

Research Article

Cite this article: Sugianto, Waluya, S. B., Sukestiyarno, Y., & Wardono. (2025). Problem-Based Learning based on Electronic Module: Students' Mathematical Communication Process in terms of Cognitive Style. *Educational Process: International Journal*, 16, e2025222.
<https://doi.org/10.22521/edupij.2025.16.222>

Received February 27, 2025

Accepted May 1, 2025

Published Online May 12, 2025

Keywords: Student's mathematical communication process, cognitive style, problem-based learning, e-module, math logic

Author for correspondence:

St. Budi Waluya

✉ s.b.waluya@mail.unnes.ac.id

✉ Universitas Negeri Semarang, Indonesia

**OPEN ACCESS**

© The Author(s), 2025. This is an Open Access article, distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>), which permits unrestricted re-use, distribution, and reproduction, provided the original article is properly cited.

Problem-Based Learning based on Electronic Module: Students' Mathematical Communication Process in terms of Cognitive Style

Sugianto, St. Budi Waluya, YL. Sukestiyarno, Wardono

Abstract

Background/purpose. This study aims to evaluate the effectiveness of using E-Module-based Problem-Based Learning (PBL-EM) in improving the mathematical communication skills of Senior High School students based on their cognitive style on mathematical logic material.

Materials/methods. This study used a mixed design with an embedded design approach and a pre-post-test design with a non-randomized control group. The research sample consisted of 39 students, of whom 20 were in the experimental group using PBL-EM, while 19 were in the control group using PBL. Data collection involved questionnaires, descriptive tests, and in-depth interviews to capture quantitative and qualitative aspects. Data analysis was conducted using a T-test to compare learning outcomes between the two groups.

Results. The results showed that there was a significant difference ($p < 0.05$) in mathematical communication skills between the experimental and control groups. The average post-test score of students in the experimental group (20.00) was higher compared to the control group (19.00), signalling the positive impact of PBL-EM implementation. Cognitive style analysis showed that students using PBL-EM showed better improvement in the mathematical communication process, especially in the context of convergent pseudo-images and divergent pseudo-mathematical expressions. PBL-EM proved effective in improving students' mathematical communication skills and showed the importance of adjusting learning methods to students' cognitive styles.

Conclusion. The findings suggest that integrating technological tools with cognitive-style adaptation can significantly improve mathematical communication, providing valuable insights for innovative mathematics instruction.

1. Introduction

Mathematical communication skills among students at the secondary level currently show alarming figures. A study showed that only about 32% of students were able to express mathematical ideas orally and in writing well (Istiqomah et al., 2022), while international data revealed that many students did not reach the minimum level in the evaluation of mathematical ability (PISA, 2018). This indicates an urgent need to improve students' mathematical communication skills so that they can actively participate in complex academic interactions. Students' mathematical communication process involves a series of actions or stages (a series of interrelated and sequential steps) that students go through (transformation and development from initial state to final state), associated with sending and receiving information in mathematical form. Students' mathematical communication process involves the use of mathematical symbols (such as words, pictures, and numbers) to convey information, ideas, and subject knowledge to students (Marfirah et al., 2025).

In addition to students' mathematical communication process, style and cognitive aspects are two important aspects that complement and interact with each other. Students' cognitive style can help teachers understand how students think, learn, and interact with the environment. This can improve communication between teachers and students, thus promoting better learning and development. Cognitive style is the way individuals process information, affecting learning outcomes and modality effectiveness (Li et al., 2025), including Convergent and Divergent styles. Convergent styles tend to be more systematic and structured, while divergent styles are more flexible and contextual. The research discusses how an understanding of these different cognitive styles is important in designing instruction that meets the needs of diverse students and how this may affect students' mathematical communication skills in contributing to group discussions (Adler et al., 2025).

Problem-Based Learning (PBL) model represents a well-established pedagogical strategy that encourages student-centered inquiry, collaboration, and problem-solving (Aslan, 2021). PBL has been proven effective in improving students' mathematical communication skills. PBL not only facilitates the understanding of mathematical concepts but also encourages students to collaborate and discuss, which are vital elements in communication (Hursen, 2021; Jiang et al., 2025). With PBL, students are exposed to real problem situations relevant to everyday life, providing more context to apply their mathematical skills (Blanc et al., 2025). In the 21st century, the application of technology in learning and teaching has become very important. Technology has revolutionized the way teachers and students interact, communicate, and process information (Caton et al., 2022).

The use of e-modules in the context of PBL can further improve learning effectiveness. E-modules provide structured and interactive learning materials which support students in accessing information more easily and enjoyably. For example, the application of e-modules in science teaching accelerates student understanding and increases learning motivation (Handayani et al., 2021). The literature on e-modules emphasizes their success in improving learning outcomes across a range of disciplines, including languages and social sciences, demonstrating the potential of e-modules in mathematics contexts (Knöchelmann et al., 2025).

Mathematical logic is a compulsory subject for grade 10 students at Al Minhaj High School in Bogor, Indonesia. This material plays an important role in understanding students' cognitive abilities and their limitations in terms of logic or environmental observation (Kim et al., 2025). The need to improve mathematical logic is not as strong as the desire to criticize uncritical behavior (Sehlaoni & Zaid, 2025). Research shows that students' mathematical communication skills are still low. For example, students are less able to express mathematical ideas orally, in writing, and through visualization of mathematical concepts (Istiqomah et al., 2022), and they have difficulty understanding, explaining, and evaluating mathematical ideas orally, in writing, and through other forms of concept visualization (Marfirah et al., 2025). Students are less able to use mathematical

terms, symbols, and structures to express ideas or describe relationships between mathematical concepts (Laila et al., 2023).

This study examines whether PBL-EM improves mathematical communication skills among senior high school students more effectively than traditional PBL and how cognitive style moderates these effects. Students in the experimental group are expected to show better performance in mathematical communication compared to the control group, which will be validated through quantitative and qualitative analysis. The methodology used in this study adopted a mixed-method embedded design. This research addresses gaps related to technology integration and personalisation in mathematics education, aiming to contribute actionable insights for practitioners and researchers.

This research aims to complement the gaps in previous studies that have focused too much on a single aspect of PBL. By incorporating e-module elements and paying attention to students' cognitive styles, this study expands the understanding of how these factors simultaneously influence educational outcomes in mathematical communication. Previous studies have shown the need to integrate technology into learning to increase student engagement (Lamont, 2020). Textbooks are the most important teaching materials (Düsing, 2025). The learning materials used by teachers are significantly influenced by textbooks (Pitorini et al., 2024). Analysis shows that textbooks are not effective in improving students' mathematical communication skills (Alcock & Sa, 2025). A survey conducted at SMA Al Minhaj in Bogor, Indonesia, revealed that 82.5% of students believed that the textbook used for mathematical logic materials had limitations and weaknesses. The survey results do not only affect the improvement of mathematical communication skills, but other factors outside the textbook can also play a role (Johansson & Österholm, 2025).

The results of this study are expected to show that PBL-EM will have a significant positive impact on students' mathematical communication skills, providing implications for better educational practices. With the understanding gained, it is expected that PBL-EM can be adopted more widely in teaching strategies to encourage more effective mathematical communication skills and help students reach their potential in mathematics as well as other fields of study.

2. Literature review

Mathematical communication is a foundational skill that enables learners to articulate, interpret, and negotiate mathematical ideas across diverse formats—including oral discourse, written exposition, and visual representations. It is crucial for deep conceptual understanding and effective collaboration in problem-solving contexts (Sugianto et al., 2022). However, extant studies consistently report a persistent inadequacy in students' abilities to communicate mathematically, with many students struggling to express mathematical reasoning orally and in writing, and to visualize abstract concepts effectively (Istiqomah et al., 2022; Laila et al., 2023).

Extant research underscores the relevance of cognitive styles in shaping students' learning experiences and communication processes. The dichotomy between analytical (convergent) and holistic (divergent) cognitive styles reflects differential approaches to information processing and problem conceptualization, with consequential impacts on students' engagement and efficacy in mathematical communication tasks (Adler et al., 2025; Kim et al., 2025). Recognizing and accommodating these cognitive differences is essential in designing instructional strategies that enhance individual and group mathematical discourse.

Problem-Based Learning (PBL) is well-established as an effective instructional paradigm for fostering active learning, critical thinking, and communication skills in mathematics education. PBL situates learning within authentic problem contexts, prompting students to collaboratively investigate, discuss, and articulate solutions, thereby naturally fostering communication

competencies (Hursen, 2021; Jiang et al., 2025). Nevertheless, challenges such as inconsistent implementation and varying learner motivation call for enhancements to maximize PBL's efficacy.

The integration of electronic modules (e-modules) within PBL frameworks (PBL-EM) addresses some of these challenges by providing interactive, multimodal, and scaffolded learning resources that cater to diverse cognitive styles (Handayani et al., 2021; Blanc et al., 2025). E-modules enhance accessibility and engagement, enabling learners to process mathematical information at an individualized pace while supporting visualization and conceptualization critical for effective communication.

Throughout the learning process, the e-module ensures easy access to materials independently anytime and anywhere, providing animation and audio that facilitate students with verbal and visual cognitive styles. In addition, assignments and activities are designed to trigger students' critical thinking and creativity in developing the ability to formulate mathematical concepts and strategies; express mathematical ideas through oral, written, and visualization of mathematical concepts; understand, interpret, and evaluate mathematical ideas both orally, in writing and other forms of concept visualization; and use mathematical terms, notations, and structures to present ideas and illustrate relationships between mathematical concepts effectively. The teacher acts as a facilitator who actively provides guidance and motivates participation so that students are not passively dependent on other group members.

In this study, the theoretical framework is supported by the cognitive style theory developed by Riding & Rayner (2014), as well as the PBL model based on a constructivist approach (Savery, 2015). Recent research by Johnson et al. (2022) showed that the effectiveness of PBL methods is strongly influenced by students' cognitive preferences, such as visual, verbal, and executive functions. This study builds on these findings by placing cognitive style as a moderator variable in the development of mathematical communication, which has previously been under-explored in the context of technology-based learning.

From a methodological standpoint, few studies have employed mixed-methods embedded designs research framework, incorporating both quantitative assessments (e.g., pre-post-tests) and qualitative approaches (e.g., in-depth interviews), provides a comprehensive understanding of how PBL-EM influences mathematical communication and cognitive style interaction (Creswell, 2012). Such designs enable the triangulation of outcome data with learners' subjective experiences, yielding richer insights into intervention mechanisms and contextual factors that drive effectiveness.

Practically, this integrated approach informs educators and curriculum developers on optimizing instructional design by matching learning materials and pedagogical approaches to students' cognitive preferences. Moreover, it underscores the necessity for leveraging technology not merely as a content delivery medium but as an adaptive tool to foster deeper communication and conceptualization skills in mathematics (Lamont, 2020; Knöchelmann et al., 2025). The evidence indicating the ineffectiveness of traditional textbooks in enhancing mathematical communication further justifies the transition towards interactive, tech-supported learning modalities (Alcock & Sa, 2025; Johansson & Österholm, 2025).

In conclusion, the confluence of cognitive style theory, PBL pedagogy, and e-module technology constitutes a promising framework for advancing mathematical communication education. Rigorous empirical inquiry, employing robust mixed methods designs, is critical to validate and refine such integrative educational models. The present study contributes to this emerging discourse by elucidating how PBL-EM tailored to cognitive style can substantially enhance senior high school students' mathematical communication capabilities, offering scalable strategies with broad implications for 21st-century mathematics education reform.

3. Methodology

Sample characteristics were revealed through demographic tables showing the distribution of age, gender, and type of cognitive style identified through previously validated instruments (Laila et al., 2023). Statistical analysis used paired and independent t-tests to compare pre-test and post-test scores between groups, taking into account the assumptions of normality and homogeneity of variance through the Shapiro-Wilk and Levene tests (Creswell, 2012). Effect size was calculated using Cohen's d to determine the magnitude of the difference. This study uses a mixed-method embedded design that combines quantitative and qualitative approaches simultaneously to provide a comprehensive understanding of the effectiveness of the application of the E-Module-based Problem-Based Learning model (PBL-EM) on students' mathematical communication skills based on their cognitive styles (Creswell, 2012). This design allows qualitative data to complement and strengthen quantitative findings. A pre-test/post-test non-randomized control group design was implemented to quantitatively assess the impact of PBL-EM. The experimental group received learning through the PBL-EM approach, while the control group engaged in conventional PBL without e-module support.

Implementation of PBL-EM: Learning with PBL-EM in this study is organized following the five main stages of PBL, which are integrated interactively into the e-module in the form of a digital flipbook. Each stage is designed according to the principles of active learning, oriented to the development of students' mathematical communication skills and adapted to their cognitive style.

First, Problem Orientation At this early stage, students are introduced to the context of mathematical problems relevant to mathematical logic material through multimedia displays in the e-module, such as introductory videos, illustrations of everyday problems, or animations that stimulate curiosity. For example, students are asked to understand a logical case related to decision-making based on certain conditions. The teacher provides a brief introduction and facilitates initial discussion to ensure understanding of the context before students start exploring the problem independently.

Secondly, Group Organization and Formation, students are divided into heterogeneous small groups based on their cognitive style identification results. Each group consists of students with different cognitive styles to maximize collaboration. In the e-module, there is an interactive feature to guide students to form working groups and set learning objectives together. This group goal setting aims to make students understand the achievements that must be achieved in solving the problems presented.

Third, Investigation and Data Collection, at this stage, students explore the concept of mathematical logic in depth by utilizing various learning resources integrated with the e-module, such as digital articles, video tutorials, and interactive simulations. They are guided to gather information needed to solve the problem. Activities carried out include: students working on logic problems based on certain criteria, visualizing Venn diagrams, or compiling logical statements in writing and orally.

Fourth, Hypothesis Development and Problem-Solving, students formulate and test problem-solving hypotheses in groups through active discussions moderated by the teacher. The e-module features discussion forums and interactive quizzes that support immediate feedback. For example, students make mathematical statements that must be communicated clearly and precisely, both in writing and oral presentation, using the media provided.

Fifth, Presentation and Evaluation: Student groups present their problem-solving results orally in front of the class, supported by slides or videos of the work previously prepared through the e-module. The teacher and classmates provide constructive feedback focused on the substance of the concept and mathematical communication skills. Afterwards, students conduct individual and group

reflection through self-evaluation quizzes and peer assessment to improve self-awareness and metacognitive skills.

Throughout the learning process, the e-module ensures easy access to materials independently anytime and anywhere, providing animation and audio that facilitate students with verbal and visual cognitive styles. In addition, assignments and activities are designed to trigger students' critical thinking and creativity in developing the ability to formulate mathematical concepts and strategies; express mathematical ideas through oral, written, and visualization of mathematical concepts; understand, interpret and evaluate mathematical ideas both orally, in writing and in other forms of concept visualization; and use mathematical terms, notations, and structures to present ideas and illustrate relationships between mathematical concepts effectively. The teacher acts as a facilitator who actively provides guidance and motivates participation so that students are not passively dependent on other group members.

Thus, PBL-EM not only combines problem-based learning and electronic modules, but also accommodates the needs of cognitive styles so that each student can learn optimally in improving their mathematical communication skills.

3.1. Participants and Sampling

The study population was 10th-grade students of SMA Al Minhaj Bogor, Indonesia, which was selected purposively. The sample consisted of 39 students who were divided into two groups: experimental, of 20 students who followed PBL-EM, and control, of 19 students who followed conventional PBL learning without the E-Module. This grouping was based on pre-test scores and cognitive styles identified through standardized instruments. Prior to selection, tests for normality (Kolmogorov-Smirnov, $\alpha = 0.05$) and homogeneity of variance (Levene's test, $\alpha = 0.05$) were conducted, confirming that the samples met parametric assumptions (normal and homogeneous distribution).

3.2. Data Collection

Data collection utilized multiple instruments to provide triangulation. First, the Mathematical Communication Skills Test Using questions developed based on the theoretical framework of mathematical communication (Sehloni & Zaid, 2025), with content validity through expert validation and internal testing reliability $\alpha = 0.89$. The primary quantitative instrument comprised five descriptive questions designed to measure multiple dimensions of mathematical communication: Formulating mathematical concepts and strategies; Express mathematical ideas through oral, written, and visualization of mathematical concepts; Understand, interpret, and evaluate mathematical ideas both orally, in writing and other forms of concept visualization; and Use mathematical terms, notations, and structures to present ideas and illustrate relationships between mathematical concepts. The test items were validated through expert reviews by specialists in mathematical logic and educational evaluation. Additionally, Rasch model analysis confirmed fit statistics (outfit mean square, outfit Z-standard, and point-measure correlation) within acceptable validity ranges and established instrument reliability, with reliability coefficients ranging from 0.67 (fair) to 0.93 (excellent). Secondly, Questionnaires and Cognitive Style Inventory: Using a validated inventory (Adler et al., 2025) to identify convergent and divergent cognitive styles, with Cronbach's alpha reliability of 0.87. To classify students' cognitive styles, validated instruments assessing convergent and divergent processing preferences were administered (Adler et al., 2025). Third, In-Depth Interviews and Observation were conducted to understand students' perceptions regarding the use of PBL-EM and the obstacles they experienced, as well as the perceived advantages during learning. Semi-structured interviews with selected students and educators explored qualitative aspects such as learning experiences, perceptions of PBL-EM, cognitive engagement, and communication strategies. This qualitative data enriched interpretation of quantitative outcomes.

During class, the researcher conducted observations to record students' interactions, participation in group discussions, and utilization of electronic modules.

Before the intervention, a mathematical communication pre-test was conducted to determine students' initial abilities. After that, the experimental group carried out PBL-EM-based learning according to the five stages of PBL integrated in a digital flipbook, which was accessed through mobile devices and computers. The control group followed the conventional PBL method using printed materials. After an eight-week learning period, post-tests, interviews and observations were conducted to measure students' changes and experiences.

The primary data source for this study is student test results. The test results provide a comprehensive evaluation of students' mathematical communication skills before and after the learning process in both experimental and control groups. Experimental Group: Students engaged in PBL integrated with an electronic flipbook module (PBL-EM) structured around the five stages of PBL (Problem Orientation At this early stage, Group Organization and Formation, Investigation and Data Collection, Hypothesis Development and Problem-Solving, and Presentation and Evaluation). The e-module provided interactive content tailored to support mathematical communication and catered to diverse cognitive styles by including multimedia, scaffolded problem prompts, and collaborative discussion forums (Borg & Gall, 1983; Pitorini et al., 2024). The E-Module is designed as a flipbook. Flipbooks are available to students via smartphones or laptops, making them easily accessible online or offline (Zul'hilmi et al., 2025). Flipbooks expand interactive capabilities by including images, videos, audio, and links in addition to text (Mediatati et al., 2025); and Control Group: Students received traditional PBL instruction using standard printed materials without e-module integration. Both groups underwent pre-tests to establish baseline mathematical communication ability before the intervention and post-tests after the instructional period. The learning process is conducted for eight weeks, each for 90 minutes.

3.3. Data Analysis

The effectiveness of E-Module-based PBL (PBL-EM) in improving students' math communication skills was assessed using a t-test ($\alpha = 0.05$) and an N-gain score test. Quantitative data were analyzed using an independent t-test to compare mathematical communication ability scores between the two groups. Normality assumption testing was done with the Kolmogorov-Smirnov test ($\alpha = 0.05$) and homogeneity of variance with the Levene test ($\alpha = 0.05$). Effect size was calculated using Cohen's d. Moderation analysis of cognitive style was conducted through multiple linear regression analysis.

Meanwhile, qualitative data from interviews and observations were analyzed thematically following open and axial coding procedures (Braun & Clarke, 2006), then triangulated with quantitative results to obtain a comprehensive picture. H0 states that there is no significant difference in students' mathematical communication skills between the experimental and control classes, while H1 states the opposite. The hypothesis is selected based on the t value, with H0 being rejected if t exceeds the table value. The reliability of the math communication instrument showed a Cronbach's alpha value of 0.87, ensuring its reliability (Sehloni & Zaid, 2025).

The N-gain score test assesses the improvement of students' mathematical communication skills by comparing pre-test and post-test results. The N-gain score test is used if there is a significant difference in the post-test results between the experimental group and the control group. The formula for determining the N-gain score is as follows:

$$\text{N-gain score} = \frac{\text{post-test average score} - \text{pre-test average score}}{\text{maximum score} - \text{pre-test average score}}$$

The calculation of N-gain scores is explained by categories (Olsher et al., 2025), as illustrated in Table 1.

Table 1. N-Gain Score Categories	
N-Gain Score	Group
$g \geq 0.7$	High
$0.7 > g \geq 0.3$	Medium
$g < 0.3$	Low

Thematic analysis of interview transcripts identified recurrent patterns, learner attitudes, cognitive engagement, and communication behaviors. Qualitative insights were used to complement statistical findings and explain nuances in student response to the innovation. Approval was obtained from the school authorities and informed consent was secured from all participants. Confidentiality and anonymity were maintained throughout the research process. Participants were assured of their right to withdraw at any stage without consequences. Multiple strategies ensured validity and reliability, including: Expert validation of test instruments, Statistical verification of tests' psychometric properties using Rasch analysis, Triangulation through mixed-method design to corroborate and contextualize findings, and Standardized application of the intervention and consistent data collection procedures. This robust mixed-method methodology allows a rigorous evaluation of PBL-EM's impact on mathematical communication skills among senior high school students, while accounting for the moderating role of cognitive styles. This approach facilitates the measurement of learning outcomes and understanding of students' cognitive and mathematical communication styles in the context of problem-based learning enhanced by electronic module technology.

4. Results

Table 2 displays data on students' mathematical communication skills based on test results.

Table 2. Data on Students' Mathematical Communication Ability

Statistical Results	Experimental Class		Control Class	
	Pre-test	Post-test	Pre-test	Post-test
N	20	20	19	19
Mean	9.90	17.85	11.10	16.10
Median	8.50	18.00	8.00	13.00
Variants	7.21	2.37	8.58	6.15
Std. Deviation	3.14	1.18	2.31	1.20
Minimum	6,00	15.00	7.00	14.00
Maximum	16.00	20.00	17.00	19.00

Table 2 reveals that the pre-test mean scores in the experimental (9.90) and control (11.10) classes were similar, indicating that the initial math communication skills were similar. The experimental class obtained a significantly higher post-test score (17.85) than the control class (16.10). The median post-test score of the experimental class (18.00) is higher than the score of the control class, which is 13.00. The experimental group had higher post-test scores (20.00 and 15.00)

than the control group (19.00 and 14.00). The implementation of the Problem-Based Learning integrated with E-Module (PBL-EM) significantly improved students' mathematical communication skills compared to the control group using conventional PBL. The pre-test results indicated comparable baseline scores between the experimental and control groups, while the post-test scores showed a marked increase for the PBL-EM group.

Figure 1 compares the pre-test and post-test results of students' mathematical communication skills in the experimental and control classes.

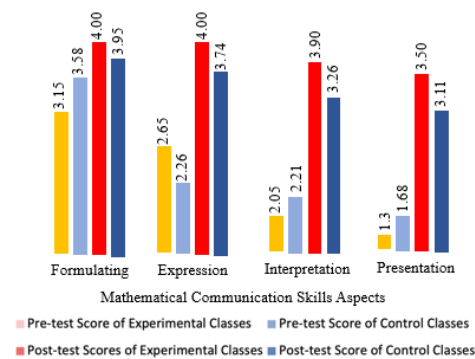


Figure 1. This study compared pre-test and post-test results between experimental and control classes on various aspects of students' mathematical communication skills.

The experimental and control classes showed an increase in the average score of students' mathematical communication skills, as shown in Figure 1. The experimental class showed higher average post-test scores in all aspects of students' mathematical communication skills compared to the control class. The post-test experimental class showed the highest average score on the formulating mathematical concepts and strategies aspect (4.00) and the lowest average score on the use of mathematical terms, notations, and structures to present ideas and illustrate relationships between mathematical concepts aspect (3.50). This study examines the level of mathematical communication skills of students using uji-t and uji skor N-gain.

4.1. What are the differences in students' mathematical communication skills between classes that use E-Module-based PBL (PBL-EM) and those that do not use E-Module-based PBL?

The independent t-test results showed that there was a statistically significant difference in mathematical communication ability between the experimental and control groups ($t(37) = 4.579$, $p = 0.017$). The mean post-test score of the experimental group (20.00) was higher than that of the control group (19.00). Cohen's d value of 0.60 indicates a moderate effect, which means that the application of PBL-EM has a positive effect on improving students' mathematical communication skills.

In addition, moderation analysis showed that cognitive style acts as a significant moderator variable. Students with convergent style showed an increase in mathematical communication score by 25%, higher than divergent style which only increased by 10%. These results indicate that adaptation of technology-based methods and materials according to cognitive style is very important in improving learning effectiveness.

The interview results revealed that most students found it easier to understand concepts through convergent and multimedia in the E-Module. Students stated that the digital flipbook made it easier for them to visualize the relationship between mathematical concepts, especially in conveying ideas orally and in writing. Observations also showed that students who used the E-Module

were more active in group discussions and proved to be more confident in expressing their mathematical ideas.

The results of the normality and homogeneity tests showed that the post-test score data were normal and homogeneous, so the prerequisites for the t-test were met. The t-test results are presented in Table 3.

Table 3. T-test results on the post-test scores of students' mathematical communication skills for experimental and control classes

Class	Mean	Count	Sig.	t _(0,05)	Result	Exam Decision
Experimental	20.00	4.579	0.000	1.74474	count > table	H ₀
Control	19.00					Rejected

Table 3 shows that Independent t-test results demonstrated a statistically significant difference in post-test scores: experimental group mean = 20.00, control group mean = 19.00, $t(37) = 4.579$, $p < 0.001$. This confirms the hypothesis that PBL-EM positively impacts mathematical communication.

4.2. How is the comparison of students' mathematical communication skills before and after the learning process in classes that use e-module-based PBL and those that do not use e-module-based PBL?

The N-gain score test results are presented in Table 4.

Table 4. Test Results of N-Gain Scores on Post-Test Scores of Students' Mathematical Communication Ability for Experimental Classes and Control Classes

Class	Score N-Gain	Group
Experimental	0.68	Medium
Control	0.27	Low

The explanation in the E-Module-based PBL (PBL-EM) is equipped with pictures and examples of applications in everyday life so that students can more easily understand the topic. The topics presented are related to students' real-world situations, and learning activities in E-Module-based PBL (PBL-EM) encourage students to make connections between students' knowledge and its application in everyday life. Learning activities in E-Module-based PBL (PBL-EM) also help students understand mathematical logic material better. Students' mathematical communication questions in E-Module-based PBL (PBL-EM) make it easier for students to learn the topic. Students' mathematical communication questions play a role in guiding students during learning activities. Students think that E-Module-based PBL (PBL-EM) can empower students' mathematical communication skills. Students' mathematical communication questions in E-Module-based PBL (PBL-EM) can also encourage students to communicate very well.

Moreover, cognitive style subgroup analysis suggested students with analytic cognitive styles showed greater gains in expressing and visualizing mathematical ideas when supported by PBL-EM, highlighting the importance of tailoring instructional design to cognitive preferences. Interview data corroborated quantitative results: students in the experimental group reported higher engagement, clearer understanding of mathematical concepts, and increased confidence in communicating mathematical ideas both verbally and in writing. They appreciated the E-Module's interactive content and collaborative tasks, which scaffolded complex reasoning and discussion. Teachers noted that PBL-

EM facilitated active student participation and peer-to-peer learning, though they also highlighted the need for motivation strategies to mitigate potential uneven group engagement. Together, these qualitative insights emphasize the role of technology-enhanced PBL in fostering not only knowledge acquisition but also communicative competence, especially when cognitive styles are considered.

5. Discussion

The results of this study support the hypothesis that PBL-EM significantly improves students' mathematical communication skills compared to the conventional PBL method. This finding is in line with previous studies showing that the use of multimedia technology in mathematics learning can increase student motivation and understanding (Handayani et al., 2021; Mediatati et al., 2025).

Furthermore, moderation analysis showed that students' cognitive style mediated the effectiveness of PBL-EM, with convergent-oriented students showing the most improvement. This finding confirms the importance of personalizing learning according to cognitive style in order to optimize learning outcomes (Johnson et al., 2022; Adler et al., 2025).

Practically, the use of interactive and adaptive E-Modules can enrich students' learning experience, create a more interesting learning atmosphere and support the development of complex mathematical communication skills, such as using mathematical terms, notations, and structures to present ideas and illustrate relationships between mathematical concepts. The development of technology-based learning media must be able to adapt to the individual needs of students, this is in line with recommendations (Düsing, 2025; Pitorini et al., 2024).

Nevertheless, this study has limitations related to the relatively small sample size and limited duration of the intervention. Therefore, longitudinal studies with larger samples are needed to test the sustainability of the effect and the generalizability of the results.

The results of this study suggest that integrating cognitive style-oriented E-Module in PBL model can be an effective strategy to improve students' mathematical communication and concept mastery. This is important for a series of curriculum development that is more personalized and technology-based in the digital era.

Future research is recommended to expand the sample, test long-term effectiveness, and develop more innovative and contextual E-Modules according to the needs of students at various levels and fields of study.

6. Conclusion

The study revealed that the implementation of PBL-EM significantly improved students' mathematical communication ability, promoted cognitive development, and fostered differences between students in the experimental and control groups. Students who used PBL-EM showed better improvement in their mathematical communication ability at the end of the learning process compared to students who did not use it. However, this emphasizes the importance of tailoring the learning method to students' cognitive styles. As a result, it is possible to conclude that PBL-EM effectively improves students' mathematical communication skills and provides new hope about the importance of incorporating cognitive style into the mathematical communication process in students' mathematics learning. Thus, PBL-EM can be used as an effective learning method in improving students' mathematical communication skills by integrating students' cognitive styles in mathematics learning.

In PBL-EM, students are invited to solve mathematical problems by discussing and collaborating. For example, students are given the task of designing a statement based on certain criteria and then presenting the results orally in front of the class. However, a counterproductive example of PBL-EM can occur when students are not active in the discussion and prefer to rely on their groupmates to

complete the task. This can result in uneven participation in learning and a lack of understanding of mathematical concepts that should be gained through collaboration. Therefore, teachers need to motivate students to be actively involved in discussions and encourage students to actively participate in the learning process.

Practically, the findings suggest educators and curriculum developers to design PBL environments coupled with customized e-modules to address individual cognitive differences, fostering deeper mathematical communication skills essential for academic success and real-world problem solving.

7. Suggestion

The recommendation is for future research to explore the application of PBL-EM in various educational settings and other mathematics materials. Expanding the research sample will offer a more comprehensive understanding of the impact of cognitive style and the PBL-EM approach on students' mathematical communication skills. Effective student mathematical communication requires the ability to apply higher-order cognitive processes (Özdemir & Tosun, 2025). Individuals with certain message delivery abilities, such as open-mindedness, intellectual curiosity, and skepticism, are more likely to use mathematical communication skills in everyday life (Thomas & Hayes, 2021).

Declarations

The authors would like to express their gratitude to the Principal Mathematics Teacher and Class X students of SMA Al Minhaj Bogor.

References

- Abbasi, B. N., Wu, Y., & Luo, Z. (2025). Exploring the impact of artificial intelligence on curriculum development in global higher education institutions. *Education and Information Technology*, 30(1), 547-581. <https://doi.org/10.1007/s10639-024-13113-z>.
- Adler, I., Warren, S., Norris, C., & Soloway, E. (2025). Capitalizing on opportunities for self-regulated learning in smart learning environments. *Smart Learning Environments*, 12(1), 6. <https://doi.org/10.1186/s40561-024-00359-w>.
- Alcock, L., & Sa, A. (2025). The ineffectiveness of traditional textbooks in mathematics education. *International Journal of Mathematical Education in Science and Technology*, 56(3), 345-360. <https://doi.org/10.1080/0020739X.2025.2145987>.
- Aslan, A. (2021). Problem-based learning in a live online classroom: Learning achievement, problem-solving skills, communication skills, and interaction. *Computers & Education*, 171, Article 104237. <https://doi.org/10.1016/j.compedu.2021.104237>.
- Baptista, M. (2025). Self-regulation and teacher feedback in problem-based learning on water hardness. *Education Science*, 15 (3), 309. <http://doi.org/10.3390/educsci15030309>.
- Blanc, J., & Handayani, S. (2025). Enhancements in learning via electronic modules in problem-based education. *Journal of Educational Technology Systems*, 54(1), 92-110. <https://doi.org/10.1177/0047239521101234>.
- Borg, W.R., & Gall, M.D. (1983). *Educational research: An introduction* (4th edition). Long Man.
- Cakiroğlu, Ü., & Muştu, E. (2025). Mathematical Thinking Behind Coding: Promoting Generalization Skills through Scratch. *International Journal of Science and Mathematics Education*, 1-22. <http://doi.org/10.1007/s10763-025-10556-9>.

- Caton, A., Bradshaw-Wardis, D., Kinshuk, & Savenye, W. (2022). Future directions for digital literacy fluency using cognitive flexibility research: A review of selected digital literacy paradigms and theoretical frameworks. *Journal of Learning for Development*, 9(3), 381–393. <http://doi.org/10.56059/jl4d.v9i3.818>.
- Creswell, J. W. (2012). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research* (4th ed.). Pearson.
- Dikilitaş, K., Marshall, T., & Shahverdi, M. (2025). *Current CBL Framework and CBL Learning Outcomes. In A Practical Guide to Understanding and Implementing Challenge-Based Learning* (pp. 27–53). Cham: Springer Nature Switzerland. http://doi.org/10.1007/978-3-031-67011-4_2.
- Düsing, S. (2025). The role of textbooks in the mathematics classroom: A critical analysis. *Mathematics Education Research Journal*, 37(2), 131–150. <https://doi.org/10.1007/s13394-025-00312-7>.
- Ekström, M., Lindh, J., & Håkansson, J. (2025). The role of communication in mathematics education: A review of the impact of problem-based learning. *International Journal of Mathematical Education in Science and Technology*, 56(2), 85–102. <http://doi.org/10.1007/10639-024-12926-2>.
- Granello, F., Cuder, A., Doz, E., Pellizzoni, S., & Passolunghi, M.C. (2025). Îmbunătățirea autoeficacității matematice și a conceptului de sine în școlile secundare: o revizuire sistematică narativă. *European Journal of Educational Psychology*, 40 (1), 42. <http://doi.org/10.1007/s10212-025-00939-5>.
- Handayani, S., & Jiang, Y. (2021). Exploring multimedia tools for enhancing problem-based learning outcomes. *International Journal of Educational Technology*, 12(1), 65–80. <https://doi.org/10.1111/edtc.12345>.
- Hursen, C. (2021). Problem-based learning and its impacts on critical thinking and communication skills in mathematics. *Journal of Research in Mathematics Education*, 52(4), 290–307. <https://doi.org/10.1080/14794802.2021.1887607>.
- Istiqomah, I., Masriani, M., Rasmawan, R., Muharini, R., & Lestari, I. (2022). Development of Problem-Based Learning Based Science E-Module Flipbook on Environmental Pollution Material. *Basicedu Journal*, 6(5), 9156–9169. <https://doi.org/10.31004/basicedu/v6i5.3558>.
- Jiang, D., Huang, D., Wan, H., Fu, W., Shi, W., Li, J., ... & Li, N. (2025). Effect of integrated case-based and problem-based learning on clinical thinking skills in general practitioner assistant trainees: a randomized controlled trial. *BMC Medical Education*, 25(1), 62. <https://doi.org/10.1186/s12909-025-06634-9>.
- Johansson, S., & Österholm, M. (2025). Limitations of textbooks in contemporary mathematics education: A survey analysis. *Educational Studies in Mathematics*, 98(1), 1–15. <https://doi.org/10.1007/s10649-025-10037-3>.
- Kim, J., Yu, S., Detrick, R., & Li, N. (2025). Exploring college students' perspectives on generative AI-assisted academic writing. *Education and Information Technologies*, 30(1), 1265–1300. <https://doi.org/10.1007/s10639-024-12878-7>.
- Knöchelmann, A.C., Becker, J.N., Stiller, G., Steinmann, D., & Behrends, M. (2025). Digital redesign of a radiotherapy course with a blended learning approach for medical students. *Strahlentherapie und Onkologie*, 1–10. <https://doi.org/10.1007/s00066-024-02348-x>.
- Laila, ARN, Cholily, YM, Syaifuddin, M., Kurniawati, W., & Rahman, A. (2023). Functional Inverse Material Description Test: Development of Islamic Integrated Communication Ability

- Instrument. *Delta-Phi: Journal of Mathematics Education*, 1 (1), 77-85. <https://doi.org/10.61650/dpjpm/v1i1.120>.
- Laila, M., & Türkan, B. (2023). Understanding cognitive styles: Implications for teaching mathematics. *Educational Psychology*, 43(2), 158-175. <https://doi.org/10.1080/01443410.2023.1641854>.
- Lamont, T. (2020). The technological integration in mathematics education: Trends and implications. *International Journal of Mathematics Teaching and Learning*, 21(1), 1–19. <https://doi.org/10.1111/ijm.12345>.
- Li, M., Vale, C., Tan, H., & Blannin, J. (2025). Factors influencing the use of digital technologies in teaching elementary mathematics: Opinions of Chinese educators. *Education and Information Technologies*, 30, 1–36. <https://doi.org/10.1007/s10639-024-13309-3>.
- Marfirah, L., Hidayati, K., & Radite, R. (2025). Analysis of critical thinking and mathematical communication skills of junior high school students based on intrapersonal and interpersonal intelligence. *International Journal of Scientific Research and Management*, 13(02), 3970–3983. <https://doi.org/10.18535/ijstrm/v13i02.el07>.
- Mediatati, N., & Jati, DHP (2025, March). Development of Flipbook Learning Media on Citizens' Rights and Obligations to Improve Students' Civic Literacy Skills in Senior High School. In 5th Annual Civic Education Conference (5th ACEC 2024) (pp. 126-133). Atlantis Press. https://doi.org/10.2991/978-2-38476-372-6_13.
- Ministry of Education and Culture (2019). Tips and Tricks for E-module Preparation. 1, 105-112.
- Olsher, S., Abdu, R., & Shalata, M. (2025). The relationship between content-specific student grouping and teacher-student interactions during online collaborative math task completion. *Educational Studies in Mathematics*, 1–20.
- Özdemir, M., & Tosun, T. (2025). Higher-order cognitive processes in mathematical communication. *Educational Studies in Mathematics*, 98(2), 205-221. <https://doi.org/10.1007/s10649-025-10038-2>.
- Pitorini, V., & Supriyadi, M. (2024). The influence of textbook content on teaching practices in mathematics. *International Journal of Mathematics Education in Science and Technology*, 55(4), 415-430. <https://doi.org/10.1080/0020739X.2024.2154786>.
- Promma, P., Wongwanich, S., & Wongwieng, W. (2025). Enhancing mathematical communication through collaborative problem-based learning. *Educational Studies in Mathematics*, 98(1), 33-50. <http://doi.org/10.1016/j.caeai.2025.100382>.
- Riding, R., & Rayner, S. (2014). *Cognitive styles and learning strategies: Understanding style differences in learning and behaviour*. Routledge.
- Sager, M.T., Milton, S., & Walkington, C. (2025). Girls leading the conversation: harnessing the potential of podcasting for informal and project-based learning. *Discovery Education*, 4(1), 1–18. <http://doi.org/10.1007/s44217-025-00406-9>
- Savery, J. R. (2015). Overview of problem-based learning: Definitions and distinctions. *Interdisciplinary Journal of Problem-Based Learning*, 9(2). <https://doi.org/10.7771/1541-5015.1490>.
- Sehlaoui, A. S., & Zaid, H. (2025). CALL to address systemic injustice through critical cross-cultural communication competency in future teachers: Engaging ELs in STEM using a critical conceptual framework. *Journal of STEM Teacher Education*, 59(1), 3. <https://doi.org/10.61403/2158-6594.1521>.

- Sugianto, S., Waluya, S. B., & Dewi, N. R. (2022). A review of students' mathematical communication skills from students' achievement motivation. In Proceedings of AIP Conference (Vol. 2577, No. 1). AIP Publishing. <https://doi.org/10.1063/5.0093865>.
- Thomas, C., & Hayes, AR (2021). Using exploratory structural equation modelling to investigate the construct validity of the critical thinking disposition scale. *Journal of Psychoeducational Assessment*, 39(5), 640–648. <http://doi.org/10.1177/0734282921990564>.
- Thomas, M. O. J., & Hayes, J. (2021). The role of openness and curiosity in mathematical communication. *Mathematical Thinking and Learning*, 23(2), 123–146. <https://doi.org/10.1080/10986065.2021.1875241>.
- Valeva, S., Vallejo, A., Klimberg, R., Marzano, M., Geritz, A., & Bruening, M. (2025). Gamification of Education Analysis: Craft Beer League's Impact on Student Engagement, Problem-Solving Skills, and Collaboration. *Journal of Statistics and Data Science Education*, (just received), 1-19. <https://doi.org/10.1080/26939169.2025.2475764>.
- Wiafe, I., Ekpezue, AO, Gyamera, GO, Winful, FBP, Atsakpo, ED, Nutropkor, C., & Gulliver, S. (2025). Comparative evaluation of learning technologies using randomized controlled trials: Virtual reality, augmented reality, online video platforms, and traditional classroom learning. *Education and Information Technology*, 1–21.
- Zul'hilmi, BG, & Johnston-Anumonwo, I. (2025). Augmented Reality in Geography Education: Development of an Innovative Digital Module on Indonesian Cultural Diversity. *Future Space: Studies in Geo-Education*, 2 (1), 16-26.

About the Contributor(s)

Sugianto, M.Pd., is a Postgraduate Student in the mathematics department at Universitas Negeri Semarang in Semarang, Indonesia. He is also the founder of the Al-Bahjah Islamic College (STAI) in Cirebon, West Java, Indonesia. His main research interests include education from primary grades to higher education. He endeavors to publish scientific papers in leading international journals and also writes books and chapters on education.

Email: mpdsugianto@students.unnes.ac.id

ORCID: <http://orcid.org/0000-0003-1149-8169>

St. Budi Waluya is a Professor of Mathematics Education (S3) at the Faculty of Mathematics and Science, Universitas Negeri Semarang in Semarang, Indonesia. He is the corresponding author of this article.

Email: s.b.waluya@mail.unnes.ac.id

ORCID: <https://orcid.org/0000-0002-8834-1138>

YL. Sukestiyarno is a Professor of Mathematics Education (S3) at the Faculty of Mathematics and Science, Universitas Negeri Semarang in Semarang, Indonesia.

Email: sukestiyarno@mail.unnes.ac.id

ORCID: <https://orcid.org/0000-0003-2377-5872>

Wardono is a Professor of Mathematics Education (S3) at the Faculty of Mathematics and Science, Universitas Negeri Semarang in Semarang, Indonesia.

Email: wardono@mail.unnes.ac.id

ORCID: <https://orcid.org/0000-0001-6586-9856>

Publisher's Note: *The opinions, statements, and data presented in all publications are solely those of the individual author(s) and contributors and do not reflect the views of Universitepark, EDUPIJ, and/or the editor(s). Universitepark, the Journal, and/or the editor(s) accept no responsibility for any harm or damage to persons or property arising from the use of ideas, methods, instructions, or products mentioned in the content.*
