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The Impact of PBL-Based E-Learning on Critical Thinking and Mathematical Communication in Ethnomathematics-Based Pythagorean Learning

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ABSTRACT

The integration of Problem-Based Learning (PBL) and e-learning represents an instructional approach that has the potential to foster higher-order thinking by actively engaging students in structured problem-solving activities. This study examines the impact of combining e-learning with the PBL model and an ethnomathematics approach on eighth-grade students' critical thinking and mathematical communication skills in learning the Pythagorean Theorem. A quasi-experimental design with a non-equivalent control group was implemented involving Grade 8 students at SMP Negeri 4 Madiun. Participants were divided into an experimental group, which received ethnomathematics-based PBL supported by e-learning, and a control group, which was taught using conventional instructional methods. Data were collected through pretests and posttests measuring critical thinking and mathematical communication skills, and the differences between groups were analyzed using inferential statistical techniques. The findings reveal that the integration of e-learning within an ethnomathematics-oriented PBL framework has a significant and positive effect on students' critical thinking and mathematical communication skills, thereby demonstrating its effectiveness in promoting higher-order thinking in mathematics education.

INTRODUCTION

The use of web-based learning media allows teachers to design learning experiences by integrating diverse forms of content, including textual materials, visual elements, audiovisual resources, and interactive assessments, thereby enriching the learning process and increasing student engagement. From a broader perspective, education plays a strategic role in driving national development and societal progress. A high-quality education system is therefore essential to equip future generations with the competencies needed to compete and respond to global challenges (Sudiartini & Margunayasa, 2023). Along with this demand, rapid advances in science and technology have transformed many aspects of human life, particularly in the educational sector. Digital technologies enable teachers to innovate in instructional practices by functioning not only as learning tools but also as flexible and accessible learning resources (Islanda & Darmawan, 2023; Pratidina & Novaliyosi, 2024).

In the formal education system, mathematics is a compulsory subject from elementary to high school levels which functions to train logical reasoning and improve students' cognitive abilities. Mathematics learning aims to develop reasoning, problem-solving, communication, and mathematical connections skills (Marfu'ah et al., 2022; Siswanto & Meiliasari, 2024). The ultimate goal of mathematics learning is to enhance students' capacities for logical, analytical, systematic, and critical thinking to be able to adapt in an increasingly competitive world (Firdaus et al., 2019; Sarnoko et al., 2024)

However, various international reports show that the critical thinking skills of students in Indonesia are still at a level that is not optimal. Data reported in the 2018 Programme for International Student Assessmen (PISA) assessment show that Indonesian students' achievement in mathematics literacy is still at the bottom of the rankings compared to other countries. These findings indicate that

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learning mathematics in schools has not fully encouraged the development of higher-order thinking skills, encompassing critical thinking skills and mathematical communication skills.

The condition of low critical thinking and mathematical communication skills is also reinforced by empirical findings in the field (Ran, 2025). Based on findings from classroom observations and interviews conducted with mathematics teachers, about 80% of students have difficulty when asked to re-explain the material that has been taught, which shows the low ability of students to understand and reconstruct concepts independently. In addition, students tend to rely on examples given by teachers and rarely use alternative strategies or examples, thus indicating limitations in flexible and critical thinking. In terms of communication, around 75% of students do not dare to express their opinions when asked to give responses to the material, and only 30% of students actively ask questions when they do not understand the teacher's explanation. In fact, when students are asked to conclude the learning material, only about 30% of students are able to draw conclusions independently. These findings show that the mathematics learning process is still dominated by a teacher-centered approach and has not fully provided room for the optimal development of critical thinking and mathematical communication skills.

Along with the development of digital technology, the use of e-learning is one of the strategic alternatives to support more student-centered learning (de la Tribonnière et al., 2025; Sterz-Burdack et al., 2025). E-learning allows the incorporation of information and communication technology (ICT) in learning activities process through the presentation of digital-based materials, learning activities, and evaluations that can be accessed flexibly (Sari et al., 2021)learning becomes more varied and interesting (Segara et al., 2021). The use of pedagogically designed e-learning has the potential to create a learning environment that encourages active student involvement and supports the development of critical thinking skills and mathematical communication.

Critical thinking and mathematical communication are essential skills in learning mathematics. Students who have critical thinking skills tend to be better able to analyze and evaluate information before receiving it (Betu, 2023). However, data reported by the Programme for International Student Assessment (PISA) in 2018 show that the mathematics ability of Indonesian students is still relatively low, with the seventh rank from the bottom and an average score of 379 (Syafitri et al., 2021). In line with that, students' mathematical communication skills are also still weak, where more than 70% of students have not been able to reach the level 2 proficiency level (Saputri et al., 2023)

One of the mathematical materials that has great potential to develop critical thinking and mathematical communication skills is the Pythagorean Theorem (Lin & Chang, 2025). This material is taught at the junior high school level and can be effectively integrated with ethnomathematical approaches. Local cultures, such as traditional architecture and batik motifs, reflect geometric principles that are in line with the concept of the Pythagorean Theorem (Abdillah et al., 2022; Dayanti et al., 2024). The application of ethnomathematics helps students understand mathematical concepts contextually, which facilitates the development of critical thinking and communication skills by linking learning with cultural elements (Ibrahim & Hendy, 2025).

The condition of low critical thinking and mathematical communication skills is inseparable from the practice of mathematics learning in the classroom which still tends to be teacher-centered. Learning often emphasizes problem-solving procedures and memorization of formulas, while opportunities for students to analyze problems, formulate reasons, and communicate mathematical ideas orally or in writing are limited (Liu et al., 2025). As a result, students are not trained to think reflexively and critically in dealing with contextual mathematical problems and are not able to convey mathematical ideas in a coherent and meaningful manner.

Therefore, learning innovations that are able to integrate student-centered approaches, the use of technology, and cultural contexts that are close to their lives are needed. E-learning-based learning combined with *the Problem-Based Learning* model and ethnomathematical approach are relevant alternatives to answer these challenges (Koçoˇglu & Kanadli, 2025). Through contextual problem-solving based on local culture presented digitally, students are encouraged to actively explore concepts, discuss, and communicate the results of their thinking (Wang et al., 2025). This approach is expected

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to not only improve understanding of mathematical concepts, but also simultaneously develop students' critical thinking and mathematical communication skills as essential 21st-century skills.

In the rapidly growing digital era, teachers are required to be able to adopt innovative learning media and be adaptive to technological developments, one of which is through the application of e-learning. The use of internet-based e-learning allows the learning process to take place in a more interactive, flexible, and accessible manner for didi participantsk (Gafur, 2024; Strouse et al., 2019). One of the platforms that is effective in supporting the implementation of e-learning is Google Sites, because it is free, easy to use, and integrates with various other Google services that support learning activities (Halim & Halim, 2024).

In addition, the application of the Problem-Based Learning (PBL) model encourages students to actively explore, analyze, and solve contextual problems, thereby creating meaningful learning and improving critical thinking and mathematical communication skills (Solihah, 2023b). Therefore, the integration of e-learning, PBL models, and ethnomathematics-based materials has the potential to create interesting, student-centered learning, and be able to improve critical thinking and mathematical communication skills (Choifah et al., 2022; Maridi et al., 2019).

Although numerous studies have investigated the effectiveness of e-learning and the Problem-Based Learning (PBL) model, or ethnomathematics separately in mathematics learning, empirical research that integrates these three components simultaneously is still limited, especially at the junior high school level. Previous research has generally focused on the influence of PBL on critical thinking skills, the use of e-learning platforms in mathematics learning, or the role of ethnomathematics in improving concept understanding (Arani, 2025; Rahmah et al., 2024) However, there is still little research that examines how the integration of PBL-based e-learning with ethnomathematics-oriented teaching materials affects critical thinking and mathematical communication skills in a complete learning framework.

This study aims to fill the research gap by examining the combined influence of PBL-based e-learning and ethnomathematics-based Pythagorean Theorem learning on students' critical thinking and mathematical communication skills. The novelty of this research lies in the integration of the three pedagogical approaches in the digital learning environment, thus providing empirical evidence relevant to the current educational context that emphasizes digital learning processes that support the the enhancement of higher-order thinking abilities.

RESEARCH METHODS

This study employed a quantitative quasi-experimental approach using a non-equivalent control group design without random assignment. The research population comprised all eighth-grade students at SMP Negeri 4 Madiun, totaling 120 students. Two intact classes were purposively selected as research samples, with one class assigned as the experimental group (31 students) and the other as the control group (31 students). The experimental group received instruction through Problem-Based Learning (PBL) supported by e-learning, whereas the control group was taught using conventional instructional methods. To assess students' abilities, both groups were administered a pretest prior to the intervention to measure initial levels of critical thinking and mathematical communication, followed by a posttest after the intervention to evaluate learning outcomes. The research instruments consisted of critical thinking and mathematical communication tests developed based on established indicators for each skill. Data were analyzed using inferential statistical techniques, specifically an independent samples t-test, to examine differences between the experimental and control groups. Prior to hypothesis testing, assumptions of normality and homogeneity were tested at a significance level of $\alpha = 0.05$. All statistical analyses were conducted using SPSS software.

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Table 1. Critical thinking instrument grid

No	Indicator	Item	Quantity
1	Analyze arguments	1,3,5,7	4
2	Evaluating information	2,4,6	3
3	Drawing conclusions	9,10,12	3
4	Provide an explanation	8,11,13,14	4

Table 2. Non-Equivalent Control Group Design

Groups	Pretest	Treatment	Posttest
Eksperimen	O_1	X	O_2
Control	O_3	–	O_4

Table 3. Mathematical communication ability instrument grid

No	Indicator	Item	Quantity
1	Present and explain mathematical situations or solutions clearly	1, 3, 5, 7	4
2	Represent a real object, picture, or diagram into a mathematical idea	2, 4, 6	3
3	Expressing mathematical concepts using mathematical symbols and notation appropriately	9, 10, 12	3

RESULTS AND DISCUSSION

A differential test using independent samples was conducted to analyze the influence of the use of e-learning with the Problem-Based Learning (PBL) model on critical thinking skills and mathematical communication skills. The results of the analysis in the pretest and posttest are presented sequentially in Table 3 and Table 4.

Table 3. Pretest results

Variabel	Average		Value T-test	Significance Value	Conclusion
	Experimental Group	Control Group			
Critical Thinking	46,61	46,13	0,242	0,405	There is no difference
Mathematical Communication	46,35	44,88	0,612	0,272	There is no difference

As shown in Table 3, the experimental group demonstrated a marginally higher mean score in critical thinking skills (M = 46.61) compared to the control group (M = 46.13); however, this difference was not statistically significant (t = 0.242, p = 0.405 > 0.05). A similar pattern was observed for mathematical communication skills, where the experimental group achieved a mean score of 46.35, while the control group recorded a mean score of 44.88, with the difference also failing to reach statistical significance (t = 0.612, p = 0.272 > 0.05). Overall, the analysis indicates that there were no significant differences between the experimental and control groups across both variables examined.

Table 4. Post test results

Variabel	Average		Value T-test	Significance Value	Conclusion
	Experimental Group	Control Group			
Critical Thinking	76,28	67,26	2,262	0,012	There is a significant difference
Mathematical Communication	73,60	69,32	1,813	0,038	There is a significant difference

The analysis revealed that students in the experimental group achieved a higher mean score in critical thinking skills (M = 76.28) compared to those in the control group (M = 67.26), and this difference was statistically significant (t = 2.262, p = 0.012 < 0.05). Similarly, for mathematical

communication skills, the experimental group obtained a higher average score (M = 73.60) than the control group (M = 69.32), with the difference also reaching statistical significance (t = 1.813, p = 0.038 < 0.05). Overall, these results demonstrate significant differences between the experimental and control groups for both variables under investigation.

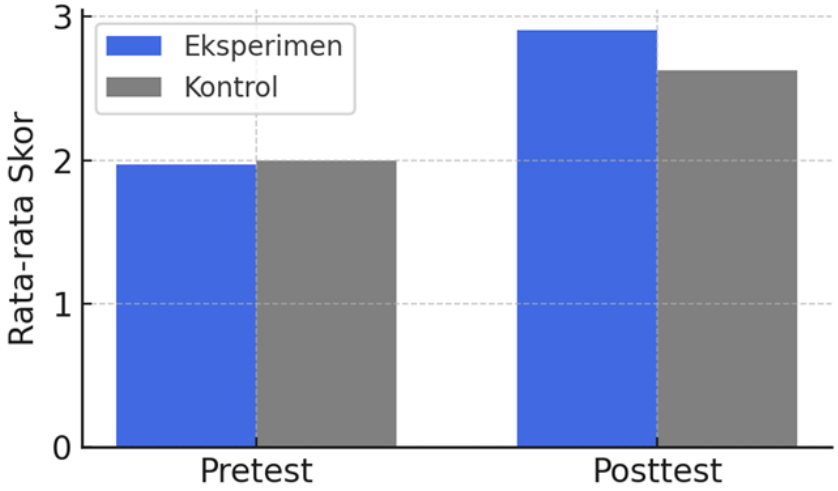

Figure 1. Comparison of Pretest and Posttest Average Critical Thinking Skills

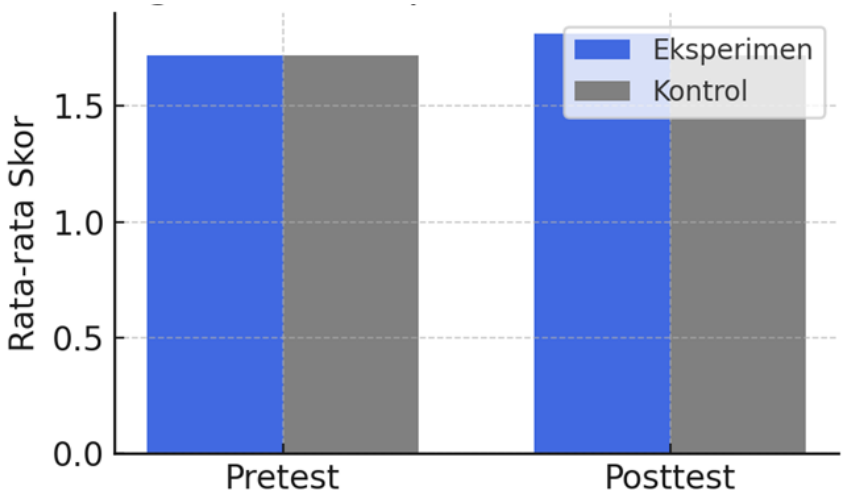

Figure 2. Comparison of Pretest and Posttest Averages for Mathematical Communication Skills

The results demonstrate that the application of e-learning supported by the Problem-Based Learning (PBL) model significantly enhances students' critical thinking skills (Dehghanzadeh & Moaddab, 2026). These findings were reinforced by the difference in higher average critical thinking scores in the experimental class compared to the control class. These results indicate that the integration of e-learning in PBL learning makes a positive contribution in facilitating students' high-level thinking processes, especially in the investigation and problem-solving phases (Arifatunnisak & Susilo, 2023; Fianingrum et al., 2023). Through e-learning, students have wider access to various digital learning resources that can be used independently, in contrast to control classes where learning resources are relatively limited to textbooks (Primasari, 2024).

These findings are consistent with previous studies (Indriani et al., 2023; Zhai et al., 2025) which indicate that e-learning media significantly enhances students' critical thinking skills by introducing innovative approaches to the learning process. E-learning features, such as digital material presentations, discussion rooms, and interactive quizzes, allow students to access information anytime and anywhere and express ideas without pressure (Cao et al., 2025; Roshal et al., 2025). In addition, the variety of media in the form of text, audio, video, and interactive elements makes learning less

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monotonous and encourages students to carry out high-level cognitive processes, such as selecting, analyzing, and evaluating information, which are the main indicators of critical thinking (Ovtšarenko, 2025).

The findings of this study indicate that the implementation of the Problem-Based Learning (PBL) model plays a substantial role in fostering students' critical thinking abilities. By engaging students in both individual and collaborative problem-solving activities grounded in real-life contexts, PBL creates learning conditions that stimulate idea generation, logical reasoning, and reflective evaluation of problem-solving outcomes (Rudolphi-Solero et al., 2025). These results align with previous studies reporting that PBL outperforms conventional instructional approaches in enhancing students' critical thinking skills and overall learning outcomes (Saputri et al., 2023) which states that the PBL model is more effective in improving students' critical thinking skills and learning outcomes compared to conventional learning (Aulia et al., 2025). Moreover, integrating PBL with e-learning and ethnomathematics-based learning materials on the Pythagorean Theorem further reinforces students' conceptual understanding and critical thinking development by connecting mathematical concepts with local cultural contexts that are meaningful and familiar to learners (Tian & Zhang, 2025).

The results further reveal that the integration of e-learning with The PBL model has a significant influence on both students' mathematical communication and critical thinking skills. This is evidenced by the results of statistical tests that show the significance value (Sig. = 0,038 < 0,05), which indicates a difference in mathematical communication ability between the experimental class and the control class. In the experimental class, students are asked to upload the results of discussions and problem-solving through e-learning platforms, so that they are encouraged to formulate mathematical answers in a systematic manner and easy to understand by teachers and peers. This activity trains students in conveying mathematical ideas in writing and structured.

These results are in line with the findings Ningsih et al. (2021) which states that ethnomathematics-based learning is able to significantly improve students' mathematical communication skills compared to conventional learning. The use of local cultural contexts in the presentation of math problems helps students' express ideas more confidently and relevantly. In addition, Solihah (2023a) also emphasized that the integration of e-learning with the PBL model is more effective in improving students' mathematical communication skills because it provides a flexible space for interaction and discussion, both between teachers and students as well as between students, with direct supervision from teachers (Hidayah Mohamed, 2025).

Conceptually, the Problem-Based Learning (PBL) model facilitates meaningful student involvement by positioning learners as active participants in the learning process rather than passive recipients of information (Sudianto & Ramdiani, 2024). Within this learning environment, students are encouraged to articulate mathematical ideas, present discussion outcomes, and justify the solutions they develop. The results of this study align with previous research demonstrating that students who engage in PBL-based instruction exhibit stronger mathematical communication skills compared to those taught through expository approaches (Putri & Wiarta, 2024; Ribawa et al., 2024) which shows that the mathematical communication skills of students taught using the PBL model are higher than those of students taught with the expository learning model (Sulistifa et al., 2023). Furthermore, the integration of e-learning with PBL and ethnomathematics in teaching the Pythagorean Theorem consistently enhances students' mathematical communication abilities, reinforcing the effectiveness of this combined instructional approach (Mursalin et al., 2025).

The results of this study support earlier evidence indicating that students instructed through the Problem-Based Learning (PBL) model demonstrate superior mathematical communication skills compared to those receiving expository instruction (Nabilah et al., 2023; Nisa' & Rayungsari, 2024) This consistency is primarily associated with the emphasis on students' active participation, particularly in expressing mathematical ideas and presenting the outcomes of problem-solving activities during learning. Despite these similarities, the present study differs from previous research in its instructional context, as it integrates e-learning with ethnomathematics-based approaches. Such a combined implementation has rarely been examined simultaneously in prior studies, thereby offering a distinct contribution to the existing literature (Kurnia et al., 2023).

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The integration of e-learning with the PBL model and ethnomathematical approach to the Pythagorean Theorem material provides a new dimension in the development of students' mathematical communication skills. Through e-learning, students gain a more flexible space to express ideas in writing and visually, while ethnomathematical contexts help students relate mathematical concepts to local cultures that are close to students' lives. Thus, this study not only corroborates previous findings, but also expands the study of PBL learning by showing that the incorporation of technology and cultural contexts is consistently able to improve students' mathematical communication skills (Meiliati et al., 2026).

This study makes a significant contribution to mathematics education by integrating e-learning with the Problem-Based Learning (PBL) model and an ethnomathematics approach within a single instructional framework, particularly in teaching the Pythagorean Theorem at the junior high school level. Unlike prior studies that have typically focused on the effects of e-learning or PBL in isolation, this research concurrently examines the combined impact of these three components on two higher-order thinking outcomes, namely students' critical thinking and mathematical communication skills. Furthermore, by positioning local cultural contexts as a core element of technology-supported instruction, this study extends the discourse on contextual mathematics learning and highlights the relevance of culturally grounded pedagogy in the digital learning environment.

This study employed a quasi-experimental design without random assignment of participants; therefore, differences in students' initial characteristics could not be fully controlled. In addition, the study was conducted in a single school and was limited to the Pythagorean Theorem, so the generalizability of the findings should be interpreted with caution. The duration of the instructional implementation was relatively short and did not consider other factors such as students' learning motivation, self-regulated learning, and digital literacy.

Based on the findings of this study, further research is suggested to examine the application of e-learning with the ethnomathematics-based Problem Based Learning model on other mathematics materials or at different levels of education (Benítez-chavira & Z, 2026). In addition, advanced research can develop research designs by involving other variables, such as learning motivation, self-regulated learning, or students' digital literacy, along with the use of mixed-methods approaches to achieve a more holistic understanding of learning processes and their impacts.

CONCLUSION

The findings indicate that the application of e-learning supported by the Problem-Based Learning (PBL) model contributes significantly to the development of students' critical thinking and mathematical communication skills. Students in the experimental class showed better learning outcomes than in the control class, both in analyzing information, solving problems, and communicating mathematical ideas. E-learning-based learning encourages active student involvement through independent problem-solving, discussion, and concept exploration activities. The integration of ethnomathematical contexts helps students relate the concept of Pythagorean Theorem to real situations, so that the process of critical thinking and mathematical communication becomes more meaningful than conventional learning. It is recommended that educators implement PBL-based e-learning with an ethnomathematical context on an ongoing basis, as well as advanced research is carried out on different materials and levels of education.

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