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Interactive mathematics learning media based on problem-based learning to enhance students' numeracy skills

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ABSTRACT

Background: Numeracy skills are one of the essential competencies of the 21st century, but they remain low among Indonesian students, as demonstrated by national assessments and international studies. This situation demands learning innovations that integrate technology and problem-solving-cantered pedagogical approaches.

Purpose: This study aims to develop and evaluate interactive mathematics learning media based on Problem-Based Learning (PBL) to improve students' numeracy skills.

Method: This study used the Research and Development method with the ADDIE model, which includes analysis, design, development, implementation, and evaluation. The subjects were eighth-grade junior high school students divided into an experimental class and a control class. The research instruments included an expert validation sheet, a student response questionnaire, and a numeracy test. Data analysis was conducted to test the validity, practicality, and effectiveness of the media, and an independent sample t-test was used to examine differences in learning outcomes.

Findings: The results indicate that the developed media is highly valid, practical, and effective. Students using the media showed significantly higher improvements in numeracy skills compared to those in the control class. These findings demonstrate that integrating PBL within interactive media provides meaningful learning experiences and enhances students' ability to apply mathematical concepts in real-life contexts.

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INTRODUCTION

Numeracy skills are one of the key competencies of the 21st century, playing a crucial role in supporting critical thinking, problem-solving, and decision-making in everyday life. Globally, numeracy is understood not only as the ability to calculate but also encompasses an individual's capacity to interpret, analyze, and use mathematical concepts in various contextual situations (Sulistyowati et al., 2023). However, various international studies, such

as the Programme for International Student Assessment (PISA), show that Indonesian students' numeracy skills remain below the global average (OECD, 2016). This indicates a gap between the demands of 21st-century competencies and the mathematics learning practices that occur in schools (Collins, 2014).

One contributing factor to low numeracy skills is the teacher-centered learning approach, which provides little opportunity for students to develop higher-order thinking skills. Mathematics instruction tends to emphasize procedures and routine problem solving, leaving students less accustomed to dealing with contextual problems that require reasoning and interpretation (Dubinsky et al., 2013). Furthermore, the use of technology in learning has not been optimal, thus underutilizing the potential of digital media to increase student engagement and understanding (Marhaeni et al., 2025). In recent years, technology integration in mathematics learning has begun to gain attention as an innovative strategy for improving the quality of learning. Interactive learning media, particularly those based on digital applications, have the potential to create more engaging, adaptive, and responsive learning experiences tailored to student needs (Eriana et al., 2024). Interactive media enable two-way communication, provide instant feedback, and visualize abstract concepts more concretely (Widyastuti et al., 2017). However, the development of learning media that focuses solely on technological aspects without being supported by an appropriate pedagogical approach tends to have little significant impact on improving numeracy skills (Bautista et al., 2024).

One learning approach considered relevant for improving numeracy skills is Problem-Based Learning (PBL). PBL positions contextual problems as the starting point of learning and encourages students to actively construct knowledge through inquiry, discussion, collaboration, and reflection (Ayanwale & Omeh, 2026). This approach aligns closely with the nature of numeracy, which emphasizes the ability to interpret and apply mathematical concepts in real-life situations. Previous studies have consistently shown that PBL contributes positively to the development of critical thinking, reasoning, and mathematical problem-solving skills (Chao et al., 2016; Sujatmika et al., 2019; Yustina et al., 2022). However, most of these studies primarily focused on classroom implementation of PBL in conventional face-to-face settings without integrating it systematically into interactive digital learning environments.

On the other hand, research on technology-based mathematics learning media has highlighted the potential of interactive media to improve student engagement, visualization, and conceptual understanding (Eriana et al., 2024; Widyastuti et al., 2017). Interactive media are considered capable of providing immediate feedback, adaptive learning experiences, and multimodal representations that support deeper cognitive processing (Blank, 2017; Buliali & Pramudya, 2022). Nevertheless, many existing digital mathematics media still

emphasize technical and visual aspects rather than pedagogical integration (Ayanwale & Omeh, 2026). Several studies reported that technology-enhanced learning tools often function merely as presentation media or practice platforms, without embedding structured learning models that guide students through higher-order thinking processes.

In the context of numeracy-oriented learning, previous studies have generally concentrated on improving procedural mathematical abilities rather than contextual reasoning and real-world problem solving (Ben-chaim et al., 1998; Jordan et al., 2013). Furthermore, research integrating numeracy, PBL, and interactive technology simultaneously remains limited. Existing studies frequently examine these components separately: some focus on PBL effectiveness, others on interactive media usability, and others on numeracy assessment (Bernard et al., 2018; Rohaeti et al., 2019). As a result, there is still a lack of comprehensive learning media that systematically integrate problem-based pedagogy, contextual numeracy tasks, and interactive digital features within a unified instructional design.

Another unresolved issue concerns accessibility and implementation challenges. Many technology-based learning media rely heavily on internet connectivity and require advanced technological infrastructure, limiting their applicability in schools with limited resources (Jitendra, A. K., et al., 2018; Irfan et al., 2023). In addition, previous research rarely discusses how digital media can operationalize the stages of PBL in a structured manner that supports independent and self-regulated learning (Rohaizati et al., 2020).

Therefore, this study attempts to address these gaps by developing an interactive mathematics learning media that integrates Problem-Based Learning principles, contextual numeracy tasks, and interactive technological features (Blank, 2017; Norton, 2017). Unlike previous studies, the developed media is designed not only to deliver content interactively but also to facilitate structured inquiry, instant feedback, contextual reasoning, and offline accessibility. Consequently, this study contributes to strengthening the state of the art in technology-integrated mathematics learning by combining pedagogical, technological, and numeracy-oriented dimensions into a comprehensive learning design.

Furthermore, previous studies on interactive numeracy-oriented learning media reveal several important limitations and unresolved issues. Research on digital mathematics media has generally emphasized multimedia presentation, visualization, and student engagement, but many studies have not systematically integrated pedagogical frameworks such as Problem-Based Learning (PBL) into the media design (Eriana et al., 2024; Kobiela & Lehrer, 2015; Laksmiwati et al., 2023; Widyastuti et al., 2017). As a result, the media often function merely as supporting instructional tools rather than as structured learning environments that facilitate inquiry, reasoning, and contextual problem-solving processes (Adeliyanti et al., 2018; Bernard et al., 2018; Widyastuti et al., 2017).

In contrast, studies focusing on PBL in mathematics education have demonstrated its effectiveness in improving critical thinking and problem-solving skills (Chao et al., 2016; Sujatmika et al., 2019). However, most PBL studies have been implemented in conventional classroom settings and remain highly dependent on teacher facilitation. The integration of PBL into interactive digital media has not been comprehensively explored, particularly in relation to how technological features can operationalize each stage of PBL systematically within students' independent learning processes.

Based on these challenges, several important research gaps can be identified from previous studies. First, studies on PBL in mathematics education have primarily focused on classroom instructional strategies and improvements in critical thinking or problem-solving skills, but have rarely integrated PBL systematically into interactive digital learning media. Second, research on interactive mathematics media has generally emphasized visual attractiveness and technological functionality without embedding structured pedagogical processes that guide students through contextual inquiry and reasoning activities. Third, studies related to numeracy-oriented learning often concentrate on procedural mathematical achievement rather than the development of contextual reasoning skills aligned with real-life problem-solving situations.

To address these gaps, this study develops an interactive mathematics learning media based on Problem-Based Learning (PBL) using the ADDIE development model. The developed media is specifically designed to integrate contextual problem-solving activities, structured PBL stages, interactive navigation, and instant feedback features that facilitate active student engagement and self-regulated learning. Unlike many previous studies, the developed media can also be accessed offline, making it more adaptable to diverse school contexts with varying technological infrastructure.

Accordingly, this study is guided by the following research questions: (1) How is the process of developing PBL-based interactive mathematics learning media using the ADDIE model? (2) What are the characteristics and features of the developed learning media? (3) How valid and practical is the developed learning media? and (4) How effective is the media in improving students' numeracy skills compared to conventional learning? Therefore, this study aims not only to evaluate the effectiveness of learning media but also to contribute to the development of a more comprehensive technology-integrated mathematics learning design that combines pedagogical structure, numeracy orientation, and interactive digital learning features within a unified framework.

The primary novelty of this research lies in the development of a numeracy-oriented interactive mathematics learning media that systematically integrates Problem-Based Learning (PBL), instant feedback mechanisms, and offline-accessible technology within a unified instructional design. Unlike previous studies that generally focused either on the

effectiveness of PBL in conventional classrooms or on the visual and technical aspects of interactive media, this study combines pedagogical structure, contextual numeracy tasks, and interactive technological features simultaneously. The developed media operationalizes each stage of PBL directly within the application environment, enabling students to engage independently in problem orientation, investigation, reasoning, evaluation, and reflection processes.

Another distinctive contribution of this study is the integration of an instant feedback system designed to support self-regulated learning and immediate conceptual correction. In contrast to many existing digital mathematics media that primarily function as content presentation tools or drill-and-practice platforms, the developed media provides direct responses to students' answers and guides them toward conceptual understanding during the learning process. Furthermore, the media is designed to be accessible offline, addressing technological accessibility issues frequently encountered in schools with limited internet infrastructure.

From a theoretical perspective, this study contributes to the development of technology-integrated mathematics learning by extending the implementation of the TPACK framework through the integration of PBL pedagogy, contextual numeracy learning, and interactive digital media within a single instructional model. This study also strengthens the conceptual understanding that the effectiveness of educational technology is influenced not only by multimedia presentation but also by the extent to which pedagogical principles are embedded systematically into the learning design.

From a practical perspective, the developed media provides teachers with a structured and applicable learning tool for facilitating numeracy-oriented mathematics instruction. The media supports the implementation of contextual problem-solving activities, independent learning, and formative feedback processes in classroom practice. In addition, the offline accessibility and interactive navigation features make the media more adaptable to diverse educational contexts, particularly in schools with limited technological resources. Consequently, this study offers a more concrete contribution to the development of accessible, pedagogically integrated, and numeracy-focused mathematics learning media.

METHODS

This study employed a Research and Development (R&D) approach with the ADDIE (Analysis, Design, Development, Implementation, Evaluation) model, which aims to produce valid, practical, and effective learning products (Branch, 2010). The ADDIE model was chosen because it provides a systematic framework for designing and developing technology-based learning media integrated with a pedagogical approach. Furthermore, to test the effectiveness of the developed media, this study adopted a quasi-experimental design with

a pretest-posttest control group design. This design allowed researchers to compare improvements in numeracy skills between groups using interactive PBL-based learning media and those using conventional learning.

This study was conducted in a junior high school in Indonesia during the 2024/2025 academic year. The subjects consisted of eighth-grade students divided into two groups: an experimental class and a control class. The experimental class received instruction using interactive Problem-Based Learning (PBL)-based media, while the control class received conventional learning methods.

The subjects were selected using a purposive sampling technique based on several specific criteria. First, both classes were taught by the same mathematics teacher to minimize differences in instructional approach and classroom management. Second, the selected classes had relatively similar academic characteristics based on previous mathematics achievement records provided by the school. Third, the classes had comparable access to learning facilities and similar learning schedules to ensure equal learning conditions during the research implementation.

To ensure equivalence between the experimental and control groups, a pretest on numeracy skills was administered before the treatment. The pretest results were analyzed statistically to determine whether there were significant differences in students' initial abilities between the two classes. The analysis showed that the two groups had relatively equivalent initial numeracy abilities, indicating that any differences found in the posttest results could reasonably be attributed to the treatment provided using the PBL-based interactive learning media.

The learning media development procedure followed the ADDIE model, which consists of five main phases. In the analysis stage, learning needs were identified, student characteristics were analyzed, and problems in mathematics learning, particularly related to low numeracy skills, were examined. This stage was conducted through observation, teacher interviews, and literature review. Next, in the design stage, the learning media was designed, including developing a PBL-based learning flow, developing storyboards and flowcharts, and developing material on the Pythagorean theorem integrated with the numeracy context. Research instruments were also designed at this stage.

In the development stage, interactive learning media was developed using authoring tool software, resulting in the "PythaMath" learning application. This media features contextual problem-based material, practice questions with instant feedback, and interactive navigation. The developed product was then validated by material experts and media experts to assess its content, instructional, and technical feasibility. The implementation stage involved applying the media to the experimental class during learning activities in accordance with the PBL syntax, namely problem orientation, student

organization, inquiry, presentation of results, and evaluation. Finally, in the evaluation stage, formative evaluation was conducted at each stage of development, as well as summative evaluation to assess the media's effectiveness based on student learning outcomes.

The instruments used in this study included an expert validation sheet, a student response questionnaire, and a numeracy ability test. The expert validation sheet was used to assess the validity of the developed media based on content, instructional, and technical aspects. The student response questionnaire was designed to measure the practicality of the media in terms of ease of use, visual appearance, interactivity, and usefulness for learning. Meanwhile, the numeracy ability test consisted of essay questions referring to three cognitive levels: knowing, applying, and reasoning, thus comprehensively measuring students' ability to understand and apply mathematical concepts in real-world contexts.

Before being implemented, all instruments underwent validity and reliability testing to ensure their quality and appropriateness for data collection. The expert validation sheet and student response questionnaire were reviewed by experts in mathematics education and educational technology to establish content validity. Revisions were made based on expert suggestions regarding language clarity, relevance of indicators, and alignment with research objectives.

The numeracy test instrument was also validated through expert judgment to ensure that each item accurately represented numeracy competencies and contextual problem-solving skills. In addition, empirical validity testing was conducted through a pilot test involving students outside the research sample. Item validity was analyzed using the product-moment correlation coefficient, and only items meeting the validity criteria were retained.

To ensure consistency, reliability analysis was conducted for both the numeracy test and the student response questionnaire. The reliability of the numeracy test was measured using Cronbach's Alpha coefficient, indicating that the instrument had a satisfactory level of internal consistency. Similarly, the student response questionnaire demonstrated reliable measurement consistency based on Cronbach's Alpha analysis. These results indicate that the instruments used in this study were both valid and reliable for measuring the quality of the developed media and students' numeracy skills.

Data collection in this study was conducted through several techniques: observation, expert validation, questionnaire distribution, and testing. Observation was used in the initial stage to identify learning needs and student characteristics. Expert validation was conducted to obtain data on the validity of the developed learning media. A questionnaire was used to collect data on the practicality of the media based on student responses. Furthermore, a numeracy test was administered in the form of a pretest and posttest to measure the improvement in students' numeracy skills after using the learning media.

The data obtained were analyzed using quantitative descriptive and inferential statistical techniques. Validity analysis was conducted by processing expert validation scores using a Likert scale, which were then converted into qualitative categories to determine the feasibility level of the developed media. Practicality analysis was carried out by calculating the percentage of student response questionnaire scores to determine the ease of use, attractiveness, and usefulness of the media in supporting learning activities.

To measure the effectiveness of the developed media in improving students' numeracy skills, several statistical analyses were employed. First, descriptive analysis was conducted by comparing students' pretest and posttest scores in both the experimental and control classes. Furthermore, the improvement in students' numeracy skills was analyzed using the normalized gain (N-Gain) formula to determine the level of learning improvement achieved after the intervention. The N-Gain scores were categorized into high, medium, and low improvement levels.

In addition, effect size analysis was conducted to determine the magnitude of the intervention effect of the PBL-based interactive learning media on students' numeracy skills. Cohen's effect size criteria were used to interpret the strength of the treatment effect, indicating whether the developed media had a small, medium, or large impact on learning outcomes.

Before conducting inferential statistical tests, prerequisite tests consisting of normality and homogeneity tests were performed to ensure that the data met parametric assumptions. Subsequently, an independent sample t-test was employed to examine the significance of differences in learning outcomes between the experimental and control groups. The effectiveness of the media was determined based on three indicators: (1) a statistically significant difference between groups ($p < 0.05$), (2) a higher N-Gain score in the experimental class, and (3) a meaningful effect size indicating the practical impact of the intervention on students' numeracy skills.

The developed learning media were deemed high-quality if they met three main criteria: validity, practicality, and effectiveness. Valid media met the appropriateness standards for content, instructional, and technical aspects based on expert assessment. Practical media were deemed easy to use and received positive feedback from students. Effective media were categorized as effective if they significantly improved students' numeracy skills compared to conventional learning.

RESULT AND DISCUSSION

Results of Product Development

The development of the interactive mathematics learning media in this study was carried out systematically using the ADDIE model, which consists of five main stages:

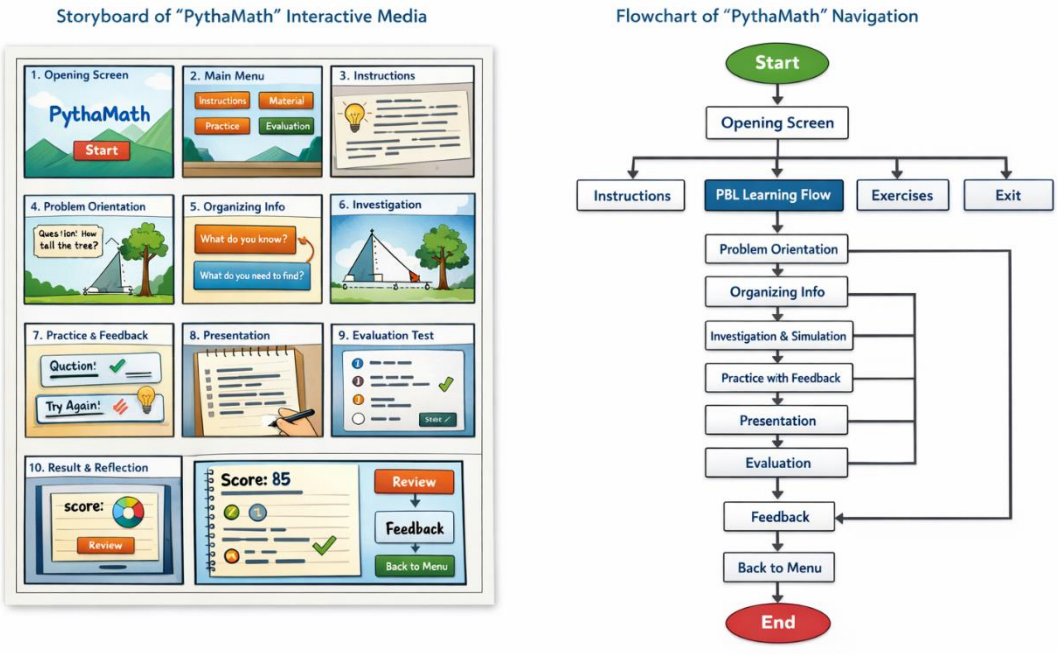
analysis, design, development, implementation, and evaluation. Each stage produced outputs that contributed to the formation of a valid, practical, and effective learning product.

At the analysis stage, the researchers identified key problems in mathematics learning, particularly related to students' low numeracy skills and the limited use of interactive media in classrooms. The results of classroom observations and teacher interviews indicated that students experienced difficulties in interpreting contextual problems and applying mathematical concepts in real-life situations. In addition, learning activities were still predominantly teacher-centered, limiting opportunities for students to engage in higher-order thinking processes.

At the design stage, the structure and framework of the learning media were systematically developed. This included designing a Problem-Based Learning (PBL) flow that integrates stages such as problem orientation, investigation, and evaluation into the media. Furthermore, storyboards and flowcharts were created to visualize user navigation and interaction within the media (see Figure 1). The learning content was also designed to align with numeracy competencies, particularly emphasizing contextual problem-solving based on real-world situations.

Figure 1.

Pytamath storyboards and flowcharts



At the development stage, the interactive learning media named PythaMath was produced using an authoring tool. The media incorporates several key features, including contextual problem scenarios, step-by-step PBL guidance, interactive exercises, and an instant feedback system. The design emphasizes user-friendly navigation and visual attractiveness to enhance student engagement. The developed

product was then validated by material experts and media experts to assess its feasibility in terms of content accuracy, instructional quality, and technical design.

At the implementation stage, the media was applied in an experimental class during mathematics learning activities. The learning process followed the PBL syntax embedded in the media, allowing students to actively engage in solving contextual problems, conducting investigations, and presenting their findings. The teacher acted as a facilitator, guiding students throughout the learning process.

Finally, at the evaluation stage, both formative and summative evaluations were conducted. Formative evaluation was carried out at each stage of development to ensure continuous improvement of the product, while summative evaluation focused on assessing the overall quality of the media in terms of validity, practicality, and effectiveness.

Validity of the Learning Media

The initial stage in evaluating the quality of the developed learning media is to assess its validity through expert judgment. This validity reflects the extent to which the media meets feasibility standards in terms of content, instructional design, and technical aspects, thereby determining its appropriateness for use in mathematics learning.

Table 1.

Results of Learning Media Validation

Assessment Aspect	Mean Score	Category
Content Quality	4.35	Very Valid
Instructional Quality	4.28	Very Valid
Technical Quality	4.32	Very Valid
Overall Mean	4.32	Very Valid

Based on Table 1, the learning media demonstrates a very high level of validity, with an overall mean score of 4.32. More specifically, the content quality aspect achieved the highest score (4.35), indicating that the material is aligned with learning objectives, conceptually accurate, and relevant to numeracy contexts. This is crucial, as content alignment serves as the foundation for ensuring that students develop accurate and meaningful mathematical understanding.

Meanwhile, the instructional aspect (4.28) indicates that the media is designed with a systematic learning flow aligned with the syntax of Problem-Based Learning (PBL). The integration of PBL stages is not merely conceptual but is operationalized through structured learning activities that guide students progressively from problem orientation to evaluation. In terms of technical quality, the score of 4.32 confirms that

the media possesses strong visual design, intuitive navigation, and effective interactivity, thereby enhancing user experience.

Overall, these findings suggest that the media is not only theoretically valid but also demonstrates strong integration of content, pedagogy, and technology (Technological Pedagogical Content Knowledge / TPACK), which is a key indicator in modern educational media development.

Practicality of the Learning Media

After being declared valid, the learning media was further evaluated in terms of practicality to determine its ease of use and acceptance by students in real classroom settings. Practicality is a critical indicator, as effective learning media must not only be conceptually sound but also user-friendly and applicable in practice.

Table 2.

Results of Student Response Questionnaire

Aspect	Percentage	Category
Ease of Use	88.5	Very Practical
Media Appearance	90.2	Very Practical
Usefulness	89.7	Very Practical
Average	89.5	Very Practical

The data in Table 2 indicate that the learning media achieved a very high level of practicality, with an average percentage of 89.5%. The media appearance aspect obtained the highest score (90.2%), suggesting that the visual design, colour composition, and multimedia elements effectively capture students' attention and enhance learning interest. This is significant, as appealing design contributes to students' cognitive engagement during the learning process.

The usefulness aspect (89.7%) indicates that students perceive clear benefits from using the media in understanding mathematical concepts, particularly in numeracy contexts. The media functions not only as a supporting tool but also as a platform for conceptual exploration, enabling students to learn independently. Meanwhile, the ease of use aspect (88.5%) suggests that the navigation is intuitive and does not impose additional cognitive load on students.

These findings demonstrate that the developed media has high usability and is capable of creating an effective and efficient learning experience. Therefore, the media is not only academically sound but also practically relevant for classroom implementation.

Effectiveness of the Learning Media

The next stage involved evaluating the effectiveness of the media in improving students' numeracy skills through a comparative analysis of learning outcomes

between the experimental and control groups. Effectiveness was measured through improvements in pretest and posttest scores as well as inferential statistical analysis.

Table 3.

Pretest and Posttest Results

Group	Pretest (Mean)	Posttest (Mean)	Gain
Experimental	62.45	84.30	21.85
Control	61.90	72.15	10.25

As shown in Table 3, both groups had relatively equivalent initial abilities, as indicated by similar pretest scores. However, after the intervention, the experimental group exhibited a substantially greater improvement compared to the control group. The gain score in the experimental group (21.85) was nearly double that of the control group (10.25), indicating that the use of PBL-based interactive media had a substantial impact on enhancing students' numeracy skills.

This improvement suggests that students not only enhanced their conceptual understanding but also developed stronger abilities in applying and reasoning mathematical concepts within problem contexts. This aligns with the nature of numeracy, which emphasizes higher-order thinking skills. To confirm the significance of these differences, an independent sample t-test was conducted.

Table 4.

Independent Sample t-test Results

Parameter	Value
t-value	3.87
Sig. (p-value)	0.000

The statistical results in Table 4 show a significance value of 0.000 ($p < 0.05$), indicating a statistically significant difference between the learning outcomes of the experimental and control groups. The relatively high t-value (3.87) suggests a strong effect of the intervention.

Discussion

More importantly, these findings indicate that integrating PBL into interactive media not only enhances student engagement but also significantly improves the quality of their mathematical understanding (Sujatmika et al., 2019; Yustina et al., 2022). A PBL process encourages students to actively construct knowledge, resulting in more meaningful learning and stronger long-term retention (Gazali & Atsnan, 2022; Irfan et al., 2019). Thus, the developed learning media has been empirically proven to be effective in improving students' numeracy skills and holds strong potential for implementation in mathematics learning aimed at developing 21st-century competencies (Campbell et al., 2020; Gal et al., 2020; Lüssenhop & Kaiser, 2020).

The results of this study indicate that the developed interactive learning media is of high quality in terms of validity, practicality, and effectiveness. These findings reinforce the idea that integrating digital technology and a problem-based pedagogical approach is a relevant strategy in addressing the challenge of low student numeracy skills.

From a validity perspective, high scores across all aspects indicate that the media meets the principles of content suitability, learning structure, and technical quality. This aligns with the Technological Pedagogical Content Knowledge (TPACK) framework, which emphasizes the importance of integrating content, pedagogy, and technology in learning (Wijaya et al., 2020; Yanuarto et al., 2023). The developed media not only presents mathematical material accurately but also packages it within a systematic PBL-based learning flow. Thus, the media serves not merely as a visual aid but also as a structured and meaningful learning environment.

From a practical standpoint, the high positive student response indicates that the media can increase student engagement in learning. These findings are consistent with multimedia learning theory (Clark & Mayer, 2016), which states that the combination of text, images, and interactivity can enhance students' cognitive processing. Furthermore, the ease of navigation and instant feedback within the media support the principle of self-regulated learning, where students have control over their own learning process. This is crucial in the context of 21st-century learning, which demands independent learning.

The main finding of this study lies in the effectiveness aspect, where the media was proven to significantly improve numeracy skills. The higher score increase in the experimental class indicates that the PBL approach integrated within the media has a stronger impact than conventional learning. This aligns with previous research showing that PBL is effective in improving critical thinking and problem-solving skills (Sujatmika et al., 2019; Zetriuslita et al., 2016).

However, this study makes a more specific contribution by demonstrating that the effectiveness of PBL is maximized when integrated within interactive learning media. Unlike conventional PBL implementation, which relies heavily on teacher facilitation, interactive media allows PBL structures to be systematically embedded within the learning design. This addresses one of the weaknesses of PBL frequently reported in the literature: implementation difficulties and high time requirements (Kirschner et al., 2006).

Furthermore, the significant improvement in numeracy skills demonstrates that this medium can accommodate three levels of numeracy cognition: knowing, applying, and reasoning. This aligns with the OECD (2019) mathematical literacy framework,

which emphasizes the importance of applying mathematical concepts in real-life contexts. The use of contextual problems in the medium allows students to connect abstract concepts to real-life situations, making learning more meaningful (Good et al., 2008).

The instant feedback feature within the medium also makes a significant contribution to improving learning outcomes. Feedback allows students to immediately identify errors and correct their understanding directly. This is supported by formative assessment theory (Black & Wiliam, 2009), which states that effective feedback can significantly improve the quality of learning. In this context, technology acts as a facilitator, accelerating the feedback cycle, making the learning process more adaptive.

From a research gap perspective, most previous research on interactive learning media has focused on technological aspects or visual design, without in-depth integration of learning models. On the other hand, research on PBL has generally been conducted in face-to-face learning contexts without the support of structured digital media. This research bridges these two approaches by integrating PBL into technology-based interactive media, resulting in a more comprehensive learning design (Porat & Ceobanu, 2024; Trelease, 2015).

Furthermore, previous research has shown that many digital-based learning media still rely on internet connections, which is a challenge in some regions. The media developed in this research is designed to be accessible offline, making it more adaptable to the current educational infrastructure in Indonesia (Irfan et al., 2023). This represents a significant practical contribution, particularly in the context of equitable access to education.

Overall, the findings of this study indicate that learning success is determined not only by the technology used, but also by how it is integrated with an appropriate pedagogical approach. The integration of Problem-Based Learning (PBL) into interactive media has been shown to create more contextual, adaptive, and student-centered learning. Therefore, this study provides theoretical contributions to the development of technology-based learning designs, as well as practical contributions for teachers in implementing innovative mathematics learning oriented toward numeracy improvement.

CONCLUSION

This study produced interactive mathematics learning media based on Problem-Based Learning (PBL) that proved valid, practical, and effective in improving students' numeracy skills. The media's validity is reflected in the suitability of the content, instructional structure,

and technical quality, which are systematically integrated. The media's practicality is demonstrated by the high level of student acceptance, indicating that the media is easy to use, engaging, and supports independent learning. Furthermore, the media's effectiveness is evidenced by the significant improvement in students' numeracy skills in the experimental class compared to the control class. These findings confirm that the integration of PBL into interactive media can encourage deeper cognitive engagement, particularly in the aspects of reasoning and contextual problem-solving. Thus, the developed media not only functions as a learning tool but also as a learning environment that facilitates the active and meaningful construction of knowledge. Conceptually, this research demonstrates that combining a problem-based pedagogical approach with interactive technology is an effective strategy for developing numeracy skills, while simultaneously addressing the challenges of learning mathematics in the digital age.

This research contributes to the development of technology-based mathematics learning studies by strengthening the integration of problem-based learning and interactive media within the TPACK framework. These findings broaden the understanding that the effectiveness of learning technology is determined not only by technical aspects but also by the underlying pedagogical design. Furthermore, this research confirms that numeracy as a 21st-century competency can be optimally developed through contextual, problem-based learning supported by adaptive technology. Future research is recommended to expand the scope of this study by involving larger and more diverse samples to enhance generalizability. Further studies can also develop similar media for different mathematical topics and educational levels. In addition, integrating adaptive learning systems or artificial intelligence features may further optimize personalized learning experiences. Longitudinal studies are also needed to examine the long-term impact of interactive PBL-based media on students' numeracy development.

DECLARATIONS

Author Contribution

Irfan, M., Conceptualization, Methodology, Supervision, Formal analysis, Writing, review & editing; **Hernawati, K.,** Methodology, Validation, Supervision, Writing, review & editing; **Amiyani, R.,** Investigation, Data curation, Formal analysis, Visualization, Writing, original draft; **Mentari, F.Z.J.,** Conceptualization, Investigation, Data curation, Software, Visualization, Writing, original draft.

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Conflict of Interest

The authors declare no conflict of interest.

Declaration of AI Use

Generative AI tools were used in the preparation of this manuscript. Specifically, ChatGPT was used to assist in improving language clarity, structuring the manuscript, and refining academic writing under the supervision and full responsibility of the authors. All content has been carefully reviewed and validated by the authors to ensure accuracy and originality.

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