



Integrating Science Contexts into a PBL-ViMomath Model: A Needs Analysis for Enhancing Elementary Pre-Service Teachers' Mathematical Problem-Solving in Geometry and Measurement

Maifit Hendriani^{1*}, I. Made Arnawa², Melva Zainil³

¹ Universitas Adzkia, Padang, Indonesia.

² Universitas Andalas, Indonesia.

³ Universitas Negeri Padang, Indonesia.

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Corresponding Author:

Maifit Hendriani

hendriani.m@adzkia.ac.id

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Abstract: This study aims to analyze the needs for developing an integrated instructional model to enhance elementary pre-service teachers' mathematical problem-solving skills in geometry and measurement. A qualitative needs analysis was conducted through diagnostic tests, interviews, classroom observations, and document analysis involving pre-service teachers and educators. Findings reveal significant difficulties in understanding abstract concepts, low confidence in problem-solving, and minimal integration of science contexts in current mathematics instruction. Despite these challenges, participants expressed strong interest in interdisciplinary, context-based learning. The results highlight the potential of integrating video and mathematical modeling into Problem-Based Learning (PBL) to improve problem comprehension and engagement. Based on the data, the PBL-ViMo model—combining PBL, video-based problem orientation (Vi), and mathematical modeling (Mo)—was developed as a responsive and structured approach. Video facilitates visual understanding of real-world problems, while modeling provides a systematic framework for translating contexts into mathematical solutions. The study concludes that the PBL-ViMo model addresses identified learning gaps and offers an innovative, learner-centered strategy to strengthen both conceptual understanding and pedagogical competence in mathematics teacher education.

Keywords: PBL-Vimo; Problem-Solving; Pre-Service Teachers; Video-Based Learning

Introduction

Mathematics education should begin by introducing meaningful problems contextualized within real-life situations to foster students' mathematical problem-solving abilities (Appelbaum, 2023; Berbegal Vázquez et al., 2024; El Bhih et al., 2024). This principle is particularly crucial in the teaching and learning of

geometry and measurement—domains that are inherently connected to spatial reasoning and practical applications, yet often taught in abstract and decontextualized ways. For elementary pre-service teachers, who are expected to become future facilitators of mathematical understanding, developing strong problem-solving skills in these areas is essential. However, many still struggle with both conceptual

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understanding and pedagogical confidence, especially when faced with non-routine or interdisciplinary problems. This challenge underscores the need for innovative instructional models that not only deepen mathematical comprehension but also situate learning within authentic, engaging contexts (Çelik & Dutta, 2025; Kandemir & Eryilmaz, 2025; Zhang et al., 2025).

One such promising approach is Problem-Based Learning (PBL), a constructivist-oriented model that positions students as active agents in their learning by engaging them in solving complex, open-ended problems (Boom-Cárcamo et al., 2024; Lucena et al., 2025; Mou et al., 2025). PBL encourages collaborative inquiry, independent knowledge construction, and the application of scientific reasoning—skills that are vital for both teaching and learning mathematics. The model typically follows structured phases: problem orientation, small-group investigation, and whole-class discussion, allowing learners to explore relevant knowledge, develop hypotheses, and refine solutions iteratively. Despite its demonstrated effectiveness in enhancing cognitive development, deep learning, and real-world competencies such as collaboration and decision-making, PBL faces practical challenges in large classrooms, including time constraints, infrastructure demands, and student readiness for self-directed learning (Alam et al., 2025; Xing et al., 2025; Zheng et al., 2025).

To address these limitations and enhance the effectiveness of PBL in mathematics education, recent innovations have explored the integration of multimedia and modeling strategies (Boom-Cárcamo et al., 2024; Li et al., 2025; Tangney et al., 2024). The use of video as an introductory tool in the problem orientation phase has shown significant potential in reducing cognitive load and improving comprehension of complex, context-rich problems. Videos provide dynamic visual and auditory representations that make abstract mathematical concepts—such as volume, area, or spatial relationships—more concrete and relatable. According to Clark & Mayer (2012) multimedia learning theory, visual narratives can facilitate deeper processing and retention compared to text-based descriptions alone (Candido & Cattaneo, 2025). In geometry and measurement, where spatial visualization is critical, video-based scenarios can depict real-world phenomena—such as water displacement, building design, or land measurement—enabling pre-service teachers to connect mathematical principles with tangible experiences (Sridharan & Sharagaharajan Akilashri, 2025).

Furthermore, embedding mathematical modeling (Mo) within the PBL framework offers a structured pathway for learners to translate real-world situations

into mathematical representations, analyze variables, and test solutions (Schoenherr & Mayer, 2025). Modeling promotes higher-order thinking, metacognitive awareness, and a sense of ownership over problem-solving processes. When conducted collaboratively, it fosters dialogue, negotiation of ideas, and iterative refinement of strategies—key competencies for future educators (Ulker & Ozaltun Celik, 2025). The integration of video and modeling into PBL has led to the emergence of the PBL-ViMomath model—an innovative, tripartite framework that synergizes Problem-Based Learning, Video for contextual problem presentation, and Mathematical Modeling for structured solution development (Joseph, 1980).

While PBL-ViMomath holds promise, its application—especially with the deliberate integration of science contexts—remains underexplored, particularly in elementary pre-service teacher education. Science phenomena offer rich, interdisciplinary contexts for mathematical inquiry: measuring plant growth involves data and scale; exploring shadows introduces angles and proportions; designing simple machines engages spatial reasoning and measurement. These natural overlaps align with STEM education goals and support meaningful, integrated learning (National Research Council, 2012). However, without a clear understanding of pre-service teachers' current difficulties, prior knowledge, and readiness for such an integrated model, the design of PBL-ViMomath risks being theoretically sound but practically ineffective.

Therefore, this study conducts a needs analysis as a foundational step in the development of a science-integrated PBL-ViMomath model. It seeks to identify the specific challenges pre-service elementary teachers face in solving mathematical problems in geometry and measurement, examine their familiarity with and attitudes toward interdisciplinary learning, and assess their needs regarding visual media and modeling support. Data were gathered through diagnostic assessments, classroom observations, and interviews within Indonesian primary teacher education programs, where curriculum reforms advocate for scientific inquiry and student-centered learning, yet implementation gaps persist.

The findings will inform the contextualization, structuring, and scaffolding of the PBL-ViMomath model, ensuring it is not only theoretically grounded in constructivism and multimedia learning but also responsive to the real pedagogical and cognitive needs of future teachers. By anchoring mathematical problem-solving in science-based, video-mediated, and modeling-supported experiences, this research aims to contribute to the advancement of innovative, interdisciplinary, and effective approaches in

mathematics teacher education. Ultimately, the PBL-ViMomath model aspires to equip pre-service teachers with the competencies to teach mathematics not as isolated procedures, but as a dynamic, connected, and meaningful discipline.

Method

This study employed a qualitative approach with a needs analysis design to inform the development of the PBL-ViMomath model— an innovative instructional framework that integrates Problem-Based Learning (PBL), video-based problem orientation (Vi), and mathematical modeling (Mo)—to enhance elementary pre-service teachers' mathematical problem-solving abilities in geometry and measurement. The research was conducted in the context of primary teacher education programs (PGSD) in Indonesia, where recent curriculum reforms emphasize scientific inquiry, student-centered learning, and interdisciplinary approaches, yet practical implementation remains inconsistent.

Data were collected through a triangulation of methods to ensure comprehensiveness and reliability. First, diagnostic tests were administered to 120 pre-service elementary teachers across three universities to identify their competencies and difficulties in solving mathematical problems related to geometry and measurement. The test consisted of non-routine, context-based problems requiring multiple steps and justification, aligned with Polya's problem-solving framework (understanding the problem, devising a plan, carrying out the plan, and looking back). The items were validated by experts and piloted for reliability.

Second, semi-structured interviews were conducted with 15 pre-service teachers selected based on their performance in the diagnostic test (high, medium, and low achievers) to gain in-depth insights into their cognitive processes, challenges, and perceptions regarding interdisciplinary learning. Additionally, five mathematics and science teacher educators were interviewed to explore their perspectives on current teaching practices, curriculum demands, and the feasibility of integrating science contexts into mathematics instruction.

Third, classroom observations were carried out during mathematics and science courses to document actual teaching and learning dynamics. Observational data focused on students' engagement, problem-solving behaviors, use of visual representations, collaboration patterns, and instructors' pedagogical strategies. Field notes were systematically coded using thematic analysis to identify recurring challenges and learning needs.

Furthermore, document analysis was conducted on syllabi, lesson plans, and student worksheets from the participating institutions to examine how geometry and measurement topics are currently taught and whether science-related contexts are integrated. This analysis helped contextualize the empirical findings within the existing curriculum framework.

The collected data were analyzed using qualitative content analysis and thematic coding to identify key themes related to pre-service teachers' mathematical problem-solving difficulties, their readiness for PBL, the potential role of video in contextualizing problems, and the need for structured modeling activities. The findings were synthesized to map the specific pedagogical, cognitive, and technological needs that must be addressed in the design of the PBL-ViMomath model.

Ethical considerations were maintained throughout the study, including informed consent, confidentiality, and the right to withdraw. The research adhered to the principles of trustworthiness through data triangulation, peer debriefing, and member checking to enhance credibility and transferability.

By grounding the model development in empirical evidence from multiple sources, this methodological approach ensures that the resulting PBL-ViMomath model is not only theoretically sound—rooted in constructivist learning theory, multimedia learning principles (Clark & Mayer, 2012), and problem-solving frameworks—but also contextually relevant and responsive to the real needs of pre-service teachers and educators. The outcome of this needs analysis serves as a critical foundation for the subsequent stages of model design, implementation, and evaluation.

Result and Discussion

Pre-Service Teachers' Difficulties in Mathematical Problem-Solving in Geometry and Measurement

The diagnostic assessment and qualitative data revealed that elementary pre-service teachers face significant challenges in solving mathematical problems, particularly in the domains of geometry and measurement. A majority of participants (68%) demonstrated limited ability to solve non-routine, context-based problems, often relying on memorized formulas without understanding their underlying concepts (Nickl et al., 2024). Common errors included misinterpreting spatial relationships, inability to visualize geometric transformations, and incorrect application of measurement principles in real-world scenarios. For instance, when presented with a problem involving water displacement to determine volume, many pre-service teachers failed to connect the physical phenomenon with the appropriate mathematical model.

This indicates a critical gap in their conceptual understanding and ability to transfer knowledge across contexts—key components of effective mathematical problem-solving (Candido & Cattaneo, 2025).

Low Confidence and Limited Engagement in Problem-Based Learning

Interviews and classroom observations highlighted that pre-service teachers generally lack confidence in tackling complex mathematical problems, especially those requiring interdisciplinary thinking. Despite the recognized importance of problem-solving skills, many expressed anxiety and passivity during problem-solving activities. Observations confirmed that traditional, teacher-centered methods still dominate mathematics instruction, with minimal opportunities for collaborative or inquiry-based learning. Even when group work was implemented, participation was often unequal, with only a few students actively contributing—supporting findings from Rehman et al. (2024) and Nickl et al. (2024) regarding limited student involvement in PBL settings. This passive learning culture undermines the development of independent thinking and collaborative problem-solving, both of which are essential for future educators.

Strong Potential for Video-Based Problem Orientation (Vi)

A key finding of this study is the strong potential of video as a tool to enhance problem orientation in PBL (Yu & Huang, 2025). Pre-service teachers consistently reported that video presentations could significantly improve their understanding of problem contexts compared to text-based descriptions. They emphasized that dynamic visuals—such as animations of real-life situations (e.g., filling a container with water, measuring plant growth, or constructing geometric shapes)—help make abstract mathematical concepts more concrete and relatable. This aligns with multimedia learning theory (Clark & Mayer, 2012) and is supported by research from Sharma & Kanwal (2025) which show that audiovisual media reduce cognitive load and improve comprehension. The use of video was seen as a way to spark curiosity, increase motivation, and ensure that all students begin the problem-solving process with a shared, clear understanding of the scenario.

Need for Structured Mathematical Modeling (Mo) to Guide Problem-Solving

Participants expressed a need for structured guidance in breaking down complex problems, which led to strong support for integrating mathematical modeling into the PBL process. Pre-service teachers acknowledged that modeling activities—such as creating diagrams, formulating equations, or building physical representations—could help them analyze

variables, test hypotheses, and develop logical solution pathways. As noted in the literature Zhou et al. (2025), modeling serves as a bridge between real-world situations and abstract mathematics, fostering deeper conceptual understanding. Furthermore, modeling was perceived as a way to promote metacognitive awareness, allowing students to reflect on their strategies and revise their approaches. One participant stated: “When we build a model first, we don’t just guess the answer—we think step by step.” This supports the inclusion of a dedicated modeling phase in the PBL framework to scaffold students’ problem-solving development (Wilfried Kouabena et al., 2025).

Untapped Opportunities for Integrating Science Contexts

Document analysis of syllabi and lesson plans revealed minimal integration between mathematics and science, despite the natural connections between the two disciplines. Topics such as measurement, data collection, geometric design, and spatial reasoning are relevant in both subjects, yet they are typically taught in isolation. Pre-service teachers, however, showed high interest in interdisciplinary learning, particularly when mathematics is contextualized within science phenomena—such as using angles to explain shadows, applying area and perimeter in garden planning, or using volume in environmental conservation projects. This aligns with the principles of STEM education and confirms that science-based contexts can serve as meaningful anchors for mathematical inquiry. The lack of current integration highlights a significant opportunity for innovation through the PBL-ViMomath model (Connell et al., 2024; Okoro et al., 2025).

Readiness and Support for the PBL-ViMomath Model

Collectively, the findings indicate that pre-service teachers are ready and motivated to engage with a restructured PBL model that incorporates video and modeling. They recognize the limitations of traditional instruction and express a desire for more engaging, visual, and structured approaches to learning mathematics. The proposed PBL-ViMomath model—comprising Problem-Based Learning (PBL), video-based problem orientation (Vi), and mathematical modeling (Mo)—is strongly supported by the empirical data as a responsive and contextually relevant solution. By beginning with a video to present a real-world, science-connected problem, followed by collaborative modeling and guided problem-solving, the model addresses the core needs identified: improving conceptual understanding, enhancing engagement, providing cognitive scaffolding, and fostering interdisciplinary thinking (Yana, 2025).

The findings of this needs analysis provide compelling evidence for the development of the PBL-ViMomath model as a responsive and innovative solution to enhance elementary pre-service teachers' mathematical problem-solving abilities in geometry and measurement. The results reveal significant gaps in conceptual understanding, procedural flexibility, and confidence when dealing with non-routine, context-based problems—challenges that align with broader concerns in mathematics teacher education. However, the data also highlight a strong readiness and motivation among pre-service teachers to engage with more dynamic, visual, and interdisciplinary approaches to learning mathematics. This discussion interprets these findings in relation to the research objectives, connects them with existing theoretical and empirical literature, and explores their implications for pedagogical innovation in teacher education (Li et al., 2025b).

The core difficulty identified—pre-service teachers' reliance on memorized formulas without conceptual grounding—reflects a persistent issue in mathematics education, where abstract instruction often disconnects mathematical content from real-world meaning (Wasserman et al., 2018). This study confirms that traditional, lecture-based methods dominate current teaching practices, limiting opportunities for inquiry, collaboration, and deep conceptual engagement. The lack of integration between mathematics and science further exacerbates this disconnection, depriving learners of authentic contexts through which geometric and measurement concepts can be meaningfully applied.

However, the strong interest expressed by participants in science-based, real-life problem scenarios suggests a fertile ground for innovation. This supports the central premise of this study: that integrating science contexts into mathematics instruction can serve as a powerful catalyst for meaningful learning. When mathematical problems are embedded in phenomena such as plant growth, water displacement, or shadow formation, they become more than abstract exercises—they transform into opportunities for scientific inquiry and mathematical modeling. This synergy aligns with STEM education principles and constructivist theories, which emphasize knowledge construction through active, contextualized experiences (Chen et al., 2025).

The proposed PBL-ViMomath model directly addresses these needs by reimagining the structure of Problem-Based Learning (PBL) through two key innovations: video-based problem orientation (Vi) and mathematical modeling (Mo). The finding that pre-service teachers struggle to visualize and interpret problem contexts justifies the integration of video at the initial stage of PBL. As demonstrated in the data, video

can reduce cognitive load and enhance comprehension by providing dynamic, multimodal representations of real-world situations (Yana, 2025). This is particularly crucial in geometry and measurement, where spatial reasoning and visualization are essential. The use of video not only makes problems more accessible but also ensures a shared understanding among learners, thereby promoting equitable participation—a critical concern in collaborative learning environments.

Furthermore, the need for structured guidance in problem-solving processes supports the inclusion of a dedicated mathematical modeling phase. Participants acknowledged that without clear scaffolding, they often feel lost when confronted with complex, open-ended problems. Modeling provides a systematic framework for translating real-world situations into mathematical representations, analyzing variables, testing hypotheses, and refining solutions (Wu et al., 2025). This structured approach not only enhances problem-solving efficacy but also fosters metacognitive awareness and collaborative reasoning. By integrating modeling into PBL, the PBL-ViMomath model transforms problem-solving from a vague, intimidating task into a guided, iterative, and reflective process.

The PBL-ViMomath model builds upon and extends previous research in several ways. First, it aligns with studies that affirm the effectiveness of PBL in developing cognitive skills, deep understanding, and real-world competencies such as collaboration and decision-making. However, it also responds to well-documented limitations of PBL—such as time intensity, student passivity in large groups, and difficulties in problem comprehension—by introducing video and modeling as strategic enhancements.

Second, the model integrates insights from multimedia learning theory (Clark & Mayer, 2012), which emphasizes the superiority of visual-audio presentations over text-only formats in promoting understanding. The positive responses to video-based problem presentation echo findings by Lin et al. (2025), who demonstrated that dynamic visuals increase engagement and facilitate deeper processing of mathematical concepts. Third, the emphasis on mathematical modeling resonates with recent calls for authentic, application-oriented mathematics education. By positioning modeling not as an add-on but as an integral phase within PBL, the model ensures that students do not merely "apply" formulas but actively construct mathematical meaning through inquiry and representation.

The development of the PBL-ViMomath model has significant implications for elementary pre-service teacher education. First, it offers a practical framework for bridging the gap between disciplinary knowledge

(mathematics and science) and pedagogical practice. Future teachers who experience interdisciplinary, problem-centered learning are more likely to implement similar approaches in their own classrooms, thus fostering a cycle of innovative teaching.

Second, the model supports the development of both content knowledge and pedagogical content knowledge. By engaging in science-integrated mathematical problem-solving, pre-service teachers not only strengthen their understanding of geometry and measurement but also learn how to design and facilitate such experiences for their students. Third, the model promotes 21st-century skills—critical thinking, collaboration, creativity, and digital literacy—through its use of video and collaborative modeling. These competencies are essential not only for teaching but also for lifelong learning and professional adaptability.

While the findings are robust and empirically grounded, this study has several limitations. First, the needs analysis was conducted within a specific cultural and institutional context—Indonesian primary teacher education programs—and may not be fully generalizable to other settings. Second, the data are primarily qualitative, relying on self-reports and observational interpretations, which may be subject to bias. Third, the study focuses on identifying needs rather than testing the effectiveness of the PBL-ViMo model itself; thus, further experimental or design-based research is needed to validate its impact.

Conclusion

Effective mathematics learning should begin by presenting contextual problems to foster students' mathematical problem-solving abilities. While Problem-Based Learning (PBL) promotes active, collaborative, and student-centered learning by engaging students in identifying and solving complex problems, its implementation faces challenges such as students' difficulty in understanding abstract problem contexts, passivity in group work, and the need for more structured guidance. To address these limitations, this study proposes the PBL-ViMo model—an innovative integration of Problem-Based Learning (PBL), video-based problem orientation (Vi), and mathematical modeling (Mo). The use of video at the problem orientation stage provides dynamic, visual representations of real-world scenarios, reducing cognitive load and enhancing comprehension, especially for abstract concepts in geometry and measurement. The inclusion of a structured mathematical modeling phase guides students in translating real-life problems into mathematical forms, analyzing variables, and systematically developing solutions, thereby fostering

deeper conceptual understanding, critical thinking, and metacognitive skills. Grounded in social constructivism and multimedia learning theory, the PBL-ViMo model offers a coherent, engaging, and learner-responsive approach that overcomes the shortcomings of traditional and conventional PBL methods, making it a promising innovation for enhancing mathematical problem-solving skills in elementary pre-service teacher education.

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