

Culture as a Mechanism of Mathematical Thinking: Developing a Bilah Panai Culture-Integrated Problem-Based Learning Model

Endi Zunaedy Pasaribu^{1,2}, Zul Amry¹, Edy Surya¹, Mukhtar¹, Edi Syahputra¹, Elmanani Simamora¹, Mesra Wati Ritonga²

¹Universitas Negeri Medan

²Universitas Al Washliyah

Corresponding Author: endipasaribu2@gmail.com

HOW TO CITE:

Endi Zunaedy Pasaribu, Zul Amry, Edy Surya, Mukhtar, Edi Syahputra, Elmanani Simamora, Mesra Wati Ritonga (2026). Culture as a Mechanism of Mathematical Thinking: Developing a Bilah Panai Culture-Integrated Problem-Based Learning Model. International Journal of Special Education, 41(8s), 885-892

COPYRIGHT STATEMENT:

Copyright: © 2026 Authors.
Open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).

ABSTRACT:

Mathematical critical thinking is an essential competency in twenty-first-century mathematics education, yet conventional instruction often fails to develop students' higher-order thinking skills effectively. This study aimed to develop a Bilah Panai Culture-Integrated Problem-Based Learning Model (PBM-BP) that is valid, practical, and effective in enhancing senior high school students' mathematical critical thinking skills. The study employed a research and development approach using the Plomp model, consisting of preliminary investigation, design, realization, testing, evaluation, revision, and implementation phases. The model integrates Bilah Panai cultural practices through *pantun* as a cognitive warming-up strategy and *merisik/telangakai* as a local inquiry process within problem-based learning. Participants were Grade 10 students at a senior high school in North Sumatra, Indonesia. Data were collected through validation sheets, observation sheets, questionnaires, and mathematical critical thinking tests, and analyzed using descriptive and inferential statistics. The results showed that the PBM-BP model met the criteria of validity, practicality, and effectiveness. Expert validation produced content and construct validity scores of 4.02 and 4.40, respectively. The model was perceived as highly practical by teachers and students, while its effectiveness was demonstrated by an increase in students' mathematical critical thinking achievement from 72.22% to 86.11%. The novelty of this study lies in positioning culture as a mechanism of mathematical thinking through *pantun*-based cognitive activation and *merisik/telangakai*-based inquiry, contributing to the advancement of ethnomathematics and culturally responsive mathematics education.

Keywords: Mathematical Critical Thinking; Problem-Based Learning; Bilah Panai Culture; Local Inquiry; Learning Model Development

1. Introduction

The rapid development of science and technology has increased the need for higher-order thinking skills, particularly critical thinking, as an essential competency for twenty-first-century learners. The Organisation for Economic Co-operation and Development (OECD, 2023) emphasizes that students should be able not only to acquire knowledge but also to apply reasoning, problem-solving, and critical evaluation skills in complex situations. If we study mathematics, we will become accustomed to solving various small to large problems, thinking positively, creatively, critically, logically and systematically (Pasaribu, 2020). Consequently, enhancing mathematical critical thinking has become a major goal of contemporary mathematics education.

Mathematical critical thinking enables students to analyze information, evaluate arguments, justify conclusions, and make reasoned decisions. However, recent studies indicate that students' mathematical critical thinking skills remain relatively low. Suryawan et al. (2023) reported difficulties in mathematical reasoning, argumentation, and solution verification, while Permatasari et al. (2024) found that conventional instructional practices tend to emphasize procedural knowledge rather than inquiry and reflection.

Problem-Based Learning (PBL) has been widely recognized as an effective approach for developing critical thinking because it engages students in authentic problem-solving, investigation, collaboration, and reflection (Hmelo-Silver, 2004). Recent studies have confirmed its positive impact on mathematical literacy and critical thinking (Sakdiyah, 2025; Saleh et al., 2022). Nevertheless, conventional PBL implementations often pay limited attention to students' cultural backgrounds, resulting in learning experiences that are less meaningful and contextual.

The ethnomathematics perspective offers a framework for integrating mathematics with culture. Studies have shown that incorporating local cultural knowledge into mathematics instruction can improve conceptual

understanding, motivation, and student engagement (Dhema et al., 2024; Sunzuma & Umbara, 2025). However, most ethnomathematics research focuses on cultural artifacts as learning contexts, while culture is rarely positioned as a mechanism for thinking and inquiry (Iskandar et al., 2022).

To address this gap, this study develops a Bilah Panai Culture-Integrated Problem-Based Learning Model (PBM-BP). The model integrates two Bilah Panai cultural practices: pantun as a cognitive activation strategy and merisik/telangkai as a local inquiry process. Unlike previous studies that use culture primarily as contextual content, PBM-BP positions culture as a mechanism of mathematical thinking through pantun-based cognitive activation and merisik/telangkai-based inquiry activities.

Therefore, this study aims to: (1) develop a Bilah Panai Culture-Integrated Problem-Based Learning Model (PBM-BP); (2) determine its validity, practicality, and effectiveness; and (3) examine its effectiveness in enhancing students' mathematical critical thinking skills.

2. Literature Review

2.1 Mathematical Critical Thinking and Problem-Based Learning

Mathematical critical thinking is an essential competency that enables students to analyze information, evaluate arguments, justify conclusions, and solve complex problems. Facione (1990) conceptualized critical thinking as involving interpretation, analysis, evaluation, inference, explanation, and self-regulation, whereas Ennis (2011) defined it as reflective and reasonable thinking used to determine what to believe or do. Despite its importance, students' mathematical critical thinking skills remain relatively low. Suryati and Maryati (2025) reported difficulties in interpretation, evaluation, and inference, while Suryawan, Sudiarta, and Suharta (2023) identified reasoning and argumentation as the most challenging aspects. Furthermore, Permatasari et al. (2024) found that student-centered learning is more effective than

procedural instruction in promoting critical thinking.

Among student-centered approaches, Problem-Based Learning (PBL) has been widely recognized for fostering higher-order thinking skills. According to Hmelo-Silver (2004), PBL engages students in authentic problem-solving activities involving investigation, collaboration, and reflection. Empirical studies further support its effectiveness. Sakdiyah (2025) reported that ethnomathematics-based PBL improves mathematical literacy and critical thinking, while Saleh et al. (2022) demonstrated that collaborative inquiry within PBL environments promotes reflective thinking and collective decision-making. Therefore, PBL provides a strong pedagogical foundation for developing students' mathematical critical thinking skills.

2.2 Ethnomathematics and Culturally Responsive Mathematics Education

Ethnomathematics, introduced by D'Ambrosio (1985), emphasizes the relationship between mathematics and cultural practices and has become an important framework for culturally responsive mathematics education. Research indicates that integrating local cultural knowledge into mathematics instruction enhances conceptual understanding, learning motivation, and student engagement (Dhema et al., 2024; Sunzuma & Umbara, 2025). Similarly, Gay (2018) and Ladson-Billings (2021) argue that students' cultural experiences should be utilized as valuable educational resources.

However, most ethnomathematics studies focus on cultural artifacts such as traditional architecture, handicrafts, games, and local products. According to Iskandar, Karjanto, Kusumah, and Ihsan (2022), culture is generally positioned as a contextual resource rather than a mechanism for thinking and inquiry. Consequently, the integration of cultural practices directly into instructional processes remains limited.

2.3 Bilah Panai Cultural Practices and the PBM-BP Theoretical Framework

Bilah Panai culture contains practices with significant educational potential, particularly pantun and merisik/telangkai. From the perspective of meaningful learning theory, pantun functions as a cognitive activation strategy by stimulating prior knowledge and encouraging interpretation and meaning construction (Ausubel, 1968). Meanwhile, merisik/telangkai involves information gathering, consultation, discussion, and collective decision-making, reflecting inquiry processes commonly found in PBL. Such collaborative inquiry activities are important for developing critical thinking because they require evidence evaluation, argument construction, and solution justification (Saleh et al., 2022).

The Bilah Panai Culture-Integrated Problem-Based Learning Model (PBM-BP) is grounded in meaningful learning theory, constructivism, sociocultural theory, PBL, and ethnomathematics. Ausubel (1968) supports the use of pantun as a cognitive activation strategy, Piaget (1970) explains knowledge construction through interaction with mathematical problems, and Vygotsky (1978) emphasizes collaborative inquiry through social interaction and collective reasoning. These perspectives are reinforced by Hmelo-Silver's (2004) conception of PBL, which promotes authentic problem investigation to develop higher-order thinking skills.

Although previous studies have demonstrated the effectiveness of both PBL and ethnomathematics, few have integrated local cultural practices directly into the syntax of a learning model. As highlighted by Dhema et al. (2024), Sunzuma and Umbara (2025), and Iskandar et al. (2022), culture is still predominantly used as a contextual resource. Therefore, this study addresses this gap by positioning Bilah Panai culture as a mechanism of mathematical thinking through the integration of pantun as a cognitive activation strategy and merisik/telangkai as a local inquiry process. This constitutes the primary novelty of the PBM-BP

model in supporting students' mathematical critical thinking skills.

3. Methodology

3.1 Research Design

This study employed a Research and Development (R&D) approach using the Plomp development model to develop a Bilah Panai Culture-Integrated Problem-Based Learning Model (PBM-BP) for enhancing students' mathematical critical thinking skills. Following Plomp and Nieveen (2013), the development process consisted of three phases: preliminary investigation, prototyping, and assessment.

The preliminary investigation involved analyzing curriculum requirements, students' mathematical critical thinking skills, and Bilah Panai cultural practices. During the prototyping phase, the PBM-BP model and its supporting learning materials were designed, validated, and revised. The assessment phase focused on evaluating the model's validity, practicality, and effectiveness through classroom implementation. The development process included expert validation, Trial I, revision, and Trial II until a valid, practical, and effective model was obtained.

3.2 Participants

The study was conducted at a senior high school in North Sumatra, Indonesia. Participants included expert validators, mathematics teachers, and Grade 10 students. Expert validators assessed the validity of the model and learning materials, teachers evaluated practicality during implementation, and students participated in field trials to examine the model's effectiveness.

Two classroom trials were conducted. Trial I was used to identify weaknesses and improve the model, whereas Trial II evaluated the effectiveness of the revised version.

3.3 Development of the PBM-BP Model

The PBM-BP model integrates Bilah Panai cultural practices into problem-based mathematics learning. Its instructional syntax consists of five stages: (1) Pantun-Based Cognitive Activation, (2) Problem Orientation

and Organization, (3) Merisik/Telangakai-Based Inquiry, (4) Presentation and Argumentation, and (5) Reflection and Evaluation.

The model was developed based on meaningful learning theory (Ausubel, 1968), constructivism (Piaget, 1970), sociocultural theory (Vygotsky, 1978), Problem-Based Learning (Hmelo-Silver, 2004), and ethnomathematics (D'Ambrosio, 1985).

3.4 Instruments and Data Collection

Data were collected using validation sheets, observation sheets, teacher and student questionnaires, and mathematical critical thinking tests. Validation sheets were used to evaluate the content and construct validity of the model and learning materials. Observation sheets and questionnaires were employed to assess practicality during implementation. The effectiveness of the model was measured through students' mathematical critical thinking tests.

The critical thinking test was developed based on four indicators: identifying and justifying mathematical concepts, generalizing mathematical relationships, analyzing algorithms, and solving mathematical problems.

3.5 Data Analysis

Data analysis focused on three quality criteria: validity, practicality, and effectiveness. Validity was determined through expert judgments on content and construct aspects. Practicality was evaluated based on implementation observations and teacher and student responses. Effectiveness was assessed through students' mathematical critical thinking achievement, mastery learning, and classroom participation.

A model was considered valid if the average validation score was at least 4.00, practical if positive responses reached at least 80%, and effective if classical mastery learning reached at least 85%. Descriptive statistics were used to summarize the data, while comparisons between Trial I and Trial II were conducted to identify improvements in students' mathematical critical thinking skills.

3.6 Success Criteria

The PBM–BP model was considered successful when it met the criteria of validity, practicality, and effectiveness. A model satisfying these criteria was regarded as appropriate for supporting the development of students' mathematical critical thinking skills through culturally responsive mathematics learning.

4. Results

4.1 Development of the PBM–BP Model

The Bilah Panai Culture-Integrated Problem-Based Learning Model (PBM–BP) was developed through the Plomp development model, consisting of preliminary investigation, prototyping, and assessment phases. The resulting model integrates Bilah Panai cultural practices into problem-based mathematics learning through two main components: (1) *pantun* as a cognitive warming-up activity and (2) *merisik/telang kai* as a local inquiry process.

The instructional syntax of the PBM–BP model consists of five stages: (1) *pantun*-based cognitive activation, (2) problem orientation and organization, (3) *merisik/telang kai*-based inquiry, (4) presentation and argumentation, and (5) reflection and evaluation. These stages were specifically designed to facilitate the development of students' mathematical critical thinking skills.

4.2 Validity of the PBM–BP Model

The validity of the PBM–BP model was evaluated by experts in mathematics education, learning models, and instructional design. The evaluation focused on content validity and construct validity.

Table 3. Results of Model Validity Assessment

Aspect	Mean Score	Category
Content Validity	4.02	Valid
Construct Validity	4.40	Very Valid
Average	4.21	Valid

The results indicate that the PBM–BP model fulfilled the validity criteria. The experts agreed that the integration of Bilah Panai cultural practices into problem-based learning was

theoretically appropriate and pedagogically relevant for developing mathematical critical thinking skills.

In addition, supporting learning materials such as lesson plans, student worksheets, teacher guides, and mathematical critical thinking tests were also evaluated and categorized as valid. These findings suggest that both the model and its supporting components possess adequate theoretical and practical foundations for classroom implementation.

4.3 Practicality of the PBM–BP Model

Practicality was evaluated through classroom observations and response questionnaires completed by teachers and students during the implementation process.

Table 4. Practicality Evaluation Results

Aspect	Mean Score	Category
Teacher Response	4.35	Very Practical
Student Response	4.28	Very Practical
Average	4.32	Very Practical

The findings demonstrate that the PBM–BP model was highly practical. Teachers reported that the model was easy to implement and provided clear instructional guidance. Students also expressed positive perceptions regarding classroom activities, collaborative discussions, and the integration of cultural elements into mathematics learning.

Observational data further indicated that all stages of the instructional syntax could be implemented successfully. The *pantun* activity attracted students' attention at the beginning of lessons, while the *merisik/telang kai* stage encouraged active participation during problem investigation.

4.4 Effectiveness of the PBM–BP Model

The effectiveness of the model was determined based on students' mathematical critical thinking achievement and classroom learning activities.

Table 5. Improvement in Mathematical Critical Thinking Skills

Trial	Percentage of Mastery	Category
Trial I	72.22%	Good
Trial II	86.11%	Very Good

The percentage of students achieving mastery increased from 72.22% during Trial I to 86.11% during Trial II. This improvement indicates that revisions implemented after the first trial contributed positively to the effectiveness of the model.

Statistical analysis also revealed a significance value below 0.05, indicating that the improvement in students' mathematical critical thinking skills was statistically significant.

Furthermore, students demonstrated improvements across all critical thinking indicators, including identifying mathematical concepts, generalizing relationships, analyzing algorithms, and solving mathematical problems.

5. Discussion

5.1 PBM–BP as a Culturally Responsive Learning Model

The findings demonstrate that the PBM–BP model successfully integrates cultural practices into mathematics learning while maintaining the core principles of problem-based learning. The validity results indicate that the model is theoretically consistent with constructivist, sociocultural, and ethnomathematical perspectives.

Unlike conventional problem-based learning models, PBM–BP incorporates local cultural practices directly into its instructional syntax. This integration creates learning experiences that are not only cognitively meaningful but also culturally relevant. Consequently, students are able to connect mathematical concepts with familiar cultural experiences, increasing engagement and participation during classroom activities.

These findings support previous studies highlighting the importance of culturally responsive mathematics instruction in promoting

meaningful learning and strengthening students' connections with their cultural identities.

5.2 The Role of Pantun in Cognitive Activation

One of the unique features of the PBM–BP model is the use of pantun as a cognitive warming-up activity. The results indicate that students responded positively to this activity and demonstrated higher levels of engagement during subsequent learning tasks.

From the perspective of Ausubel's meaningful learning theory, pantun functions as an advance organizer that activates students' prior knowledge before formal instruction begins. By interpreting the meaning embedded within the pantun, students engage in cognitive processes such as identification, interpretation, and inference. These processes represent important foundations for mathematical critical thinking.

The findings suggest that pantun contributes not only to cultural preservation but also to the development of higher-order cognitive skills. Therefore, integrating cultural expressions into mathematics learning may provide an effective strategy for preparing students to engage in critical thinking activities.

5.3 Merisik/Telangai as a Local Inquiry Process

The merisik/telangai stage emerged as the most influential component of the PBM–BP model. During this stage, students investigated mathematical problems collaboratively by gathering information, discussing alternatives, evaluating strategies, and constructing solutions.

This process reflects key principles of inquiry-based learning and problem-based learning. According to Hmelo-Silver, inquiry activities encourage students to develop reasoning, problem-solving abilities, and self-directed learning. Similarly, Vygotsky's sociocultural theory emphasizes that cognitive development occurs through social interaction and collaborative meaning-making.

The findings indicate that *merisik/telangkai* provided opportunities for students to engage in critical analysis and collective reasoning. Students were required to justify their ideas, evaluate alternative solutions, and negotiate conclusions through discussion. These activities directly supported the development of mathematical critical thinking skills.

5.4 Culture as a Mechanism of Mathematical Thinking

The most significant contribution of this study lies in demonstrating that culture can function as a mechanism of mathematical thinking rather than merely as a learning context.

Most ethnomathematics studies integrate cultural artifacts, traditional games, architecture, or local products as contextual examples for mathematical concepts. While these approaches enrich learning experiences, culture generally remains external to the thinking process itself.

In contrast, the PBM–BP model integrates cultural practices directly into cognitive and inquiry activities. *Pantun* stimulates interpretation and cognitive activation, whereas *merisik/telangkai* structures collaborative inquiry and reasoning. Consequently, culture becomes embedded within the learning process and supports the development of mathematical critical thinking.

This finding extends current ethnomathematics perspectives by proposing a process-oriented approach to cultural integration. Rather than viewing culture solely as a contextual resource, the present study positions culture as an epistemological and pedagogical mechanism that shapes how students think, reason, and solve mathematical problems.

Therefore, the PBM–BP model contributes both theoretically and practically to the advancement of culturally responsive mathematics education.

6. Conclusion

This study developed and evaluated a Bilah Panai Culture-Integrated Problem-Based Learning Model (PBM–BP) to enhance students'

mathematical critical thinking skills. The findings demonstrated that the model met the criteria of validity, practicality, and effectiveness. Expert validation confirmed that the model possessed strong theoretical and pedagogical foundations, while classroom implementation showed that it was highly practical for both teachers and students. The effectiveness of the model was reflected in the improvement of students' mathematical critical thinking achievement from 72.22% in the first trial to 86.11% in the second trial.

The findings indicate that integrating Bilah Panai cultural practices into problem-based mathematics learning can create meaningful and cognitively engaging learning experiences. The use of *pantun* as a cognitive activation strategy supported students in connecting prior knowledge with new mathematical concepts, whereas *merisik/telangkai* facilitated collaborative inquiry, reasoning, and reflective problem solving.

The main contribution of this study is the extension of current ethnomathematics perspectives by positioning culture not merely as a learning context but as a mechanism of mathematical thinking. Unlike previous studies that primarily employ cultural artifacts as contextual resources, the PBM–BP model integrates cultural practices directly into the learning process through *pantun*-based cognitive activation and *merisik/telangkai*-based inquiry. This finding suggests that culture can serve as an epistemological and pedagogical resource for fostering mathematical critical thinking.

Practically, the PBM–BP model provides an alternative framework for culturally responsive mathematics instruction that may be adapted to other cultural contexts. Future research is recommended to investigate its implementation across different educational levels, mathematical topics, and cultural settings, as well as its impact on other higher-order thinking skills. Overall, the study contributes to the advancement of ethnomathematics, culturally responsive pedagogy, and innovative mathematics education in the twenty-first century.

References

- Ausubel, D. P. (1968). *Educational psychology: A cognitive view*. Holt, Rinehart and Winston.
- D'Ambrosio, U. (1985). Ethnomathematics and its place in the history and pedagogy of mathematics. *For the Learning of Mathematics*, 5(1), 44–48.
- Dhema, M., Cholily, Y. M., & Rahardjanto, A. (2024). Tracing local wisdom in the integration of ethnomathematics in mathematics education: A systematic literature review. *Journal of Mathematics Education*.
- Ennis, R. H. (2011). *The nature of critical thinking: An outline of critical thinking dispositions and abilities*. University of Illinois.
- Facione, P. A. (1990). *Critical thinking: A statement of expert consensus for purposes of educational assessment and instruction*. The Delphi Report.
- Gay, G. (2018). *Culturally responsive teaching: Theory, research, and practice* (3rd ed.). Teachers College Press.
- Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review*, 16(3), 235–266. <https://doi.org/10.1023/B:EDPR.0000034022.16470.f3>
- Iskandar, J., Karjanto, N., Kusumah, Y. S., & Ihsan, H. (2022). Trends and developments in ethnomathematics research: A review of cultural approaches in mathematics education.
- Ladson-Billings, G. (2021). *Culturally relevant pedagogy: Asking a different question*. Teachers College Press.
- OECD. (2023). *PISA 2022 results: The state of learning and equity in education*. OECD Publishing.
- Pasaribu, E. Z., et al. (2020). Pengembangan lembar kerja siswa matematika berbasis model discovery learning terhadap kemampuan pemahaman konsep matematis siswa kelas XI di SMA Negeri 1 Rantau Selatan. *Maju*, 7(2).
- Permatasari, D. A., Nurhayati, N., & Kusuma, A. (2024). The impact of teaching strategies on students' critical thinking in mathematics education: A systematic literature review. *International Journal of Educational Research*.
- Piaget, J. (1970). *Science of education and the psychology of the child*. Viking Press.
- Plomp, T., & Nieveen, N. (2013). *Educational design research*. Netherlands Institute for Curriculum Development (SLO).
- Sakdiyah, S. K. (2025). Implementation of problem-based learning with ethnomathematics to enhance students' mathematical literacy: A systematic review and bibliometric analysis (2020–2025). *Media Pendidikan Matematika*, 13(2), 1104–1117. <https://doi.org/10.33394/mpm.v13i2.18488>
- Saleh, A., Phillips, T. M., Hmelo-Silver, C. E., Glazewski, K. D., Mott, B. W., & Lester, J. C. (2022). A learning analytics approach toward understanding collaborative inquiry in a problem-based learning environment. *British Journal of Educational Technology*, 53(5), 1321–1342.
- Sunzuma, G., & Umbara, U. (2025). Ethnomathematics-based technology in Indonesia: A systematic review. *International Journal of Research in STEM Education*, 4(1). <https://doi.org/10.1177/27527263241305812>
- Suryati, D., & Maryati, I. (2025). Students' mathematical critical thinking skills: Trends, challenges, and future directions in mathematics education. *Journal of Mathematics Learning Research*.
- Suryawan, I. P. P., Sudiarta, I. G. P., & Suharta, I. G. P. (2023). Students' critical thinking skills in solving mathematical problems: A systematic literature review. *Journal on Mathematics Education*.
- Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.