their educational potential, museums do not automatically become effective mathematics learning environments. Without clear learning objectives and instructional scaffolding, museum visits may remain observational rather than pedagogical experiences (Anderson et al., 2003). Teachers' pedagogical beliefs and instructional readiness strongly influence how contextual learning environments are designed and implemented (K. Li et al., 2024; R. Li et al., 2024; Schmidt et al., 2022). Consequently, the success of museum-based mathematics learning depends not only on the learning environment itself but also on teachers' capacity to organize meaningful instructional experiences within that environment.

This issue becomes especially important in teacher education. Pedagogical beliefs and instructional reasoning developed during pre-service education often shape future classroom practices and professional identities (Ferguson & Bråten, 2022). However, developing pedagogical reasoning for unfamiliar learning contexts such as museums requires more than theoretical exposure. Pre-service teachers need opportunities to reflect on instructional decisions, reconsider assumptions, and connect contextual experiences with pedagogical purposes.

Reflective practice has long been recognized as an important mechanism for developing pedagogical understanding. Through reflection, teachers critically examine instructional choices, interpret students' thinking, and reorganize pedagogical ideas (Z. Chen & Chen, 2022; Cramer et al., 2023; H. Li, 2025). Nevertheless, traditional reflective activities such as written journals or peer discussions are often constrained by limited feedback, time restrictions, and uneven levels of critical engagement. Recent developments in artificial intelligence offer new possibilities for extending reflective dialogue beyond conventional approaches. By responding adaptively to participants' ideas, AI-mediated dialogue may encourage deeper elaboration, clarification, and justification of pedagogical reasoning.

Emerging studies suggest that AI-mediated tools can strengthen reflective learning by supporting metacognitive awareness and helping learners externalize their reasoning processes (S.-Y. Chen et al., 2025; Maples et al., 2025; Sun & Rui, 2025; Tsakeni et al., 2025). Recent findings in mathematics education further indicate that AI-based feedback may also support persistence and reflective engagement during learning activities (Siregar et al., 2026).

At the same time, research on museum-based mathematics learning has largely focused on students' conceptual understanding, spatial reasoning, or cultural engagement. For example, museum-based mathematics activities have been explored through learning trajectory and spatial literacy perspectives in elementary geometry learning (Octaria et al., 2026). Comparatively little attention has been given to how pre-service mathematics teachers develop pedagogical reasoning for museum-based mathematics instruction.

Taken together, previous studies have primarily examined museum-based mathematics learning from the perspective of students' conceptual understanding, spatial reasoning, or cultural engagement, while studies on AI-supported reflection have focused mainly on metacognitive development in general learning contexts. Little attention has been paid to how AI-mediated reflective dialogue supports the development of pre-service mathematics teachers' pedagogical reasoning for designing mathematics instruction in museum settings. This

intersection of museum-based mathematics education, teacher pedagogical reasoning, and AI-mediated reflection therefore remains underexplored.

Accordingly, this study contributes to the literature by integrating museum-based mathematics learning and AI-mediated reflective dialogue to examine the development of pre-service teachers' pedagogical reasoning. Unlike previous studies that primarily emphasized learning outcomes or perceptions of museum learning, this study adopts a process-oriented perspective by tracing how pedagogical reasoning evolves through iterative reflective interactions with an AI chatbot.

Therefore, this study aimed to investigate how pre-service mathematics teachers develop pedagogical reasoning in museum-based mathematics instruction through AI-mediated reflective dialogue. Specifically, the study explored how pre-service teachers initially conceptualized museum-based mathematics learning, how their pedagogical reasoning was shaped through reflective dialogue with an AI chatbot, and how their instructional reasoning evolved following the reflective process.

Methods

This study employed a qualitative approach to explore how pre-service mathematics teachers developed pedagogical reasoning within the context of museum-based mathematics learning. A reflective and iterative design was used to capture not only participants' initial ideas but also the development of their reasoning throughout reflective interaction with an AI chatbot.

The study was conducted in three sequential phases: initial response, AI-mediated reflection, and response revision. These stages allowed the researchers to examine how participants' pedagogical reasoning evolved over time. In this study, pedagogical reasoning refers to participants' ability to justify and organize instructional decisions related to learning objectives, students' thinking, instructional strategies, contextual integration, and assessment.

Seventeen pre-service mathematics teachers participated in this study. The participants had completed coursework in pedagogy and educational technology but had no prior experience designing museum-based mathematics instruction. Purposive sampling was used to select participants who were considered relevant to the objectives of the study. The emphasis was placed on the richness and relevance of participants' responses rather than statistical representation (Miles & Huberman, 1994).

Data were collected through written interaction transcripts between participants and the AISI (Artificial Intelligence-Supported Instruction) chatbot platform. AISI is an AI-based platform designed to facilitate reflective dialogue in educational contexts. Rather than providing direct instructional answers, the platform responds adaptively to participants' ideas by generating follow-up prompts that encourage clarification, elaboration, and reconsideration of instructional thinking.

Participants engaged individually in reflective dialogue sessions without time restrictions. At the beginning of each session, participants responded to a stimulus text describing a contextual scenario involving museum-based mathematics learning. The scenario introduced examples of mathematical ideas embedded within cultural artifacts and museum environments.

This stimulus functioned as a contextual trigger intended to elicit participants' pedagogical reasoning (see Figure 1).

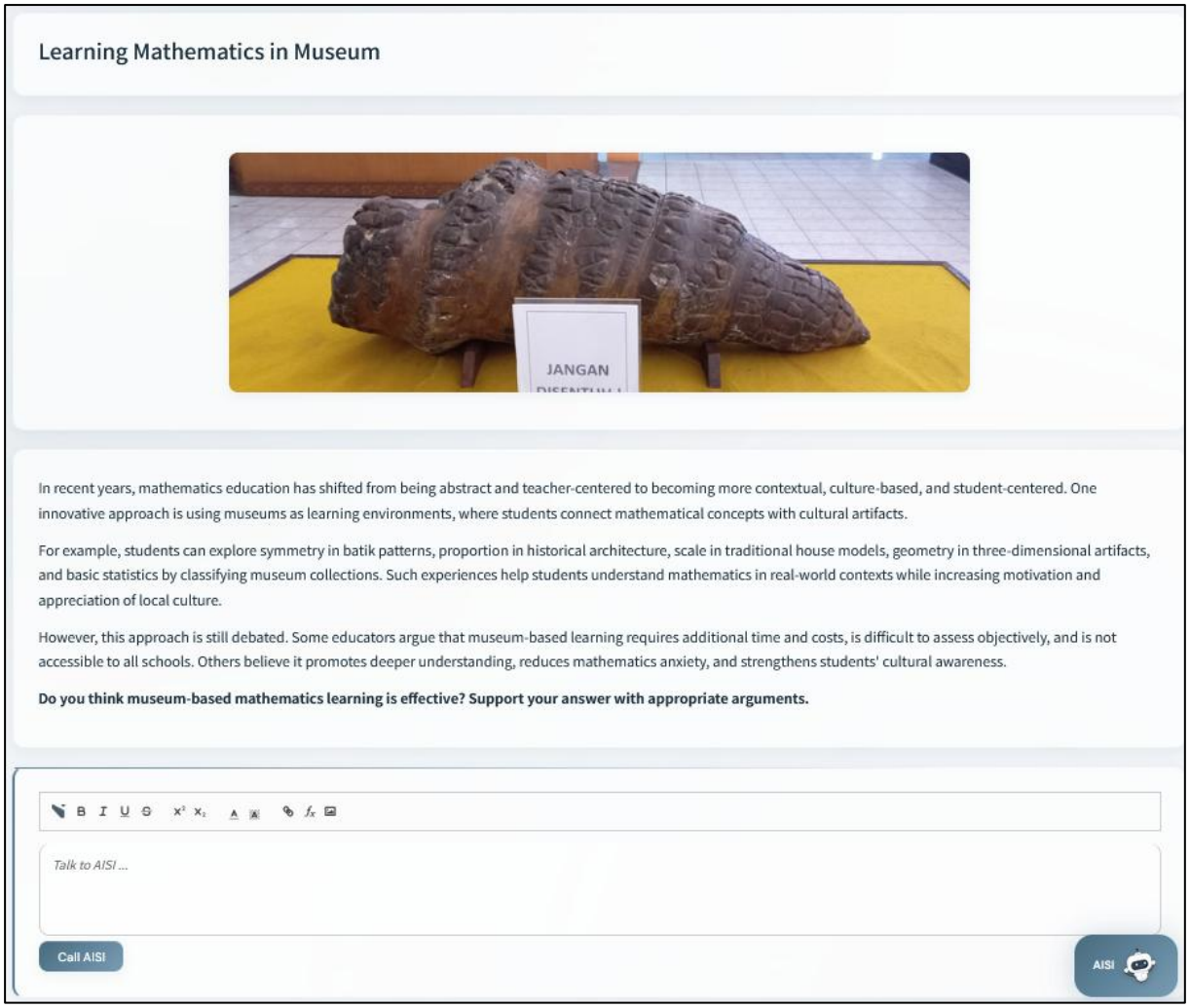


Figure 1. Stimulus text on museum-based mathematics learning presented within the AISI chatbot interface

To guide reflection, participants responded to structured prompts related to key dimensions of pedagogical reasoning, including learning objectives, instructional strategies, anticipated student difficulties, students' ways of thinking, contextual integration, and assessment approaches.

Following participants' initial responses, the AI chatbot acted as a reflective dialogue partner by generating adaptive follow-up questions. Rather than functioning as an answer provider, the chatbot encouraged participants to justify instructional choices, clarify assumptions, and reconsider the coherence between instructional goals and teaching strategies. This dialogic approach was informed by previous studies on AI-supported reflective learning (Celik et al., 2022; Murugesan & Cherukuri, 2023).

Examples of chatbot prompts included questions such as: "How would students demonstrate their understanding during the museum activity?" and "What mathematical reasoning might students develop through this task?" These prompts were intentionally

designed to deepen reflective engagement and encourage participants to move beyond broad statements toward more specific instructional reasoning.

Data collection took place in three stages. In the first stage, participants produced initial written responses to the stimulus text and reflective prompts. In the second stage, participants engaged in AI-mediated reflective dialogue. In the third stage, participants revised and expanded their responses after reflection. Semi-structured interviews were subsequently conducted to clarify emerging themes and explore participants' experiences during the reflective process.

The data were analyzed using the qualitative framework proposed by (Miles & Huberman, 1994), consisting of data reduction, data display, and conclusion drawing. The analysis focused on identifying patterns and changes in participants' pedagogical reasoning across the three stages. Coding categories included instructional specificity, alignment between objectives and assessment, responsiveness to students' thinking, pedagogical justification, and contextual integration.

The coding process combined deductive categories derived from pedagogical reasoning frameworks with inductive interpretations emerging from participants' responses. To enhance trustworthiness, investigator triangulation was conducted through collaborative coding and discussion among researchers. Member checking was also conducted by sharing preliminary interpretations with selected participants. Thick description and an audit trail were used to support transferability and dependability.

This study adhered to ethical principles for research involving human participants. Participants were informed about the purpose of the study, the voluntary nature of participation, and their right to withdraw at any time. Written informed consent was obtained from all participants, and all data were anonymized prior to analysis.

Results

This study explored how pre-service mathematics teachers developed pedagogical reasoning in museum-based mathematics learning through AI-mediated reflective dialogue. Across the three stages of data collection, participants' responses showed a gradual movement from broad and intuitive ideas toward more structured and pedagogically grounded reasoning.

Initial forms of pedagogical reasoning (RQ1)

At the initial stage, most participants (14 of 17) described museum-based mathematics learning in positive but broad terms. Their responses primarily emphasized motivation, contextual learning, and student engagement rather than detailed instructional planning.

One participant explained:

"*Students can understand mathematics more easily because they can directly observe objects in the museum*." (P4).

Similarly, another participant noted:

"*The museum provides many real examples that make mathematical concepts easier to understand*." (P11)

Another participant stated that museum visits could help students "visualize concepts directly and connect them to cultural knowledge" (P2). These responses indicate that participants initially viewed museums primarily as supportive visual contexts rather than as instructional environments requiring carefully designed pedagogical structures.

Thirteen participants identified mathematical concepts embedded within museum artifacts, including symmetry, ratio, scale, and three-dimensional geometry. However, these ideas were rarely accompanied by explanations of how learning activities would be organized, how students' thinking would be supported, or how learning outcomes would be assessed.

Descriptions of instructional procedures also remained general. Eleven participants proposed a general sequence consisting of pre-visit, visit, and post-visit activities, although these descriptions rarely included explicit instructional objectives or assessment strategies.

Nine participants raised practical concerns related to museum access, transportation, and classroom management during museum visits. One participant noted that museums were "*too far away*" (P3), while another expressed concern about managing students in crowded public spaces (P1). These challenges were identified descriptively, but participants rarely proposed pedagogical solutions at this stage.

AI-mediated reflective dialogue (RQ2)

After engaging in reflective dialogue with the AI chatbot, 15 participants articulated their pedagogical ideas in more detailed and organized ways. A noticeable shift emerged as participants moved beyond describing museum learning as merely "interesting" or "contextual" and started discussing specific instructional purposes and learning processes.

The chatbot frequently redirected participants from broad statements toward more instructional thinking. When participants described museum activities as "fun" or "engaging," the chatbot responded with prompts related to learning objectives, students' reasoning, and assessment. One participant initially wrote:

"*Museum activities can make learning more interesting*." (P7)

After reflective interaction with the chatbot, the same participant revised the response to:

"*Students can explore geometric transformations and proportional relationships by analyzing patterns found in museum artifacts*." (P7)

This shift illustrates how reflective dialogue encouraged participants to move from motivational descriptions toward more conceptually grounded instructional reasoning.

More than half of the participants (10 of 17) demonstrated greater attention to instructional structure by describing learning sequences that included preparation activities, guided observation tasks during museum visits, and post-activity reflection or presentation

sessions. Participants began describing learning sequences that included preparation activities, guided observation tasks during museum visits, and post-activity reflection or presentation sessions. Assessment ideas also became more specific. Participants proposed observation rubrics, reflective worksheets, structured presentations, and quizzes that were explicitly aligned with learning objectives. For example, one participant proposed "*report presentation*" (P4), whereas another suggested using "*quiz*" to monitor students' understanding during or after museum activities (P2).

The reflective dialogue also influenced how participants viewed practical constraints. Six participants who initially described museum access as a major obstacle later proposed alternatives such as virtual museum visits, school-based museum replicas, and collaboration with local cultural institutions. These alternatives were also reflected in the interview responses. For example, one participant suggested the use of a "*mini museum at school*" (P5), while another proposed "*virtual museum visits*" when physical access to museums was limited (P4). Together, these responses show that participants increasingly viewed contextual limitations as challenges that could be addressed through instructional adaptation.

Transformation of pedagogical reasoning (RQ3)

In the final stage, most participants (15 of 17) demonstrated more coherent and pedagogically grounded reasoning. Their revised responses showed stronger alignment between learning objectives, instructional activities, students' thinking, and assessment approaches.

Learning objectives became broader and more integrated. In addition to conceptual understanding, participants discussed goals related to motivation, cultural awareness, mathematical communication, and the reduction of mathematics anxiety. One participant explained during the interview:

> "*Museum learning not only helps students understand mathematical concepts but also builds their appreciation of cultural heritage*." (P6)

Similar ideas emerged from other participants. One participant emphasized that museum activities should culminate in a scrapbook and a field trip report (P5), while another suggested incorporating problem-solving tasks to help students connect museum observations with mathematical concepts (P3). These responses show that participants increasingly viewed museum-based mathematics learning as supporting not only conceptual understanding but also students' cultural awareness and reflective learning.

Instructional procedures also became more detailed and context-sensitive. Participants proposed activities such as measuring miniature artifacts, identifying symmetry in batik patterns, exploring proportional reasoning through architectural structures, and analyzing statistical information from museum collections. Compared with the initial stage, these activities reflected greater alignment between contextual museum experiences and specific mathematical concepts.

Eight participants demonstrated increased awareness of students' learning processes and potential misconceptions. Structured observation worksheets, guided questioning, and

collaborative discussion activities were proposed as strategies to support students' conceptual understanding.

Assessment approaches also became more comprehensive. Twelve participants proposed combinations of reflective journals, observation rubrics, presentations, and written tasks aligned with instructional objectives.

The categories presented in Table 1 were developed through an iterative coding process of participants' initial responses, AI-mediated dialogue transcripts, revised responses, and interview data. During the first cycle of analysis, descriptive codes were assigned to recurring ideas related to instructional thinking. These codes were then compared, refined, and grouped into eight broader dimensions of pedagogical reasoning—learning objectives, rationale, teacher knowledge, student difficulties, students' thinking, contextual factors, instructional procedures, and assessment strategies—which consistently appeared across the three stages of data collection.

Table 1. Development of preservice teachers' pedagogical reasoning across stages

Pedagogical Aspect	Initial Responses (RQ1)	AI-Mediated Prompts (RQ2)	Revised Responses (RQ3)
Learning Objectives	General expectations (e.g., easier understanding through real objects)	Emphasized measurable outcomes	Expanded to include motivation, anxiety reduction, and cultural awareness
Rationale	Contextual and engaging learning	Encouraged theoretical and empirical justification	Integrated broader impacts (literacy, motivation, culture)
Teacher Knowledge	Basic awareness of ethnomathematical contexts	Prompted alignment with curriculum and instructional goals	Developed interdisciplinary and context-sensitive instructional perspectives
Student Difficulties	Identified constraints (access, time, cost)	Prompted solution-oriented thinking	Proposed concrete alternatives
Students' Thinking	Focus on concrete observation	Suggested evaluation of conceptual transfer	Recognized students' conceptual interpretation and engagement
Contextual Factors	Cultural relevance and readiness	Highlighted logistics and training	Included ethics and inclusivity
Instructional Procedures	General sequence	Encouraged structured design	Provided detailed and specific activities
Assessment Strategies	Informal methods	Emphasized objective tools	Integrated multiple assessment approaches

As summarized in Table 1, participants' responses became progressively more detailed across the three stages of data collection. Changes were evident across all eight dimensions of pedagogical reasoning, particularly in learning objectives, instructional procedures, and assessment strategies, where revised responses showed greater specificity and alignment than the initial responses.

Discussion

This study examined how pre-service mathematics teachers developed pedagogical reasoning in museum-based mathematics learning through AI-mediated reflective dialogue. Overall, the findings indicate that participants' pedagogical reasoning developed progressively across three stages of AI-mediated reflective dialogue. Development was evident across multiple dimensions of pedagogical reasoning—including learning objectives, instructional procedures, students' thinking, contextual considerations, and assessment strategies—as participants moved from broad and intuitive ideas toward more coherent, context-sensitive, and instructionally grounded reasoning. This developmental pattern suggests that reflective dialogue supported not only the refinement of individual pedagogical ideas but also the integration of different components of instructional planning into a more coherent pedagogical framework.

At the beginning of the study, most participants viewed museum-based mathematics learning primarily as a contextual and motivational experience. Museums were commonly described as environments that could make mathematics more engaging, concrete, and culturally meaningful. However, these initial responses were rarely accompanied by clear explanations of instructional procedures, assessment strategies, or anticipated students' thinking. In many cases, participants recognized the value of contextual learning but had difficulty translating that appreciation into structured pedagogical design.

This pattern echoes previous research showing that the educational potential of informal learning environments is not automatically realized without purposeful instructional scaffolding (Anderson et al., 2003). Similar tendencies have also been identified in museum learning research, where teachers often appreciate the experiential and interdisciplinary value of museums yet struggle to organize those experiences into coherent learning opportunities (Cesário & Campos, 2024; Kim et al., 2024). In the context of mathematics education, this challenge becomes particularly important because contextual experiences alone do not necessarily support mathematical understanding unless they are pedagogically organized around explicit learning goals and mathematical reasoning processes.

The broad and tentative nature of participants' early responses may also reflect the pedagogical uncertainty often experienced by pre-service teachers when engaging with unfamiliar instructional settings. Previous studies have shown that pre-service teachers frequently experience academic and pedagogical anxiety when required to explain mathematical ideas or design innovative learning activities (Pahmi et al., 2025). Museum-based learning introduces additional layers of complexity, including contextual adaptation, classroom management, and the integration of cultural artifacts into mathematics instruction. Such conditions may partly explain why participants initially focused more on general benefits and

logistical concerns than on detailed instructional planning. This reinforces the importance of reflective support during teacher preparation, particularly when pre-service teachers are still constructing their pedagogical identities and instructional beliefs (Ferguson & Bråten, 2022).

As the reflective dialogue progressed, participants began to articulate more specific and operational pedagogical ideas. Through iterative interaction with the chatbot, they gradually refined their learning objectives, considered students' mathematical thinking more carefully, and proposed more coherent instructional procedures. Several participants moved beyond describing museum learning as merely "interesting" and instead discussed how museum artifacts could support the exploration of symmetry, proportion, geometric transformation, and measurement. These developments suggest that reflective dialogue encouraged participants to connect contextual experiences with disciplinary mathematical ideas in more meaningful ways.

An equally important development was the refinement of participants' assessment strategies. Initial responses relied primarily on informal discussions or general observations, whereas the revised responses incorporated multiple assessment approaches, including observation rubrics, quizzes, written reports, oral presentations, and reflective journals that were explicitly aligned with instructional objectives. This progression suggests that participants increasingly viewed assessment not as an isolated activity conducted at the end of instruction, but as an integral component of pedagogical planning that supports students' conceptual understanding, engagement, and reflection.

The emergence of more detailed instructional ideas in this study reflects constructivist and experiential learning perspectives, which view reflection as an important mechanism for transforming experience into conceptual understanding (Illeris, 2007; Uyen et al., 2022; Žakelj et al., 2024). From a constructivist standpoint, learning develops through active interpretation and interaction with meaningful experiences rather than through passive reception of information (Larsari & Abouabdelkader, 2024; Wetering et al., 2022).

Consistent with these theoretical perspectives, the iterative dialogue between participants and the chatbot provided opportunities to revisit, reorganize, and expand instructional thinking. These findings suggest that contextual learning environments such as museums become pedagogically meaningful not simply through exposure, but through guided and sustained reflective engagement.

An important aspect of the findings concerns the role played by the AI chatbot itself. Rather than functioning as a provider of direct answers, the chatbot acted more as a reflective mediator that encouraged participants to clarify assumptions, justify instructional choices, and reconsider the coherence between learning objectives, students' thinking, instructional activities, and assessment strategies. The dialogue process appeared to help participants externalize tacit pedagogical assumptions that might otherwise have remained unexamined. This process of articulation and revision is consistent with views of pedagogical reasoning as something that develops iteratively through reflection rather than emerging as fixed knowledge (Cramer et al., 2023; H. Li, 2025).

The findings also resonate with emerging evidence suggesting that AI-mediated dialogue can strengthen reflective learning by supporting metacognitive awareness and encouraging learners to externalize their reasoning processes (Chen et al., 2025; Maples et al., 2025; Sun &

Rui, 2025; Tsakeni et al., 2025). In this study, participants were not simply responding to static prompts; instead, they engaged in adaptive reflective interaction that pushed them to elaborate and reconsider their pedagogical ideas. These findings indicate that the value of AI in teacher education may emerge not primarily from automation, but from its ability to sustain reflective and inquiry-oriented pedagogical dialogue. Recent work on AI-based feedback in mathematics learning similarly suggests that AI systems may function as cognitive and affective scaffolds that support engagement and persistence during learning activities (Siregar et al., 2026).

Another meaningful finding concerns the way participants reframed contextual challenges throughout the reflective process. Initially, several participants viewed issues such as limited museum access, transportation constraints, and classroom management difficulties as barriers to implementation. Following reflective dialogue, however, many participants began proposing alternatives such as virtual museum visits, school-based museum replicas, and collaboration with local institutions. This shift suggests that reflective dialogue may help pre-service teachers move beyond identifying problems toward engaging in pedagogical problem solving. Similar observations have been reported in studies highlighting the role of reflection in reshaping teachers' problem orientations and instructional decision-making (Z. Chen & Chen, 2022; Cramer et al., 2023).

The findings additionally highlight the pedagogical potential of culturally grounded mathematics learning environments. As participants refined their instructional reasoning, museums were no longer viewed merely as supplementary or motivational spaces but increasingly as legitimate contexts for structured mathematics learning connected to curricular goals. This observation aligns with previous research emphasizing that museums can support interdisciplinary and contextually meaningful learning experiences when integrated thoughtfully into instruction (Hansson & Öhman, 2022; Xu et al., 2023). It also resonates with ethnomathematics-oriented perspectives showing that cultural contexts can support students' mathematical understanding and connections through meaningful engagement with local artifacts and practices (Marshall, 2023; Virliani et al., 2026).

At the same time, the findings reveal variability in the depth of participants' reflective engagement. Although many participants demonstrated substantial development in their pedagogical reasoning, some responses remained relatively procedural and lacked deeper theoretical justification. This suggests that reflective dialogue alone does not automatically guarantee pedagogical transformation. The quality of reflection may also depend on participants' readiness, prior experiences, and willingness to critically engage with instructional ideas. Similarly, H. Li (2025) argues that productive reflection requires active interpretation and critical evaluation rather than surface-level response revision.

From a teacher education perspective, the findings indicate that AI-supported reflective dialogue may provide meaningful support for developing pedagogical reasoning in innovative and context-rich learning environments. Museum-based mathematics learning requires teachers to simultaneously integrate mathematical concepts, contextual experiences, students' thinking, cultural relevance, and coherent instructional design. Reflective dialogue may help pre-service teachers navigate these interconnected dimensions more systematically and thoughtfully.

Methodologically, this study contributes by examining pedagogical reasoning as a developmental process rather than relying solely on pre–post comparisons. Through iterative analysis of participants' initial responses, AI-mediated dialogue, revised responses, and interview data, the study captures not only changes in pedagogical outcomes but also the evolving relationships among learning objectives, instructional procedures, students' thinking, contextual considerations, and assessment strategies. This process-oriented perspective responds to calls for more fine-grained analyses of teacher learning and reflective development in technology-enhanced educational contexts (Celik et al., 2022; Murugesan & Cherukuri, 2023).

Beyond its empirical findings, this study contributes to the literature in three important ways. First, it extends previous museum-based mathematics education research by shifting the focus from students' learning outcomes to the development of pre-service teachers' pedagogical reasoning. Second, it demonstrates that AI can function not merely as a provider of information or feedback, but as a reflective partner that scaffolds pedagogical thinking through iterative dialogue. Third, by tracing participants' responses across successive stages of reflection, this study offers a process-oriented perspective on how pedagogical reasoning develops, providing insights that are often overlooked in studies relying solely on pre- and post-intervention comparisons.

Despite these contributions, several limitations should be acknowledged. First, the relatively small and purposive sample limits the transferability of the findings to broader populations. Second, the reflective interactions occurred within a text-based environment rather than during authentic museum teaching practice. Furthermore, variations in participants' engagement with the chatbot, as well as their familiarity and comfort with AI-mediated interaction, may have influenced the depth of reflection observed throughout the dialogue process. Finally, the findings are based primarily on participants' self-reported pedagogical reasoning rather than observations of their actual instructional practices, limiting conclusions about how these reflections might translate into classroom implementation.

Future research could explore how AI-mediated reflective dialogue functions in authentic classroom or museum settings, particularly across longer periods of implementation. Further studies may also investigate how different prompting strategies influence reflective depth and whether reflective gains translate into sustained instructional practice.

Conclusion

This study investigated how AI-mediated reflective dialogue supported the development of pre-service mathematics teachers' pedagogical reasoning in museum-based mathematics instruction. Initially, participants tended to describe museum learning in broad and motivational terms, with limited instructional specificity and assessment coherence. Through iterative reflective dialogue, participants gradually developed more structured instructional reasoning by clarifying learning objectives, refining instructional procedures, anticipating students' thinking, and proposing more aligned assessment strategies.

The findings indicate that reflective dialogue played an important role in helping participants reconsider and reorganize their instructional ideas within contextual and culturally grounded learning environments. Museum-based mathematics learning became more meaningful when participants moved beyond viewing museums simply as engaging spaces and began considering how contextual experiences could support structured mathematical understanding.

Theoretically, this study contributes to the literature by extending research on museum-based mathematics education from a focus on students' learning outcomes to the development of pre-service teachers' pedagogical reasoning. It also demonstrates how AI-mediated reflective dialogue can function as a reflective scaffold that supports the integration of learning objectives, instructional procedures, students' thinking, contextual considerations, and assessment into a more coherent pedagogical framework. By tracing the evolution of pedagogical reasoning across successive stages of reflection, this study offers a process-oriented perspective that enriches current understandings of teacher learning in technology-enhanced and culturally grounded educational contexts. Practically, the findings suggest that AI-supported reflective dialogue may serve as a valuable tool in teacher education programs to foster reflective practice and prepare pre-service teachers to design contextual mathematics instruction in museum and other informal learning environments.

Despite these contributions, the findings should be interpreted in light of several limitations. The study involved a relatively small purposive sample and examined participants' pedagogical reasoning through text-based reflective dialogue rather than authentic classroom or museum teaching practice. Consequently, the findings primarily reflect the development of pedagogical reasoning rather than its direct implementation in instructional settings.

Future research could explore how AI-mediated reflective dialogue functions in authentic classroom or museum settings, examine its long-term influence on instructional practice, and investigate how different forms of AI prompting support the development of pedagogical reasoning across diverse teacher education contexts.

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Declarations

Conflicts of Interest	:	The authors declare no conflict of interest.
Generative AI Statement	:	AI Used for Limited and Non-Substantive Support Generative AI tools, such as ChatGPT, were used exclusively to improve language clarity and make minor editorial revisions. All research ideas, analyses, interpretations, and academic content were independently produced and validated by the authors.
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