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Exploration of Learning Innovations to Improve Critical Thinking in Student Problem-Solving Through the Design Thinking

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Abstract

This research aims to understand and analyze the problems experienced by teachers and students in learning mathematics, and explore initial solution ideas based on user needs. The focus of the research is the low critical thinking skills of students and the difficulty in visualizing geometry. This research method uses a qualitative approach with the framework of Design Thinking. Five stages of Design Thinking is (1) empathize, (2) define, (3) ideate, (4) prototype, and (5) test, however this research is limited to ideate stage. Participants consisted of 5 teachers and 98 students from MA Al Utsmani Kajen, MA YMI Wonopringo, and MASS Proto. Data were collected through electronic questionnaires, interviews, and observations using standardized instruments. The exploration results show the need for a problem-based learning model integrated with a gamification approach and supported by Android-based interactive learning media. This research contributes to designing innovative user needs-based solutions that can improve students' critical thinking skills and facilitate the visualization of geometry concepts.

Keywords: critical-thinking; design thinking; learning media

INTRODUCTION

Mathematics is a compulsory subject taught at all levels of education in Indonesia, from elementary school to high school. The role of mathematics is not only as a calculation tool, but also as a means to shape logical, critical, systematic, and analytical ways of thinking in daily life. (Lee et al., 2023). According to Risah and Sutirna (2020), mathematics has logical and critical characteristics so it is very strategic in improving the quality of human resources.

However, various studies and observations in the field show that mathematics learning still faces major challenges, especially in developing students' critical thinking skills. Based on the results of interviews with teachers and students in Pekalongan, it was found that learning is still dominated by lecture methods. Students tend to be passive, only taking notes and imitating the completion steps without understanding the concepts in depth. Students feel unconfident in their mathematical abilities, especially when they have to solve new problems that are different from the examples, especially in geometry material. This shows the low critical thinking ability caused by the lack of active student involvement and lack of conceptual understanding (Pramuditya, Supandi, & Nugroho, 2019; Meilina, 2023).

Mathematical problem solving is a complex cognitive process and requires high critical thinking skills, such as the ability to analyze, reason, predict, and do self-reflection (Arif, Zaenuri, & Cahyono, 2020). Rahmadani and Manullang (2024) emphasize that effective problem solving requires systematic observation and critical thinking to find the right solutions. Therefore, a learning strategy that can foster student activeness and creativity is needed.

Critical thinking ability is a high-level cognitive ability that is very important in solving mathematical problems. According to Facione (in Putri, Nusantara, & As'ari, 2025), critical thinking is an organized thinking process to analyze, evaluate, and logically conclude information or arguments. Indicators of critical thinking skills include: (1) problem clarification, (2) information gathering and assessment, (3) logical inference, (4) argument assessment, and (5) decision making (Ratnaningsih, Suprapto, & Prayogi, 2022). In the context of mathematics, these indicators appear in students' ability to identify problems, analyze available data, choose a solution strategy, and reflect on the solution taken.

Unfortunately, there are still many students who have difficulty in visualizing geometry concepts (Putri et al., 2025; Schoenherr & Schukajlow, 2024; Wu et al., 2024). Visualization is an important element in learning geometry because it relates to spatial understanding, object representation, and relationships between elements in two and three-dimensional space (Rohendi et al., 2025). Visualization of spatial concepts is often an obstacle for students, especially in understanding the shape, space, and relationships between geometry objects (Sari, Sagala, & Simanjuntak, 2024). Students' inability to describe, construct, or manipulate geometric shapes is a major obstacle in solving problems that require visual understanding. The lack of use of visualization media makes it difficult for students to imagine abstract concepts, which has an impact on low learning outcomes. This is exacerbated by teachers' limitations in developing or accessing relevant and easy-to-use interactive learning media (Irkhamni & Najibufahmi, 2023). This condition shows that the problem of visualization in geometry learning does not only come from student limitations, but also closely related to the role and readiness of teachers in providing supportive learning media.

Teachers' limitations in accessing or developing interactive learning media are also an obstacle in implementing effective learning. Teachers often rely on textbooks or conventional media, and have not optimally utilized digital technology in learning (Utomo, Muhtarom, & Dwijayanti, 2024). In fact, interactive learning media has been proven to increase student motivation, engagement, and concept understanding through a more enjoyable and meaningful learning experience (Cahyani & Ahmad, 2024; Hakeu, Pakaya, & Tangkudung, 2023). Interactive learning media is software or applications that allow users to actively interact with learning content. According to Arif and Dewi (2024), the use of interactive learning media assisted by Construct 2 can significantly improve students' critical thinking skills, especially when combined with a problem-based learning model. Furthermore, research by Hakeu, Pakaya, and Tangkudung (2023) showed that the use of gamification-based interactive media can significantly increase student motivation and critical thinking skills.

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One approach that can bridge these problems is Design Thinking (DT). Design Thinking (DT) is a human-centered, collaborative, and iterative approach, designed to solve complex problems through creative and analytical thinking processes (Sekarwulan, 2022). In an educational context, DT allows students to more actively explore contextual and meaningful problems, and participate in creating innovative solutions (Utomo, Muhtarom, & Dwijayanti, 2024). With stages such as empathize, define, ideate, prototype, and test, Design Thinking provides a systematic framework for developing higher-order thinking skills.

By identifying the gap between the need for critical thinking development and the learning approaches that have been used so far, this research aims to explore learning innovations through the Design Thinking framework as an effort to improve students' critical thinking skills in solving mathematical problems. This research is expected to make theoretical and practical contributions to the development of mathematics learning models that are more contextual, interactive, and student-centered.

METHOD

This research method uses a qualitative approach with the framework of Design Thinking, which focuses on creating solutions to complex problems based on a deep understanding of the needs of users, in this case teachers and students. Design Thinking was chosen because it is able to integrate the learning process and design in a multidisciplinary manner, which is relevant to improve students' critical thinking skills in mathematics learning (Utomo, Muhtarom, & Dwijayanti, 2024). This research aims to understand the problems of mathematics learning in the field, analyze them, and explore solution ideas based on the real needs of users.

The subjects in this study were 98 students and 5 teachers from several madrassas in Pekalongan Regency, namely MA Al Utsmani, MA YMI Wonopringo, and MASS Proto. The selection of participants is carried out purposively based on their involvement in the mathematics learning process and willingness to provide the required information. Data was collected through electronic questionnaires, semi-structured interviews, and direct classroom observations. The research instruments, both questionnaires and interview guidelines, have been validated by linguists and subject matter experts to ensure clarity and accuracy of the content.

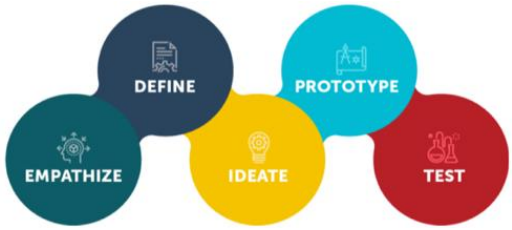

Figure 1. Phases Design Thinking

The research process is carried out through five stages of Design Thinking (Figure 1) according to Stanford d.school (Sekarwulan, 2022), namely: (1) empathize, a stage where the researcher builds a deep understanding of the problems faced by users through questionnaires, interviews, and observations; (2) define, which is analyzing the results of the empathy phase to formulate specific problems based on the needs and perspectives of the user; (3) ideate, which is the process of exploring various creative ideas and solutions that are relevant to user problems; (4) prototype, where the ideas that have been formulated are translated in the form of an initial design in the form of a learning model or interactive media; and (5) test, which is the stage of testing prototypes to teachers and students to obtain feedback and improve the solutions that have been developed.

Data analysis was carried out thematically by following the steps from Braun and Clarke (2006 in Rozali, 2022). The process begins with familiarization of the data through repeated reading, followed by coding the relevant data, grouping the code into themes, reviewing and defining the theme, to the preparation of a narrative that connects the findings with relevant theories. In addition, this study is also

equipped with a meta-analysis of articles from national journals published between 2021 and 2025. Meta-analysis was used to reinforce field findings and evaluate the effectiveness of problem-based learning models and interactive media on students' critical thinking skills. The value of the effect size is calculated using the formula:

$$ES = \frac{\overline{x_E} - \overline{x_K}}{S_k}$$

with the interpretation of the results based on the classification from Anggreani (2019 in Dwijayanti & Nugroho, 2023), namely: less (), low (), medium (and high ().$0{,}00 < ES \leq 0{,}20 < ES \leq 0{,}50 < ES \leq 1{,}00, ES > 1{,}00$

To ensure the credibility, dependability, and confirmability of research results, various strategies are implemented. Credibility is obtained through data triangulation (questionnaires, interviews, and observations), member checking with participants, and detailed presentation of context as suggested by Lincoln and Guba (1985 in Setianingrum, 2021). Dependability is guaranteed through systematic recording of research procedures so that the process can be traced or replicated by other researchers. Meanwhile, confirmability is enforced through trail audit documentation and researchers' reflection on the analysis process that is consciously carried out to minimize personal bias, as stated by Shenton (2004 in Astuti, 2022).

RESULTS

1. Emphatize Stage

The Empathize stage is an important foundation in the Design Thinking approach, as it allows researchers to deeply understand the needs and challenges faced by users, in this case teachers and students, in the mathematics learning process. This approach emphasizes the importance of human-centered understanding to design relevant and effective solutions (Sekarwulan, 2022).

In this study, researchers collected data through electronic questionnaires, in-depth interviews, and observations of 98 students and 5 teachers in several madrasas in Pekalongan. The results of the questionnaire showed that 57.1% of students felt challenged when learning mathematics, indicating an intrinsic motivation despite the perception that mathematics is a difficult subject. However, 55.1% of students have difficulty understanding material that requires visualization, especially on geometry topics. As many as 68.4% of students stated that geometry material was the most difficult to understand, and 64.3% attributed the difficulty to the lack of use of visual aids by teachers.

These findings are in line with research showing that spatial visualization skills are essential in geometry learning. This limitation in ability can hinder the understanding of abstract geometric concepts (Rohendi, 2025). The use of technology-based learning media, such as augmented reality, has been shown to be effective in increasing students' interactivity and understanding of complex geometric concepts (Rohendi, 2025).

From interviews with teachers, concerns were expressed about students' low critical thinking skills in solving math problems, especially those in the form of contextual story problems. Teachers also stated that the limitation in providing adequate learning media is one of the factors causing student difficulties. Previous research emphasizes that critical thinking skills are essential skills in 21st-century mathematics learning, which enable students to analyze, evaluate, and solve problems effectively (Putri, Nusantara, & As'ari, 2025).

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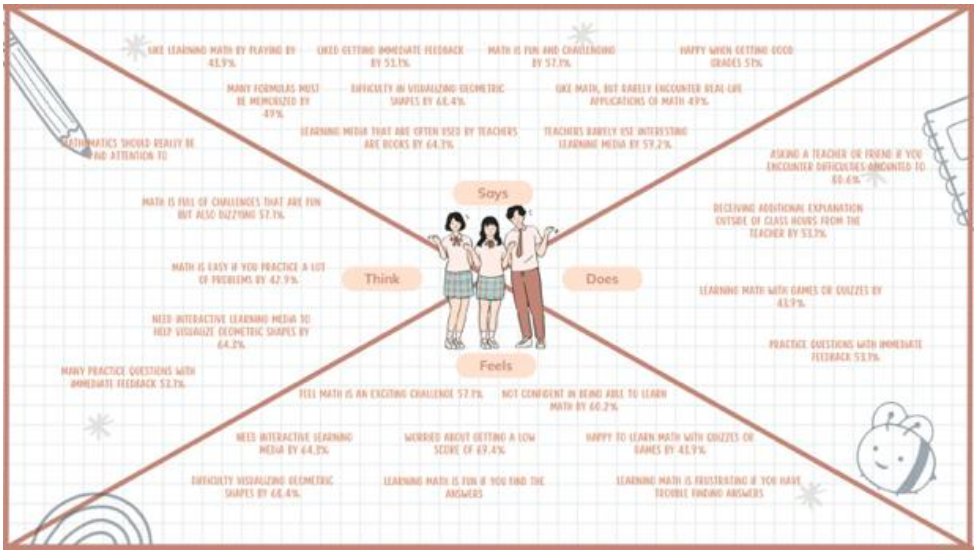

Figure 2. Emphaty Map Student

Based on the data obtained, the researcher compiled an empathy map for students and teachers to identify their needs and challenges in more depth. The students' empathy map (Figure 2) showed that although they found math challenging and fun, they had difficulty visualizing geometric shapes, such as distinguishing between cubes and blocks or understanding geometric transformations. This shows the need for a more interactive and visual approach to learning to help students understand abstract concepts in geometry.

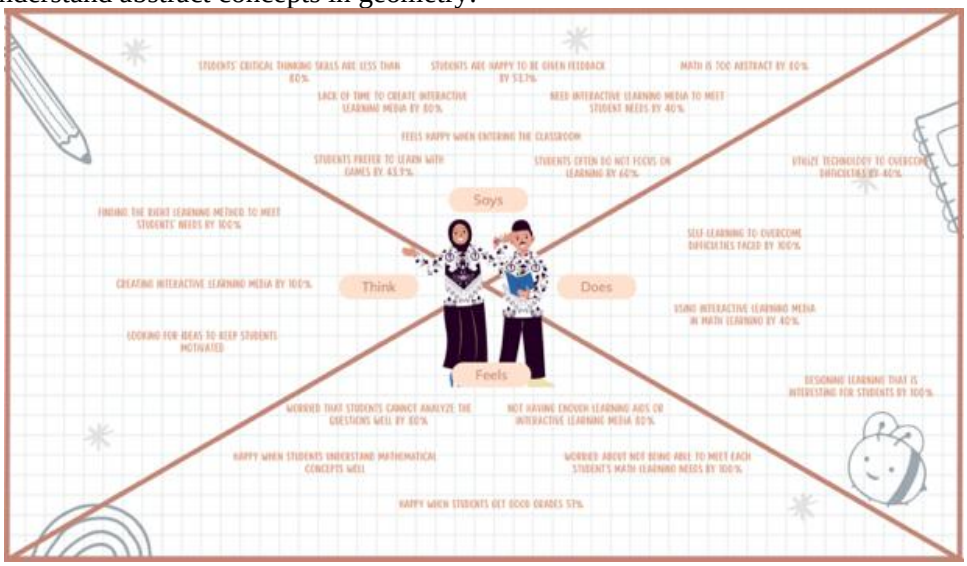

Figure 3. Emphaty Map Teacher

Meanwhile, the empathy map of teachers (Figure 3) revealed that they were concerned about students' low critical thinking skills and felt limited in providing effective learning media. Teachers need learning aids that can help students visualize geometry concepts better. Research shows that the use of technology-based learning media can improve students' understanding of complex mathematical concepts (Rohendi, 2025).

By understanding the needs and challenges faced by students and teachers through the Empathize stage, researchers can design learning solutions that are more effective and appropriate to the context of mathematics learning in madrasas. This approach is expected to improve students' critical thinking skills and make it easier for them to understand complex geometric concepts.

2. Define Stage

The Define stage is an important step in the Design Thinking approach, which aims to analyze the findings of the Empathize stage in order to formulate the problem clearly and focusedly.

According to Sekarwulan (2022), this phase involves interpreting various user insights through techniques such as Point of View (PoV) and How Might We (HMW), to ensure that the needs of users (teachers and students) are represented concretely in the formulation of problems.

a. Defining Problems with Point of View

Point of View is used to formulate problems based on the perspective of users, namely students and teachers, which have previously been analyzed through empathy maps. The results of this PoV are then visualized in Figure 4 (student) and Figure 5 (teacher).

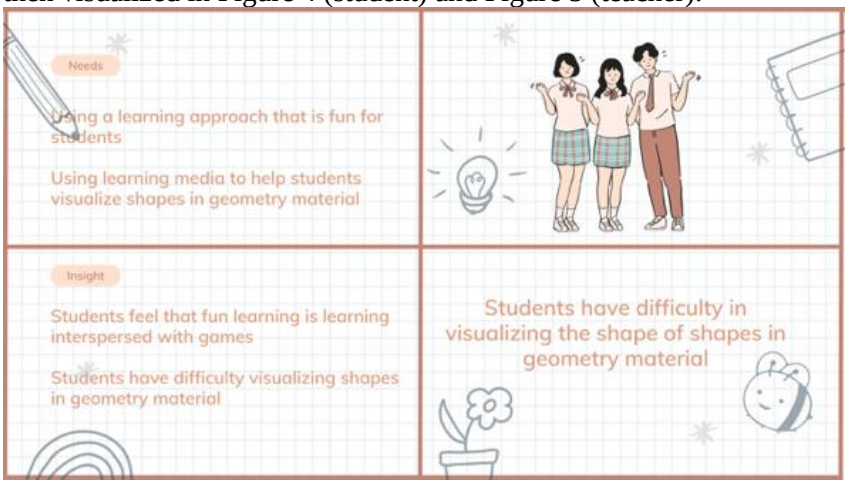

Figure 4. Point of View Siswa

From the 98 students analyzed, it was found that students had difficulty in visualizing geometric shapes. They state the need for a fun learning approach, such as through games or quizzes, as well as learning media that can help them visually understand geometric shapes. This is supported by Purnama et al. (2022), who stated that the use of gamification-based interactive learning media can help students visualize geometry concepts more effectively.

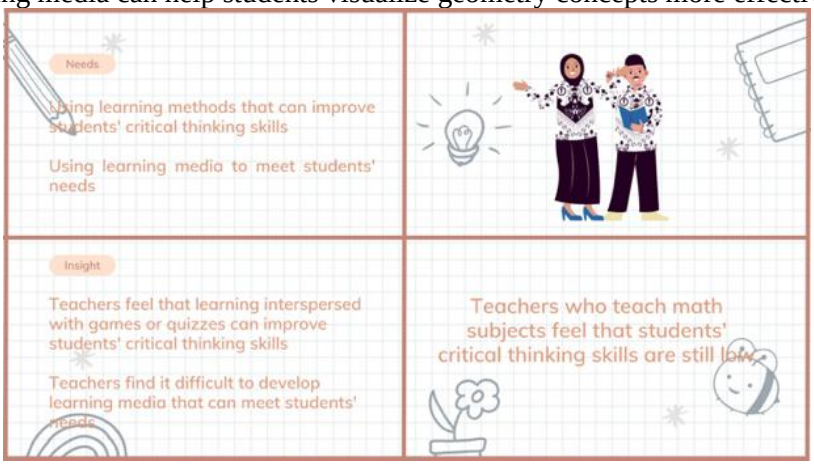

Figure 5. Point of View Guru

Meanwhile, from the 5 teachers interviewed, it was found that teachers felt that students had difficulty in understanding geometry materials and showed low critical thinking skills. Teachers need a learning approach that inserts games or quizzes to foster students' reasoning power. Meilina (2023) shows that the use of games in learning can help improve students' critical thinking skills. In addition, Arif and Dewi (2024), and Hakeu, Pakaya, and Tangkudung (2023) concluded that gamification-based learning media is also effective in increasing students' critical thinking skills towards mathematics content.

b. Problem Analysis with How Might We Technique

The How Might We (HMW) method is used to formulate problems into open-ended questions that can be explored for solutions. Figure 6 illustrates how researchers developed some of the key questions based on the problems found.

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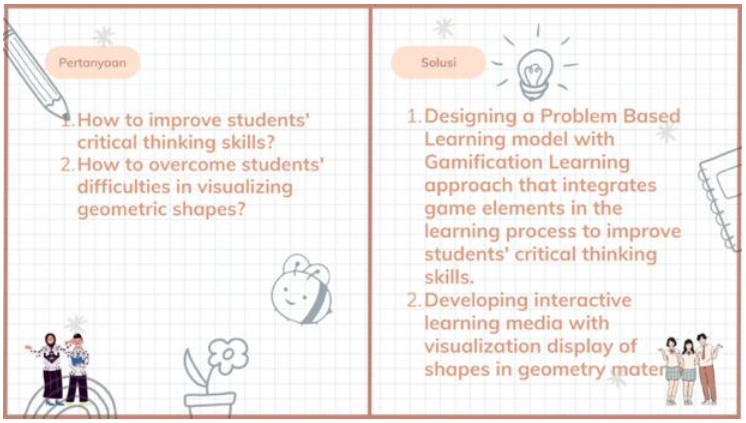

Figure 6. How Might We

1) How to improve students' critical thinking skills? The solution is to design a Problem-Based Learning (PBL)-based learning model that is integrated with a gamification approach. This model is expected to foster critical thinking skills through challenging and fun problem-solving. Fitriana and Indriyani (2024) in their meta-analysis study showed that the integration of PBL with gamification was able to significantly improve students' critical thinking skills.
2) How to maintain students' enthusiasm for learning mathematics? The solution is to develop interactive learning media with an attractive visual appearance and contain geometric shapes that can be manipulated visually. This is in line with the findings of Purnama et al. (2022), who emphasized that interactive visual media is able to increase students' understanding of flat-sided spaces in geometry learning.

With these two main approaches, researchers get a clear and solution-oriented mapping of the problem, which will be the basis in the next stage to design a technology-based learning prototype.

3. Ideate Stage

The ideate stage is a transition process from problem formulation to problem solving (Sekarwulan, 2022). This process focuses on the development of ideas as the basis of solution design. One of the approaches used is brainstorming, which is a collaborative idea gathering technique to solve problems that have been formulated (Komarudin, et al. 2024).

Figure 7. Brainstorming of Idea

Figure 7 shows the results of the exploration of ideas developed through team discussions based on the needs of students and teachers.

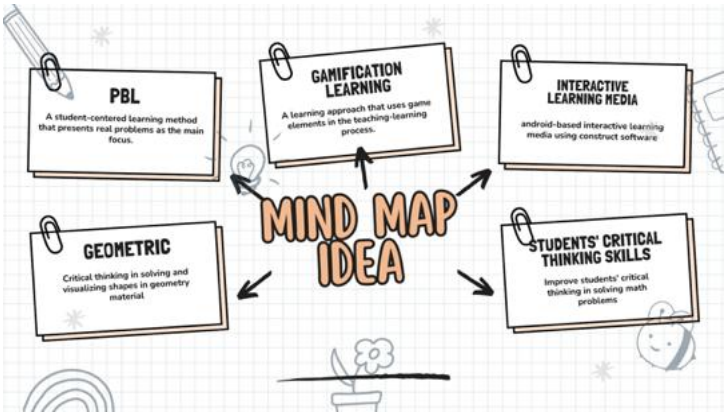

Figure 8. Mind Map Idea

Figure 8 presents a mapping of the main ideas that will form the basis of prototype development. The five main ideas include critical thinking skills, geometry, Problem Based Learning (PBL), gamification learning, and interactive learning media. The elaboration and analysis of each idea is as follows.

a. Critical Thinking Skills

Critical thinking skills are important in solving problems and making decisions (Nahak, 2022). Strengthened by the research of Ratnaningsih, Suprapto, & Prayogi (2022), students with problem-based learning showed significant improvements in reflective and logical thinking skills. Critical thinking indicators refer to clarification, assessment, strategy, and conclusion (Perkins & Murphy in Nahak, 2022).

b. Geometry

Geometry materials are a challenge in itself because they require the ability to visualize two- and three-dimensional buildings (Irkhamni & Najibufahmi, 2024). Mandailina, (2024) emphasized that the use of interactive media and gamification can improve spatial understanding and abstraction of geometry concepts.

c. Problem Based Learning (PBL)

Problem Based Learning (PBL) is a learning model that uses problems as the starting point in the learning process. This model utilizes real-world problems as a context for students to build knowledge independently, hone critical thinking skills, increase independence, and strengthen confidence (Lestari, Dwijayanti, and Siswanto, 2023). Research by Cahyani & Ahmad (2024), Buchori & Nugroho (2024), and Putri, Rosyana, & Rohaeti (2024) shows the effectiveness of PBL in improving students' learning outcomes and critical thinking skills. The effect of problem-based learning on critical thinking skills over the past 5 years was carried out through effect size calculation. The following is a table of effect size calculation data based on the results of research in the last 5 years (2021-2024)

Table 1. Value the Effect Size Problem Based Learning

Year	n_E	$\overline{x_E}$	n_K	$\overline{x_K}$	S_K	ES
2021	22	87.41	22	67.91	4.975	3.92
	20	87.35	20	79.20	4.06	2.01
2022	36	13.35	36	7.75	8.05	0.70
	32	66.06	32	51.13	15.80	0.94
2023	23	54.35	23	53.36	2.81	0.35
	10	20.92	10	18.14	5.735	0.48
2024	25	77.25	25	67	6.295	1.63
	30	87.41	30	67.91	4.97	3.92

Based on the results of the effect size calculation in Table 1, the largest effect size value is 3.92 in 2021 and 2024. Meanwhile, the smallest effect size value is 0.35 in 2023.

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Table 2. Value the Effect Size of Problem Based Learning Every Year

Year	n_E	$\overline{x_E}$	n_K	$\overline{x_K}$	S_K	ES	Category
2021	42	87.38	42	73.55	4.52	2.965	High
2022	68	79.41	68	58.88	11.925	0.82	Keep
2023	33	75.27	33	71.50	4.27	0.415	Low
2024	55	82.33	55	67.455	6.63	2.775	High

Based on the results of the calculation of effect size every year in Table 2, the effect size value in 2021 and 2024 is classified as high effect size category. The magnitude of the effect size value of the problem-based learning model on students' critical thinking skills is presented in Figure 9.

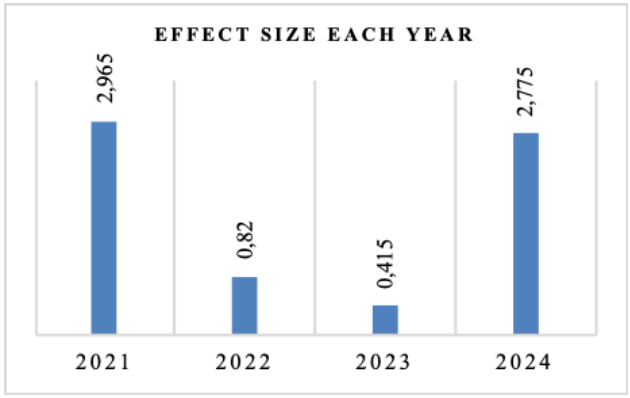

Figure 9. Effect Size Value Chart of Problem Based Learning Every Year

Based on Figure 9, it can be seen that the effect size value of the problem-based learning model on students' critical thinking skills from 2021 to 2024 tends to be unstable every year. This needs to be reviewed related to the application of the PBL model, steps to use the PBL model, and analyzing and evaluating PBL that has been carried out so that maximum results can be obtained. This is in line with research conducted by Santi et al. (2023) stating that the use of problem-based learning models is effective in improving student learning outcomes.

d. Gamification Learning

Gamification integrates elements of play to increase student motivation and participation (Kapp in Fitriana & Indriyani, 2024). Studies by Hebebci & Alan (2021), Rivera & Garden (2021), and Al-Hafdi & Alhalafawy (2024) prove that gamification in education effectively improves students' critical thinking skills and engagement in learning.

e. Interactive Learning Media

The use of Android-based interactive media, such as Construct 3, supports both self-paced and project-based learning. Research by George, et al. (2024) and Tong et al. (2022) supports the effectiveness of this medium in improving geometry visualization as well as collaboration in learning.

The results of the idea analysis at this ideate stage enriched the research knowledge by bringing together the PBL and gamification approaches in one interactive platform. This study reinforces previous findings that hybrid approaches can improve students' conceptual understanding and critical thinking skills (Marera & Tendrita, 2024). By compiling a prototype based on these ideas, the solutions developed are responsive to the needs of students and teachers.

DISCUSSION

The results of this study show that the main problem in mathematics learning in partner schools is the difficulty of students in visualizing geometric shapes and low critical thinking skills. These findings reinforce the findings of Fahlevi & Zanthy (2020) and Sari, Sagala, & Simanjutak (2024), who stated that students often encounter obstacles in understanding geometric concepts due to limited spatial visualization skills. According Scippo, Madiai & Cuomo (2025) also shows that geometry visualization

skills have a significant impact on the success of learning mathematics, particularly in the topic of two- and three-dimensional geometry.

In addition, teachers at partner schools conveyed the need for interactive learning media that can support the learning process visually and fun. This is in line with the results of studies by Purnama et al. (2022) and Arif & Dewi (2024) which emphasized the effectiveness of application-based media in improving understanding of geometry concepts. In an international context, studies by Scippo, Madiai & Cuomo (2025) and Dong, et al. (2024) show that the use of mobile learning-based technologies and gamification can improve student participation and improve understanding of complex geometry concepts.

The Problem Based Learning (PBL) model was chosen because based on the results of the meta-analysis in this study, PBL has a significant influence on improving critical thinking skills. International studies by Manuaba et al. (2022) and Razak et al. (2022) show that the PBL approach consistently improves higher-level thinking skills, including critical thinking, problem-solving, and self-reflection. Combining PBL with gamification elements is recommended to encourage students' intrinsic motivation and increase engagement in learning (Fitriana & Indriyani, 2024; Meilina, 2023). This is also strengthened by findings from Angelelli et al. (2023) who found that gamification in learning can significantly improve critical thinking skills, interaction, motivation, and learning outcomes.

However, the results of the meta-analysis show that there are fluctuations in the effect size value of the PBL model every year. This phenomenon can be caused by differences in research contexts, variations in model implementation, and lack of systematic training for teachers in implementing PBL optimally. A study by Aslan & Duruhan (2021) suggests that the success of PBL is highly dependent on the quality of learning design, infrastructure support, and teacher facilitation skills. Therefore, continuous teacher training and structured learning planning are needed to ensure the effectiveness of PBL implementation in various educational contexts.

The limitation of this study lies in the scope of implementation which is still limited in one partner school and has not been tested on the learning media developed. In addition, the influence of gamification and PBL has not been explored more deeply on other types of math materials outside of geometry. For further research, it is recommended to: (1) develop a comprehensive Android-based interactive media prototype, (2) conduct extensive field experiments to test the effectiveness of such media, and (3) explore the implementation of gamification-based PBL on various mathematical sub-subjects. Future research may also explore artificial intelligence-based or augmented reality approaches as innovative learning strategies to improve students' engagement and critical thinking skills (Supriyadi & Kuncoro, 2023).

CONCLUSION

Based on the formulation of the problem, research objectives, methods, results, and discussion, it can be concluded that the main problem faced by students is the difficulty in visualizing the shape of the building in geometry material. In addition, students need an interesting and interactive learning approach, such as game-based learning (gamification). On the other hand, teachers face challenges related to students' low critical thinking skills and need learning aids that can support students in understanding visualizations of geometric shapes effectively. Responding to these problems, a Problem Based Learning (PBL) learning model design combined with a gamification approach is needed. This approach integrates elements of play in the learning process to increase students' engagement, motivation, and critical thinking skills. In addition, the development of Android-based interactive learning media with geometry visualization features is an important solution that supports the successful implementation of this learning model. The process of exploring solution ideas through brainstorming techniques produces three main components, namely: problem-based learning models, game-based learning approaches, and the use of interactive learning media. These three components are believed to be able to improve students' critical thinking skills and overcome difficulties in visualizing shapes and shapes in geometry materials.

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