

Integrating Educaplay into Project-Based Learning: An Innovative Approach to Foster Critical Thinking among Pre-Service Teachers

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Abstract: Low critical thinking skills among students affect their ability to understand and solve complex academic problems. This study looks into how combining project-based learning with interactive digital media from Educaplay can help improve critical thinking skills among PGMI students. The study used a quasi-experimental approach with a design that includes a pretest and posttest along with a control group. The study used two classes that were similar, each having 30 students. One group was the experimental group, and the other group was the control group. The study used a test to measure critical thinking skills that experts had reviewed and approved. The test had a reliability score called Cronbach Alpha, which was above 0.70. Data were collected by giving both groups a pretest and a posttest. The data was checked with an independent t-test, and the effect size was figured out using Cohen's d. The results showed a big difference between the experimental group and the control group. The significance value was less than 0.05, and the effect size was 1.79, which is considered high. This indicates that the Educaplay-based PjBL model effectively supports PGMI students in developing their critical thinking skills. Using project-based learning combined with interactive digital tools like Educaplay can be a smart choice for teaching in today's world.

Keywords: Critical Thinking Skills; Digital Learning Media; Educaplay; Pre-Service Teachers; Project-Based Learning

1. Introduction

The Madrasah Ibtidaiyah Teacher Education (*Pendidikan Guru Madrasah Ibtidaiyah*/PGMI) program needs to help students improve their ability to think critically, according to (Cortazar et al., 2021). Future teachers who want to teach math need to not only know the subject well but also be able to think carefully and come up with new, useful ways to help students learn. This matches the difficulties of the 21st century, which focus on thinking critically, solving problems, and being creative (Affandy et al., 2024).

Critical thinking skills are one of the essential competencies that prospective teachers must have, especially in facing the challenges of 21st-century education (Merris et al., 2021). In the context of PGMI, critical thinking skills not only play a role in solving academic problems but also form the foundation for pedagogical decision-making and the delivery of meaningful material to students. The main issue in this study is the low critical thinking skills of PGMI students, particularly when dealing with conceptual and complex material such as fraction operations in mathematics learning (Yudiana et al., 2024).

This situation matches the results from the Programme for International Student Assessment (PISA), showing that Indonesian students' math skills are still considered low. A 2018 report by the OECD says that almost 80% of Indonesian students have only basic math skills, showing that there are problems with the quality of education they have been getting up to now. This situation also affects how prepared students are when they start higher education, especially when it comes to understanding math concepts and thinking logically. In addition, the Directorate General of Islamic Education highlights that the curriculum in the MI teacher

training program continues to focus on teaching knowledge rather than encouraging the development of advanced thinking skills. Because of this, students don't have enough room to properly develop their critical thinking abilities.

1.1. Problem Statement

Fraction operations are often considered difficult by students because they involve a deep understanding of concepts, procedures, and applications that require logical reasoning and precision (Fazilla et al., 2024). Conventional one-way learning tends to be unable to encourage students to actively explore and reflect on these concepts independently (Batai et al., 2024). Therefore, a learning model is needed that can integrate the cognitive, affective, and psychomotor aspects of students and provide space for them to practice critical thinking in a meaningful context (Nurhayati et al., 2025).

One relevant approach is Project-Based Learning, which has been proven effective in improving higher-order thinking skills. The PjBL model encourages students to actively participate in designing, implementing, and evaluating projects that are relevant to real life (Mukni et al., 2024). In the context of education digitalization, the application of this model can be collaborated with digital media such as Educaplay, an interactive learning platform that provides activities such as quizzes, crossword puzzles, and educational games (Sari et al., 2025). This media not only increases student motivation to learn, but also provides a more personalized and contextual learning experience (Rahayu et al., 2024).

1.2. Related Research

Several previous studies have revealed that Educaplay-based PjBL is effective in improving critical thinking skills. For example, research by Dayanti et al. (2025) showed significant changes through the application of Educaplay media, which had an impact on student learning activities and critical thinking skills. Research by Saiful Anwar & Jasiah, (2024) found that the use of Educaplay games can encourage student activity. In addition, Yasa et al. (2025) found that after using the Educaplay media, there was an improvement in student learning outcomes. The percentage of students who reached the minimum passing grade increased a lot, reaching 86.48% in the second cycle. At the same time, the average score for the class went up to 84.59. According to Rukoyah et al. (2025) found that using the PjBL model with Educaplay helped students develop their creativity much more than traditional teaching methods.

Nevertheless, studies specifically examining the implementation of Educaplay-based PjBL among prospective Madrasah Ibtidaiyah (MI) teachers remain limited, as most previous research has focused on students at the elementary and secondary school levels (Dewi et al., 2025). Therefore, research is needed to examine the effectiveness of this model in the context of higher education, particularly in teacher education programs.

The novelty of this study lies in the application of the Educaplay-based Project-Based Learning (PjBL) model to prospective Madrasah Ibtidaiyah (MI) teacher students, analyzed using an effect size approach such as Cohen's *d* to quantitatively measure the strength of the model's influence—an approach rarely employed in previous research.

1.3. Research Objectives

As future teachers, PGMI students are expected not only to understand educational theory but also to be able to apply it in real-world teaching situations (Eliyanti et al., 2024). Therefore, a learning model is needed that not only emphasizes mastery of the subject matter but also fosters the development of critical thinking skills. One promising approach is PjBL based on Educaplay, which provides interactive features to encourage students' cognitive, reflective, and collaborative engagement in the learning process (Harizah & Rahmiati, 2025).

Based on this, this study focuses on how the implementation of the Educaplay-based PjBL model can improve PGMI students' critical thinking skills, as well as measure the extent of its impact through an effect size analysis.

2. Theoretical Framework

2.1. Project-Based Learning and the Use of Interactive Digital Media

PjBL is a learning model that emphasizes student involvement in exploring and solving authentic problems through the completion of structured projects. This approach is grounded in constructivist learning theory, which asserts that learners actively construct knowledge through experience, inquiry, and reflection rather than passively receiving information (Hamdani & Thamrin, 2024). In PjBL settings, learners engage in investigation, collaboration, and decision-making processes that promote deeper understanding and meaningful learning. Within teacher education, PjBL is particularly relevant because it reflects real instructional situations and supports the development of professional competencies among pre-service teachers (Juhanaini et al., 2025).

The integration of digital learning media within PjBL has been shown to enhance learner engagement and cognitive processing. Digital tools provide interactive environments that support visualization, self-regulated learning, and immediate feedback, which are essential for meaningful knowledge construction. According to multimedia learning theory, learning becomes more effective when information is presented through well-designed combinations of text, visuals, and interactivity, as this helps learners organize and integrate knowledge more efficiently (Serin, 2019). Therefore, digital media function as cognitive supports that strengthen inquiry-based learning in project-oriented instruction.

Educaplay is an online interactive learning platform that offers various game-based activities such as quizzes, matching tasks, and video-based exercises. The use of Educaplay is theoretically aligned with gamification principles, which emphasize motivation, engagement, and feedback as key factors in effective learning environments (Cruz et al., 2022). When incorporated into PjBL, Educaplay can support different stages of project implementation, including concept exploration, practice, and formative assessment. This integration allows learners to actively engage with learning content while maintaining the inquiry-driven and collaborative nature of project-based learning.

2.2. Critical Thinking Skills in Pre-Service Teacher Education

Critical thinking is commonly defined as a set of higher-order cognitive skills that include analysis, evaluation, inference, and reflective judgment (Cortazar et al., 2021). In teacher education programs, critical thinking is regarded as a core competency that pre-service teachers must develop in order to make informed pedagogical decisions and respond effectively to diverse classroom challenges. As future educators, pre-service teachers are expected to critically evaluate learning materials, instructional strategies, and student needs to ensure effective teaching and learning processes.

From a theoretical perspective, the development of critical thinking is closely related to constructivist and socio-cultural learning theories, which emphasize learning through active engagement, problem-solving, and social interaction (Viro et al., 2020). Learning environments that involve complex tasks and reflective dialogue encourage learners to question assumptions, analyze information, and justify their reasoning. PjBL supports these processes by engaging learners in real-world problems that require investigation, collaboration, and evaluation of multiple perspectives, thereby fostering higher-order thinking skills (Thi et al., 2024).

The integration of Educaplay into PjBL further enhances critical thinking development by providing interactive and feedback-oriented learning activities. Through digital tasks that require learners to analyze questions, make decisions, and reflect on outcomes, Educaplay supports metacognitive processes that are essential for critical thinking. Immediate feedback provided by the platform enables learners to evaluate their understanding and adjust their thinking strategies accordingly (Himmi et al., 2025). Theoretically, the combination of PjBL and Educaplay creates an innovative learning environment that promotes active engagement, reflective thinking, and critical analysis, making it a promising approach for fostering critical thinking skills among pre-service teachers.

Based on the theoretical review above, this study identifies Educaplay-based PjBL as the independent variable and the critical thinking skills of PGMI students as the dependent variable. Conceptually, PjBL, grounded in constructivist theory, encourages students to engage in problem-solving, collaboration, and reflection, which are key components in the development of critical thinking. The integration of Educaplay as an interactive medium reinforces this process by providing digital-based activities that encourage analysis, decision-making, and immediate feedback.

Thus, the implementation of Educaplay-based PjBL in this study is operationalized through project activities integrated with digital interactive activities, while critical thinking skills are measured through indicators of analysis, evaluation, inference, and reflection. The relationship between these two variables was tested using a quantitative research design with a pretest-posttest approach and effect size analysis to determine the strength of the influence of the applied learning model.

3. Method

3.1. Research Design

This study employed a quantitative approach and followed a quasi-experimental method as described by (Creswell dan Creswell 2018; Oranga & Matere, 2025). His method was used to determine the extent to which the Educaplay-based Project Based Learning (PjBL) model could improve the critical thinking skills of PGMI students. This study employed a pretest-posttest non-equivalent control group design, a quasi-experimental approach that involves comparing an experimental group and a control group without random assignment to evaluate the effect of an intervention (Capili & Anastasi, 2024). Both groups were given a pretest and a posttest to measure the development of critical thinking skills before and after the treatment. The research design is shown in the following Table 1.

Table 1. Development of Critical Thinking Skills

Group	Pretest	Treatment	Posttest
Experiment & Control	Initial test critical thinking	PjBL + Educaplay/ Conventional learning	Final test critical thinking

3.2. Participant

The population in this study was second-semester students enrolled in the Madrasah Ibtidaiyah Teacher Education Program (PGMI) at a religious university in Jambi Province. The sampling technique used was purposive sampling, considering that the subjects had taken relevant courses and were in their active semester. The research sample consisted of two parallel classes, each with 30 students. One class was designated as the experimental group, which received instruction using the Educaplay-based Project Based Learning (PjBL) model, while the other class was the control group, which received conventional instruction.

The following are respondents in the research and research subjects who were taken randomly from a number of elementary school populations in the Madrasah Ibtidaiyah Teacher Education Program (PGMI) at a religious university in Jambi Province.

Table 2. Characteristics of Research Participants

No.	Characteristics	Category	Frequency (n)
1	Educational Background	Undergraduate Students (PGMI)	60
2	Semester	Second Semester	60
3	Sampling Technique	Purposive Sampling	60
4	Group Assignment	Experimental Group (PjBL-Educaplay)	30
		Control Group (Conventional)	30
5	Gender	Male	15
		Female	45

3.3. Data Collection

Data were collected through pretests and posttests administered to both the experimental and control groups. In addition, observations of learning activities were conducted as supporting qualitative data to capture students' engagement during the implementation of the learning model.

The primary instrument used in this study was a critical thinking test developed based on the framework of The Delphi Report by Harahap et al. (2025), which includes five indicators: interpretation, analysis, inference, evaluation, and explanation. The test consisted of essay questions aligned with the instructional material.

The research procedure was conducted in three stages. First, the preparation stage involved designing the learning instruments, preparing Educaplay media, and organizing learning resources based on the PjBL model. Second, during the implementation stage, the experimental group was taught using Project-Based Learning integrated with Educaplay for four sessions, while the control group received conventional instruction. Third, in the post-treatment stage, both groups were given a posttest to evaluate the effectiveness of the intervention.

3.4. Data Analysis

Data were analyzed using descriptive and inferential statistics. Descriptive statistics were used to determine the mean, standard deviation, minimum score, and maximum score of the pretest and posttest results. An independent samples t-test was performed using SPSS. Prior to the t-test, normality (Shapiro-Wilk) and homogeneity (Levene) tests were conducted. Effectiveness was also checked by using Cohen's d formula to figure out the effect size.

3.5. Validity and Reliability

The validity and reliability of the instrument were examined to ensure its accuracy and consistency in measuring students' critical thinking skills. Content validity was established through expert judgment involving three specialists in education and learning technology, who evaluated the relevance and appropriateness of the test items based on the indicators of critical thinking proposed in The Delphi (Taskiran, 2021).

Reliability testing was conducted using Cronbach's Alpha, and the results showed a coefficient greater than 0.70, indicating that the instrument had acceptable internal consistency. Therefore, the instrument was considered valid and reliable for measuring the effectiveness of the Educaplay-based PjBL model on students' critical thinking skills.

4. Findings

This section presents the findings of the study aimed at examining the effectiveness of the Educaplay-based PjBL model in improving the critical thinking skills of PGMI students. The analysis is based on pretest and posttest data from both experimental and control groups, using SPSS with prerequisite tests and effectiveness analysis, including effect size measurement.

4.1. Descriptive Statistics

To provide an overview of students' critical thinking performance before and after the treatment, descriptive statistics of pretest and posttest scores for both the experimental and control groups are presented in Table 3.

Looking at Table 3, the descriptive statistics indicate that the experimental group's average posttest score is higher compared to the control group's average score. The experimental group's average score before the test was 63.40, and after the test, it went up to 82.73, which is an increase of 19.33. The control group scored an average of 62.87 before the test and 70.10 after the test, which is an increase of 7.23. This shows a bigger rise in the experimental group.

Tabel 3. Descriptive Statistics of Students' Critical Thinking Skills

Group	Number of Students (n)	Pre-test Average	Post-test Average	Improvement
Experimental (PjBL+ Educaplay)	30	63,40	82,73	+19,33
Control (Conventional)	30	62,87	70,10	+7,23

4.2. Normality and Homogeneity Tests

To ensure that the data met the assumptions required for parametric statistical analysis, normality and homogeneity tests were conducted. The results of the normality test using the Shapiro-Wilk method are presented in Table 4.

Table 4. Shapiro-Wilk Normality Test Results

Group	Test Type	Statistics	Sig. (p-value)
Experiment	Pretest	0,967	0,310
Experiment	Posttest	0,954	0,092
Control	Pretest	0,961	0,188
Control	Posttest	0,947	0,070

Based on Table 4, the Shapiro-Wilk normality test shows that the pretest and posttest values in both groups are normally distributed (Sig. value > 0.05). The Levene's test for homogeneity produced a Sig. value of 0.231 (> 0.05), which means that the data comes from a homogeneous population.

To further examine whether the data have equal variance between groups, a homogeneity test using Levene's test was conducted. The results are presented in Table 5.

Table 5. Results of Levene's Homogeneity Test

Variable	Levene's Test	Sig. (p-value)
Critical Thinking Skills Posttest	1,478	0,231

4.3. Hypothesis Testing (t-test)

To determine whether there is a significant difference in critical thinking skills between the experimental and control groups, an independent samples t-test was conducted. The results of the analysis are presented in Table 6.

Table 6. Independent Sample Test Results

Variable	Group	Mean	Std. Deviasi	Sig. (2-tailed)	Description
Critical Thinking Skills Posttest	Experiment	82,73	6,18	0,001	Significant (p < 0,05)
	Control	70,10	5,94		

Looking at Table 6, the independent sample t-test results show a significance value (2-tailed) of 0.001, which is less than 0.05. This indicates there is a significant difference between the posttest scores of the experimental group and the control group. So, we can say that using the Educaplay-based PjBL model helps improve the critical thinking skills of future PGMI teachers.

4.4. Effect Size Analysis

To determine the magnitude of the effect, an effect size analysis using Cohen's d was conducted. The results are presented in Table 7.

Table 7. T-test Results and Effect Size

Statistical Test	Value	Description
Sig. (2-tailed)	0,000	Significant ($p < 0,05$)
Cohen's d	1,79	Big impact

Looking at Table 7, when we use Cohen's d formula to calculate the large effect size, the result we get is 1.79, which is classified as a big effect. Using the Educaplay-based PjBL model really boosts critical thinking skills a great deal.

5. Discussion

This study demonstrates that the implementation of the Educaplay-based PjBL model significantly improves the critical thinking skills of PGMI students. This is evidenced by the higher posttest mean score of the experimental group (82.73) compared to the control group (70.10), supported by the independent samples t-test result ($p = 0.001 < 0.05$). Furthermore, the effect size value of 1.79 indicates a strong practical impact of the intervention. These findings confirm that integrating interactive digital media such as Educaplay within a project-based learning framework is highly effective in fostering higher-order thinking skills among pre-service teacher Sinta et al (2024). In addition, Amrullah, (2025) also emphasize that interactive digital media can optimize the project learning process because it provides space for students to explore independently.

The findings of this study are consistent with constructivist learning theory, which emphasizes active knowledge construction through experience, collaboration, and reflection (Taskiran, 2021). The results also align with multimedia learning theory, suggesting that interactive digital tools enhance cognitive processing and knowledge retention (Nasution et al., 2021). Empirically, this study supports previous research indicating that PjBL combined with digital media improves critical thinking skills (ŞEN-AKBULUT & ÖNER, 2021). Similarly, studies by Imarida (2024) and Hadistia et al. (2025) found that Educaplay enhances student engagement and learning outcomes. However, most prior studies focused on primary or secondary education, whereas this study extends the application to pre-service teacher education, thereby filling an important research gap (Trianggono et al., 2026). These findings are in line with Harahap et al. (2025), who both reported that the PjBL model supported by digital media contributed to a significant improvement in students' critical thinking skills. So, it's clear that the Educaplay-based PjBL model works really well in boosting critical thinking skills, as shown by (Fazilla et al., 2024).

The better critical thinking skills in the experimental group came from the features of the PjBL model, which makes students more involved and active in their learning (Dag & Durdu, 2017). Students take part in research, talks, and making projects that need them to think critically and judge things carefully. When this model is used with Educaplay, learning activities become more engaging, relevant, and fun. This digital media offers different types of educational games that help students practice and understand concepts better while also encouraging them to think deeply (Tamana, 2025).

The PjBL model helps students learn by working on projects that relate to real-life situations (Eli, 2022). Project activities ask students to create, find information, check its accuracy, and put everything together into a final project that shows what they have learned. These activities help improve important thinking skills, like looking at information carefully, checking if ideas are strong, and coming up with ways to fix problems. Educaplay, as an interactive tool that helps with this process, makes learning more engaging by offering challenging and fun digital activities (Hamdani & Thamrin, 2024).

Using Educaplay helps students learn in different ways and makes them more interested by showing information through pictures, sounds, and hands-on activities. This media includes features that can be adjusted based on what students need to learn, like multiple-choice

questions, crosswords, matching activities, and videos that let users interact (Harahap et al., 2025). When used in project-based learning, this media helps students understand things step by step, through active participation, and by thinking about what they are learning. This type of involvement matches the ideas of constructivist learning and deeper thinking, as mentioned by Hadistia et al (2025). They stress how important it is for students to be active and take responsibility for building their own understanding.

Critical thinking skills cannot be developed solely through the delivery of theoretical material. Students need to be given space to ask questions, examine arguments, seek information, and develop ideas and solutions to complex problems. In this case, the Educaplay-based PjBL model addresses these needs through learning activities that facilitate dialogue, collaboration, and systematic and contextual problem solving (Septiana & Lutfi, 2025). The results show that students in the experimental group achieved better outcomes, meaning this method can lead to greater success than traditional teaching approaches. These results match what Apriliyanti et al (2025) found, showing that using Educaplay in PjBL can really boost student involvement and their learning results. Utami et al (2025) mention that using interactive digital media helps students feel more motivated and focused during learning, which in turn affects their ability to think critically and deeply.

Furthermore, the use of Educaplay in the context of project-based learning provides a personalized and collaborative learning experience. Students not only complete tasks individually, but also develop communication and teamwork skills, which in turn strengthen their social and intellectual critical thinking skills (Rizmayannudin & Zulikhatin, 2025). The Educaplay-based PjBL model has a strong and significant effect on helping students develop their critical thinking skills, as shown by an effect size of 1.79. This shows that the integration of project-based learning models and interactive digital media is an effective strategy in 21st-century education, especially for producing reflective, analytical, and creative prospective madrasah teachers. This finding reinforces the report by Alotaibi (2020), which states that digital projects can provide contextual learning experiences that enable students to better connect theory with real-world practice and produce creative and analytical solutions.

This aligns with the views of Mariam et al. (2023), who state that digital competence and critical thinking skills are two fundamental skills for prospective educators in the modern era. Thus, this study presents new contributions compared to previous studies. This study is special because it uses the Educaplay-based PjBL model for future MI teachers, not just regular students, offering a new way to look at how critical thinking skills can be developed in higher education. In addition, the use of effect size analysis confirms the quantitative impact of the intervention, which is rarely presented in similar studies. Therefore, the findings of this study not only support earlier results but also broaden the application of interactive digital media within the context of teacher education (Affandy et al., 2024).

These findings also have practical implications for teacher education programs in developing innovative learning strategies that are more effective and aligned with 21st-century skills requirements (Cortazar et al., 2021). Overall, this study concludes that integrating Educaplay into the Project-Based Learning model is not merely a technological aid, but an innovative pedagogical approach that substantially strengthens the development of critical thinking skills in pre-service teachers. PjBL provides a learning structure that demands analysis, evaluation, and problem-solving, while Educaplay serves as an interactive medium that enriches the learning experience thru more contextual, reflective, and engaging activities. Using both methods together makes a learning environment where students are encouraged to think carefully, with a clear goal, and back up their ideas with evidence (Trianggono et al., 2026).

This study also shows that the better thinking skills are not just because of using technology, but because of the way the learning is designed, which includes using Educaplay at every step of the project. In other words, how well this method works relies on how good the thinking skills are that come from planning the project, finding information, making arguments, and thinking about the results of the work. This idea adds value to the existing research on teaching methods that use digital tools and shows how important it is to create

project-based activities that help future teachers develop skills in analyzing, working together, and exploring on their own (Trianggono et al., 2026).

The synergistic integration of PjBL, Educaplay, and critical thinking skills plays an important role in advancing 21st-century learning, particularly in supporting the achievement of Quality Education targets. Theoretically, this research contributes to the development of innovative learning models that place interactive technology as a medium for building high-level cognitive skills. Practically, the research findings emphasize the need for educators to strategically design the implementation of Educaplay-based PjBL to enable students to think critically in making decisions, solving problems, and producing technology-based learning products (Imarida, 2024).

This research shows that using interactive digital tools like Educaplay in project-based learning can help future teachers improve their ability to think reflectively, creatively, and critically, making them better prepared to handle challenges in education. This method shows that technology is more than just a tool; it plays an important role in helping to create teachers who are skilled and adaptable, meeting the needs of modern education (Ndiung & Menggo, 2024).

This study provides several theoretical contributions. First, it extends constructivist learning theory by demonstrating how the integration of interactive digital media (Educaplay) within Project-Based Learning enhances critical thinking in higher education contexts, particularly in teacher education. Second, this study contributes to the theoretical development of technology-enhanced learning by showing that digital tools are most effective when systematically embedded into pedagogical models rather than used as supplementary media. Third, it offers empirical support for the synergy between PjBL, gamification principles, and critical thinking development, thereby enriching the literature on innovative instructional design in the digital era. Finally, this study introduces the use of effect size (Cohen's *d*) as a strong quantitative indicator to measure the impact of instructional interventions, which is still relatively underutilized in similar educational research contexts.

6. Conclusion

This study shows that integrating Educaplay into PjBL can greatly improve critical thinking skills of PGMI students, as shown by the t-test results ($p < 0.05$) and an effect size of 1.79, which falls into the high category. Using the PjBL model based on Educaplay in the context of educating future madrasah ibtidaiyah teachers shows a new approach. This approach not only helps improve students' cognitive performance but also strengthens their reflective, collaborative, and creative abilities, making them more suitable as professional educators who meet the demands of 21st-century learning. Further, the analysis of effect size provides quantitative evidence that confirms the strong impact of interactive digital media in supporting project-based learning processes. This study is meant to help create new learning methods that use technology, which will help teachers develop better thinking skills and become more comfortable with digital tools in the future education system.

Limitation

This study has some things that aren't perfect and need to be mentioned. Using a quasi-experimental design with groups that aren't exactly the same limits how confident we can be about the results because the groups weren't randomly assigned. In addition, the sample included only second-semester PGMI students from one religious university in Jambi Province, which might make it harder to apply the results to other groups. The intervention took place in just four sessions, and the evaluation of critical thinking mostly used an essay test. This method might not fully show how critical thinking develops over time or in different areas. Thus, future research is encouraged to include more diverse samples, longer intervention periods, and multiple assessment methods to enhance the validity and applicability of the results.

Recommendation

Future researchers are encouraged to conduct further studies using randomized experimental designs and larger, more diverse samples to enhance the generalizability of the findings. Extending the duration of the intervention is also recommended in order to examine the long-term effects of Educaplay-based PjBL on critical thinking and other higher-order skills, such as problem-solving and creativity. In addition, employing mixed-methods approaches that combine quantitative and qualitative data may provide deeper insights into students' learning processes, engagement, and cognitive development during technology-enhanced PjBL activities.

For educational stakeholders, including lecturers, teacher educators, and curriculum developers, the findings indicate that integrating interactive digital platforms such as Educaplay into PjBL can be an effective strategy for enhancing pre-service teachers' critical thinking skills. Teacher education institutions are therefore encouraged to provide continuous professional development and technical support to help educators design meaningful, student-centered learning experiences. Furthermore, integrating technology-supported PjBL into the curriculum may better prepare pre-service teachers to implement innovative and digital-based instructional practices in their future classrooms.

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Conflict of Interest Statement

The authors declare that there are no conflicts of interest regarding the publication of this research. The study was conducted independently without any financial, commercial, or personal relationships that could be construed as a potential conflict of interest. All authors have approved the final version of the manuscript and agree to its submission for publication.

Declaration of Generative AI and AI-assisted Technologies

This manuscript was prepared with the assistance of Generative AI tools, including ChatGPT. These tools were used to support language refinement, content organization, and clarity of expression. All intellectual contributions, data analysis, interpretations, and final decisions remain the responsibility of the authors. The authors have carefully reviewed and validated all content to ensure its accuracy, originality, and academic integrity.

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