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Artificial Intelligence Based Educational Game Design for Literacy and Numeracy Skills in Elementary School Mathematics Learning

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Abstract

Low literacy and numeracy achievement among elementary school students, particularly in mathematics learning, indicates the need for innovative learning media capable of providing adaptive and engaging learning experiences. Therefore, this study aims to design and evaluate an Artificial Intelligence (AI) based educational game for plane geometry learning to improve elementary school students' literacy and numeracy skills. The study employed the Research and Development (R&D) method using the ADDIE model, consisting of analysis, design, development, implementation, and evaluation. The developed product is an AI based Monopoly educational game that integrates adaptive question generation, automatic feedback, and learning analytics to adjust the difficulty level according to students' performance. The game was validated by two media experts and two mathematics education experts before being implemented in learning. The trial involved 25 fifth-grade students at Muhammadiyah 1 Labschool Umsida Elementary School. Data were collected through expert validation, classroom observation, and literacy and numeracy pretests and posttests. The validation results indicated that the developed game was highly feasible for classroom use. During implementation, students demonstrated high enthusiasm and active engagement in learning activities. The average pretest score increased from 65.64 to 80.16 in the posttest. The data met the normality assumption (pretest = 0.253; posttest = 0.567; $p > 0.05$). Furthermore, the Paired Sample t-test revealed a significant improvement in students' literacy and numeracy skills ($p = 0.000$), while the average N-Gain score of 40.07% indicated a moderate level of effectiveness. These findings demonstrate that the proposed AI based educational game is a feasible and effective learning medium for enhancing elementary students' literacy and numeracy skills while supporting Sustainable Development Goal 4 on Quality Education.

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INTRODUCTION

Elementary education plays a crucial role as the foundation for students' competency development, both in literacy and numeracy, which are inseparable parts of the global Sustainable Development Goals (SDGs), particularly Goal 4 on Quality Education. Literacy and numeracy at the elementary level are not merely basic academic skills but also essential competencies for developing logical, critical, creative, and adaptive thinking in the digital transformation era (Samukroni et al., 2024). Mastery of these competencies determines students' readiness to face 21st-century learning challenges while also serving as an indicator of a country's educational quality. In the context of sustainable development, strengthening literacy and numeracy is also an important strategy to create a generation that is able to contribute to social, economic, and technological development in a sustainable manner (Akbar et al., 2025).

In Indonesia, the results of the National Assessment, particularly the Minimum Competency Assessment (AKM), show that elementary school students' literacy and numeracy skills are still uneven and generally below the expected minimum competency standards. This finding is reinforced by the Program for International Student Assessment 2022 report, which placed Indonesia at 366 for mathematics and 359 for reading, far below the Organization for Economic Cooperation and Development (OECD) averages of 472 and 476, respectively (Abdullah et al., 2024). This situation demonstrates that the challenge in basic education is not simply access to schools, but rather the quality of learning experiences that truly develop students' essential competencies. In other words, classroom learning systems still need to be transformed to be more oriented toward problem-solving, reasoning, and the application of concepts to real-life situations (Pudyastuti et al., 2024).

Mathematics, particularly the topic of plane geometry, is a fundamental competency crucial for developing elementary school students' literacy and numeracy skills (Syakur et al., 2021). Plane geometry plays a strategic role as it serves as the foundation for understanding geometry, measurement, visual representation, and spatial reasoning. Furthermore, the concepts in plane geometry are closely related to everyday activities, such as calculating area, understanding object shapes, and designing simple objects. Therefore, learning plane geometry emphasizes not only formula mastery but also the development of mathematical thinking skills and applied contextual literacy (Nurmalitasari & Purnomo, 2025). Learning practices that are still oriented towards procedures, formula memorization, and solving routine problems make students less accustomed to dealing with authentic problems that require higher-level reasoning. As a result, mathematics is often perceived as an abstract and difficult subject, rather than a useful thinking tool in real life. Improving numeracy performance requires pedagogical innovations that are relevant to the needs of 21st-century students, including the integration of adaptive digital media in learning (Wijaya et al., 2024).

Digital transformation encourages teachers to utilize innovative learning media as a means of improving students' conceptual understanding (Afidah & Subekti, 2024). Changing student characteristics, who are increasingly familiar with technology, demand more interactive, visual, and experiential learning. Teachers no longer act solely as transmitters of material but also as facilitators capable of integrating technology pedagogically (Sitopu et al., 2023). In this context, digital media becomes a strategic instrument for bridging abstract concepts with concrete and enjoyable learning experiences (Robiah et al., 2023).

Educational games are an effective medium because they can provide interactive, engaging learning that aligns with the learning styles of the digital native generation (Firmandasari et al., 2020). Through elements of challenge, exploration, rewards, and immediate feedback, educational games can increase students' intrinsic motivation to learn. Furthermore, game mechanics encourage active engagement, collaboration, and persistence in completing tasks. This makes educational games not only a means of entertainment but also an experiential learning strategy that supports in-depth conceptual mastery (Sofi & Hasanah, 2024). In the context of learning about flat geometry mathematics, digital media allows for more concrete visualization of shapes, properties, and applications (Amir et al., 2018).

Previously abstract geometric concepts can be visualized through simulations, animations, and direct interaction with virtual objects. This allows students to more easily understand the relationships between shapes, measurement processes, and the application of concepts to real-world situations. This visualization is particularly important at the elementary school level, where students' cognitive development still requires the support of concrete representations to build conceptual understanding. Existing digital media are often static, limited to simple practice problems, and do

not support personalized learning experiences. Most only provide linear problems without adapting to student abilities, making them less effective in accommodating diverse learning needs. Effective learning requires instructional differentiation so that each student receives challenges appropriate to their level of competence (Lavin-Mera et al., 2009).

This limitation has resulted in the potential of educational technology not being optimally utilized. This indicates a gap between the need for competency-based learning in numeracy literacy and the availability of digital media that truly supports these achievements (Hidayat et al., 2025). This gap demands the development of more intelligent, responsive, and data-driven learning media. Simply presenting material in digital form is not enough. Media needs to be designed to understand user performance, adjust the learning flow, and provide appropriate recommendations to improve competency.

The development of artificial intelligence (AI) in education is a global trend with significant potential to address these challenges (Anam et al., 2016). AI offers a new paradigm in learning through data analysis capabilities, automated decision making, and performance-based adaptation. In the educational context, AI opens up opportunities to create more personalized, inclusive, and efficient learning systems (Akbar et al., 2025). The integration of AI will not only revolutionize the way students learn but also how teachers monitor their progress in real time. AI enables adaptive learning, personalized materials, automated feedback, and more engaging learning interactions (Sabariah et al., 2024). This technology can analyze student response patterns, identify conceptual weaknesses, and then adjust the difficulty level of questions to suit individual abilities. Thus, students receive a more tailored learning experience, while teachers gain data to inform more appropriate learning interventions. In the context of primary education, the application of AI through educational games can be an innovative solution that not only motivates students but also adapts the difficulty of questions to individual abilities, thereby supporting the improvement of numeracy literacy more effectively (Akhyar et al., 2023).

This integration is highly relevant for basic mathematics, as students require a gradual, challenging, and contextual learning experience. With AI support, educational games can function not only as a training tool but also as a diagnostic and competency development tool (Rusdial Marta et al., 2025). Therefore, the design of AI-based educational games capable of (1) adapting tasks to ability levels, (2) recording learning paths (learning analytics) for measuring literacy and numeracy, and (3) presenting real-world contexts for geometric shapes is highly urgent as an innovative solution supporting SDG 4, namely Quality Education (Wang et al., 2022). Furthermore, such designs can become a model for future learning that integrates intelligent technology with a humanistic pedagogical approach. Research on AI-based educational game design for literacy and numeracy skills in elementary school, mathematics learning is crucial for filling the research gap while providing practical contributions to the development of adaptive, meaningful, and sustainable basic education (Jonathan, 2024).

Although previous studies have demonstrated the effectiveness of educational games and digital learning media in mathematics learning, few studies have integrated AI to provide adaptive question generation, automatic feedback, and learning analytics to improve elementary students' literacy and numeracy skills. Therefore, this study addresses this research gap by designing an AI-based educational Monopoly game for learning plane geometry. Specifically, this study aims to design, develop, validate, and evaluate the effectiveness of the proposed AI-based educational game in improving elementary school students' literacy and numeracy skills while supporting Sustainable Development Goal 4 (Quality Education).

RESEARCH METHODS

This study employed the Research and Development (R&D) method using the ADDIE instructional design model, which consists of five phases: Analysis, Design, Development, Implementation, and Evaluation (Molenda, 2015). The purpose of this study was to design, develop, validate, and evaluate an Artificial Intelligence (AI)- based Monopoly educational game to improve elementary school students' literacy and numeracy skills in plane geometry learning.

A. Analysis

The first phase of the ADDIE model is the learning analysis stage, which aims to identify learning needs, analyze students' characteristics, examine learning problems, and determine appropriate instructional solutions (Cresswell, 2014). This stage includes needs assessment, problem identification, task analysis, and learning context analysis to ensure that the developed educational game addresses students' literacy and numeracy needs in learning plane geometry.

In this study, the learning analysis stage consisted of analyzing students' characteristics, identifying difficulties encountered in learning mathematics, particularly plane geometry, analyzing instructional needs, reviewing previous research findings in accordance with the research roadmap, developing the system flowchart, and determining the specifications of the AI-based educational game to be developed. The results of this stage served as the foundation for designing an educational game that is pedagogically appropriate, technologically feasible, and capable of improving students' literacy and numeracy skills.

B. Design

The design stage is the stage carried out to create a product blueprint, encompassing the design of the media in the form of an AI-based educational game, media specifications, media content, and storyboard design, including UI/UX design plans and materials. The storyboard serves as an overview or guideline for the game to be developed, which then moves on to the display design stage, also known as interface design.

The developed educational game integrates Artificial Intelligence to provide adaptive learning experiences during gameplay. The AI module analyzes students' responses to each question, provides immediate feedback, records students' performance as learning analytics data, and adjusts the difficulty of subsequent questions based on students' previous performance. Through this mechanism, students receive personalized learning experiences while teachers can monitor students' literacy and numeracy progress. The AI system architecture diagram is shown in Figure 1.

Figure 1 illustrates the architecture of the AI-based Monopoly educational game. During gameplay, students move their tokens according to the Monopoly rules and receive mathematics questions generated by the AI module based on the predefined learning objectives and students' previous performance. The AI engine automatically evaluates students' answers, provides immediate feedback, records learning analytics, and recommends the difficulty level of subsequent questions. The learning analytics generated by the system are summarized in a learning report that enables teachers to monitor students' literacy and numeracy development throughout the learning process.

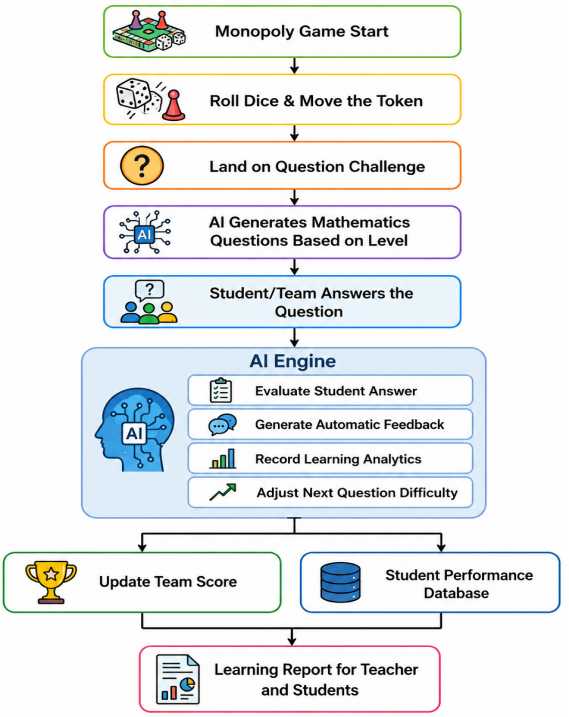

Figure 1. AI system architecture diagram

C. Development

The development stage is the implementation of the blueprint. At this stage, learning media in the form of an AI-based educational game is developed and tested. After product development is complete, the educational game is validated by media experts and subject matter experts to ensure its quality for use in the learning process (Amirulloh et al., 2019). The expert validation involved one subject matter expert and one media expert. The implementation stage involved 25 fifth-grade students of Muhammadiyah 1 Labschool Umsida Elementary School. Media expert validation criteria include visual design, interactivity, and user experience, AI implementation, and technical aspects. Subject-matter expert validation includes aspects such as curriculum suitability, learning outcomes, material accuracy and depth, literacy and numeracy, AI integration in learning, and support for the SDGs. If the media is declared valid, it is ready for limited-scale trials. The media feasibility test instrument used by users, namely students, is based on aspects of media interest, literacy and numeracy, and learning motivation. The data analysis technique for valid and feasible criteria uses Formula 1. The educational game suitability criteria are presented in Table 1.

$$P = \frac{\Sigma x}{N} x100\% \quad (1)$$

Description:
P : Percentage score
∑x : Total score
N : Maximum score

Table 1. Feasibility Criteria

Range	Feasibility Level	Description
81-100	Very Feasible	Can be used without revision
61-80	Feasible	Can be used with minor revisions
41-60	Fairly Feasible	Can be used with major revisions
21-40	Less Feasible	Can not be used
0-20	Not Feasible	Can not be used

D. Evaluation

The evaluation stage is the stage for evaluating the results of the implementation stage. This evaluation stage will determine the effectiveness of the developed educational game media. This stage is conducted through tests to assess improvements in students' literacy and numeracy skills so that game-based learning media can be disseminated and provide maximum benefits in accordance with the SDGs' goal of quality education. Data collection techniques include literacy and numeracy ability tests. A flowchart of the research procedures to be carried out is shown in Figure 2.

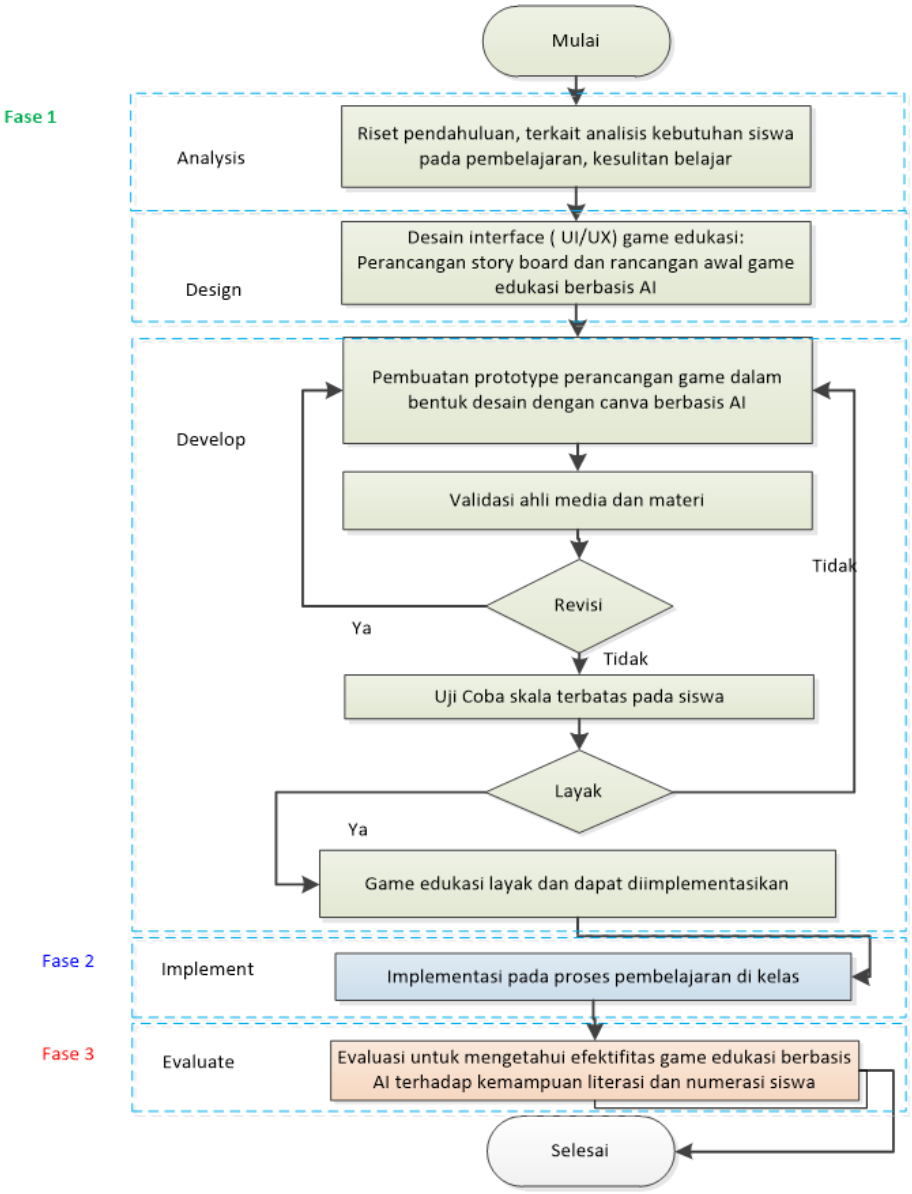

Figure 2. Educational game development procedure

RESULT AND DISCUSSION

This research resulted in an AI-based educational game for the subject of flat geometry mathematics that combines visual elements, level-based challenges, automatic feedback, and adapts problem difficulty levels based on student performance. This development aimed to create a learning experience that was not only engaging but also supported the strengthening of literacy and numeracy competencies in an integrated manner. This website-based Monopoly game was developed using the Gemini application and Cloud AI.

In accordance with the research procedures outlined in the methods, this section presents the stages of educational game development, validation results, and testing of the game's effectiveness. Game development began with a needs analysis. The analysis phase, the first phase, aimed to identify learning needs, student characteristics, and challenges faced in the mathematics learning process, particularly in the topic of flat geometry. This phase also analyzed the need for innovative media that could improve students' literacy and numeracy skills. The results of the analysis phase served as the basis for designing the media, a Monopoly game for flat geometry.

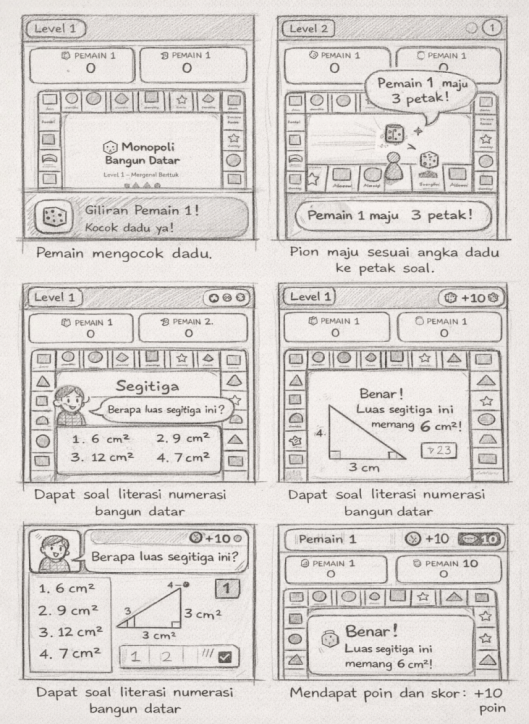

Figure 3. Storyboard of the educational game Monopoly on flat shapes

Based on the needs analysis, in the design phase, the researchers designed an AI-based educational game that incorporates flat geometry material using an interactive and adaptive learning approach, namely the Monopoly game for flat geometry. This game is designed with several key features, such as game levels, geometric shape quizzes, a scoring system, and automatic feedback that helps students understand mathematical concepts gradually according to their ability level. Furthermore, the game design also considers attractive visual aspects, simple language, and navigation that is easy for elementary school students to use. This monopoly educational game is also equipped with audio to make students more enthusiastic and enjoy learning (Luh et al., 2025). In accordance with research, the initial design of this game is depicted in the storyboard shown in Figure 3.

Next in the development stage, the designed educational game is then developed into a product that can be used in learning. The Monopoly educational game interface consists of several sections. The main page contains the adventure start menu, game rules, and developer menu. The rules of the Monopoly educational game are shown in Figure 4.

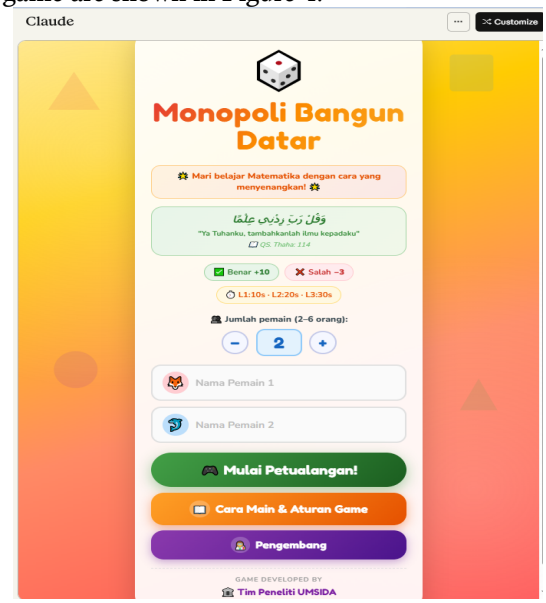

Figure 4. Media homepage

Users can determine the number of players (2–6) using the interactive buttons (+ and -), and enter each player's name, complete with an emoji avatar as a visual identity. This educational game is inspired by the game Monopoly, which consists of a square game board with a track consisting of colorful squares. Each square represents a different geometric shape in Indonesian, including: Square (red), Triangle (green), Circle (purple), Rectangle (orange), Parallelogram

(brown), Trapezoid (light blue), and Rhombus (indigo). The main interface of this Monopoly educational game is shown in Figure 5.

The quiz page interface in the Monopoly educational game consists of three learning levels with gradually increasing difficulty: Level 1, Level 2, and Level 3. Each quiz page is designed to be interactive, visual, and user-friendly to support elementary school students' understanding of mathematical concepts.

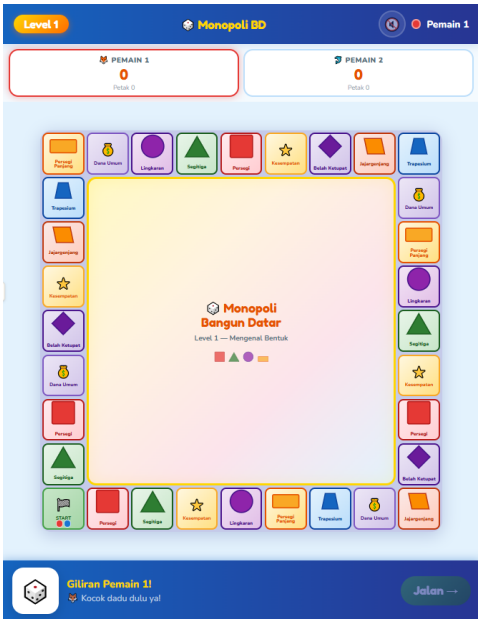

Figure 5. Interface of the flat monopoly educational game

This game is divided into three levels. Level 1 focuses on recognizing geometric shapes. Questions are presented in simple text, such as the name of a geometric shape like a rectangle, followed by a question like "How many sides does this shape have?" Answer choices are presented in interactive buttons. This level is designed as an initial stage to train students' basic understanding of the characteristics of geometric shapes. At Level 2, the difficulty level increases by presenting visual and numerical-based questions. Students are given a picture of a geometric shape (e.g., a square) complete with specific dimensions, then asked to calculate the perimeter or length of a side. At this level, the system provides immediate feedback in the form of a correct notification (e.g., "Yay! Correct! +10 points") when students answer correctly, thus increasing learning motivation. Level 3 is an advanced level that focuses on calculating the area of geometric shapes. Questions are presented visually, such as a picture of a rhombus with diagonal information, and students are then asked to calculate its area. If the answer is incorrect, the system will display corrective feedback, such as a point deduction (e.g., -3 points), along with information about the correct answer. This aims to help students understand errors and correct concepts that have not been mastered.

The developed educational game was validated by one subject matter expert and one media expert to evaluate the accuracy and appropriateness of the learning content, the quality of the media design, the implementation of AI features, and its suitability for use in elementary school mathematics learning.

Figure 6. Games based on levels

Table 2. Material Expert Validation Results

Validator	Aspect	Average Score (%)
Material	Curriculum alignment and learning outcomes	90
	Accuracy and depth of material on geometric shapes	84
	Integration of literacy and numeracy	75
	Integration of AI in learning	80
	Support for SDGs	80
Average		**83**
Media	Visual Design Media	100
	Interactivity and User Experience	70
	AI Implementation	100
	Technical	100
Average		**93**

Based on the validation results, the educational game was declared feasible for classroom implementation, with only minor revisions suggested regarding the interface design and the presentation of several questions. The validation results from the subject matter expert and the media expert are presented in Table 2.

Table 2 shows the validation test of the Monopoly game for flat shapes by material and media experts, with average scores of 83% and 93%, respectively, placing both in the very high category. This indicates that the Monopoly game for flat shapes has met the eligibility criteria in both the material and media aspects of learning. In terms of material, the learning content presented is considered in accordance with the competencies of elementary school mathematics learning, especially in the material on flat shapes, and is able to support the development of students' literacy and numeracy skills. Meanwhile, in terms of media, the design display, game flow, interactivity, and ease of use are considered attractive and in accordance with the characteristics of elementary school students. Thus, the educational game developed is suitable for use as a learning medium and can be continued to the trial stage with students to determine its effectiveness in improving literacy and numeracy in mathematics learning.

A limited trial of the media was also conducted to assess its functionality and initial usability. Initial trial results showed that the developed educational game was well-suited for student use and increased student engagement in mathematics learning, with an average score of 92.12%. Students appeared more enthusiastic in answering questions and understanding the concept of plane figures through interactive game activities. Thus, the preliminary results of the study indicate that the developed AI-based educational game media have good potential for use as a learning medium to improve student literacy and numeracy in the topic of plane figures (Susana et al., 2026).

The implementation phase was carried out by implementing the Monopoly game in mathematics learning in grade V of Muhammadiyah 1 Labschool Umsida Elementary School, involving 25 students. The learning activity began with a pretest to determine students' initial literacy and numeracy skills. Next, students participated in learning using the Monopoly game, which was designed to be interactive and competitive in groups. At the end of the activity, a reward was given to the team that obtained the highest score as a form of strengthening learning motivation, followed by a posttest to measure the improvement in student learning outcomes after using the media.

The implementation stage involved 25 fifth-grade students at Muhammadiyah 1 Labschool Umsida. Students first completed a pretest to measure their initial literacy and numeracy skills before participating in mathematics learning using the AI-based Monopoly educational game. After the learning activities were completed, students took a posttest using the same indicators to evaluate improvements in their literacy and numeracy skills.

The quantitative results showed that the average pretest score was 65.64, which increased to 80.16 in the posttest, indicating an improvement in students' literacy and numeracy skills after using the developed educational game. Prior to hypothesis testing, the data were subjected to a normality test. The results indicated that both the pretest and posttest data were normally distributed, with significance values of 0.253 and 0.567, respectively ($p > 0.05$). Therefore, the data met the assumptions for parametric analysis, and a Paired Sample t-test was subsequently performed. The statistical analysis results are presented in Table 3.

Table 3. Paired Sample t-test Results

	Std. Deviation	Sig. (2-tailed)	t
Pretest-Postest	8.851	0.000	-8.202

The results of the Paired Sample t-test showed a significance value of $0.000 < 0.05$, which means there is a significant difference between the pretest and posttest results. This finding indicates that using the Monopoly educational game on flat shapes significantly improves students' literacy and numeracy skills. In addition, the results of the N-Gain calculation showed an average value of 40.07%, which is included in the medium category. This indicates that the developed media is quite effective in improving student learning outcomes. Although it has not reached the high category, this increase shows that integrating educational games into learning can positively contribute to understanding of mathematical concepts, especially in material on flat shapes.

Overall, the implementation and evaluation results demonstrate that the AI-based Monopoly educational game effectively improved elementary school students' literacy and numeracy skills, as evidenced by the significant increase in posttest scores and the Paired Sample t-test results. These findings indicate that the developed game is a feasible and

effective A learning medium for mathematics instruction, particularly in learning plane geometry. Furthermore, the integration of AI features and game-based learning provides an innovative approach that supports interactive and meaningful learning experiences in line with the principles of twenty-first century education (Bell, 2010) and contributes to the achievement of Sustainable Development Goal 4 (Quality Education).

The results of this study indicate that the use of the AI-based Monopoly educational game significantly improved elementary school students' literacy and numeracy skills. This finding is evidenced by the significant difference between the pretest and posttest scores, with the average score increasing from 65.64 to 80.16 after the implementation of the educational game. These findings demonstrate that the developed game effectively supports the improvement of students' literacy and numeracy skills in learning plane geometry. These findings align with constructivist learning theory, which emphasizes that students construct knowledge through active learning experiences and interactions with the environment (Masgumelar & Mustafa, 2021). In this context, educational games serve as a medium that enables students to learn through exploration, experimentation, and direct problem-solving (Alani et al., 2026). This aligns with the use of digital game-based learning, which has been shown to improve elementary school students' numeracy literacy skills (Rahayu et al., 2025).

The improvement in learning outcomes, as demonstrated by the moderate N-Gain score, indicates that the developed learning media have facilitated students' thinking processes, particularly in understanding the concept of plane figures in a more contextual manner. This aligns with the concept of numeracy literacy, which emphasizes not only calculation skills but also the ability to understand, interpret, and use mathematical information in everyday life (Otaya et al., 2025). With the game context, students not only work on problems but are also faced with situations that require decision-making and strategy.

In terms of learning motivation, observations show that students are more enthusiastic and active during the learning process. This supports the notion that educational games can increase students' intrinsic motivation through elements of challenge, competition, and rewards (Hasanah et al., 2021). In this study, providing rewards to the winning team proved to be a positive stimulus that encouraged students to be more involved in the learning process. These findings align with previous research suggesting that the use of games in learning can increase student engagement and create a more enjoyable, less monotonous learning environment (Dinihari et al., 2024).

The integration of AI into educational games offers added value compared to conventional learning media. AI allows for the adjustment of problem difficulty levels to suit student abilities, enabling each student to receive a more personalized learning experience (Sabariah et al., 2024). This aligns with the concept of adaptive learning, which emphasizes instructional differentiation based on individual needs. Thus, students with lower abilities can still participate in learning, while students with higher abilities receive appropriate challenges. The use of AI-based educational games in this study is relevant as an innovative solution that can bridge these needs. This medium not only helps students understand mathematical concepts but also trains critical, analytical, and application thinking skills (Akhyar et al., 2023).

The results of the study indicate that the improvement is still in the moderate category. This could be due to several factors, such as limited implementation time, student adaptation to new media, and variations in students' initial abilities. Therefore, further development is needed in game features, duration of use, and integration with other learning strategies to achieve more optimal results. Overall, this study shows that AI-based educational game design has great potential to improve the quality of mathematics learning in elementary schools. These findings reinforce the importance of innovative learning media that are not only engaging but also adaptive and oriented towards developing literacy and numeracy competencies as part of efforts to achieve quality education.

CONCLUSION

This study successfully designed, developed, validated, and evaluated an AI-based Monopoly educational game for plane geometry learning. The findings demonstrate that the developed game is valid, feasible, and effective in improving elementary school students' literacy and numeracy skills, as indicated by the significant improvement in pretest and posttest scores and the moderate N-Gain category. These results suggest that integrating AI into educational games can provide an innovative learning medium to support mathematics learning and contribute to achieving Sustainable Development Goal 4 (Quality Education). This study has several limitations. First, the

implementation was conducted at only one elementary school, involving 25 fifth-grade students, which limited the generalizability of the findings. Second, the effectiveness of the developed game was evaluated only in terms of students' literacy and numeracy skills over a relatively short implementation period. Therefore, future studies are recommended to involve larger and more diverse samples, extend the implementation period, and further develop AI features such as personalized learning pathways, adaptive learning recommendations, and learning analytics to optimize students' learning experiences.

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