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Integration of ethnomathematics in culturally responsive STEM education to foster computational thinking

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Abstract:
This study aims to describe the implementation of culturally responsive STEM learning integrated with an ethnomathematics approach to enhance students' computational thinking skills. The research employed a descriptive qualitative method and was conducted at SMA Zainul Hasan Genggong, involving 30 tenth-grade students (class X-A) and one mathematics teacher. Data were collected through observation, interviews, documentation, and bibliometric analysis using VOSviewer. The findings indicate that incorporating local cultural elements such as Madurese batik motifs, bamboo weaving, and traditional culinary units created meaningful and contextual learning experiences. Students showed clear progress in key components of computational thinking, including breaking down cultural tasks into smaller mathematical components, identifying geometric and symmetrical patterns in cultural artefacts, and developing structured steps to address practical problems. Both teachers and students responded positively, highlighting increased engagement, motivation, and collaboration during group projects. The teacher reported that students became more active, creative, and critical, while students expressed that learning felt more relevant and enjoyable. Word Cloud visualisation revealed dominant keywords such as culture, mathematics, patterns, symmetry, problem-solving, and collaboration, reflecting the strong connection between cultural contexts and STEM education. Bibliometric analysis further confirmed the interrelation between STEM, computational thinking, and contextual learning. These findings suggest that culturally rooted STEM learning not only enhances conceptual mastery but also fosters systematic, reflective, and creative thinking, positioning it as an effective strategy for addressing the challenges of 21st-century education.

Keywords: Computational Thinking; Contextual; Ethnomathematics; Local Culture; STEM Learning.

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Introduction

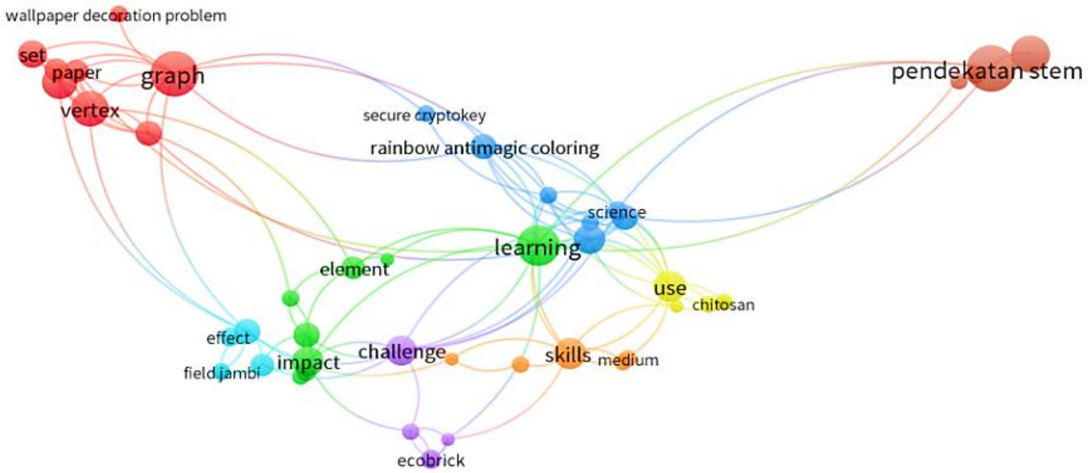
In the rapidly evolving digital era, computational thinking skills have become a crucial competency that extends beyond computer science, serving as an essential foundation for individuals to navigate the complexities of global challenges (Marleny et al., 2023). This ability enables individuals to formulate problems and design effective solutions, both for execution by humans and machines, making it comparable to fundamental literacies such as reading, writing, and arithmetic. Cultivating computational thinking skills not only enhances students' analytical abilities but also equips them with a framework for addressing real-life dilemmas and contradictory situations (Candraningtyas & Khusna, 2023; Hidayat et al., 2020).

Amid rapid global advancement, the need for adaptable human resources who can think logically, analytically, and systematically is increasingly urgent (Fatimah & Purba, 2021). These abilities involve problem-solving through information processing and algorithmic thinking, making them essential across disciplines from STEM fields to social sciences and culture (Lestari & Kurniati, 2025a). Therefore, education must facilitate the integrative development of these skills. The STEM (Science, Technology, Engineering, and Mathematics) approach is widely recognized as an effective framework for strengthening these skills because it enables learners to understand concepts deeply and apply them to complex, real-world problems. Through STEM learning, students develop not only theoretical mastery but also the ability to implement their knowledge in contextual problem-solving situations (Irawan & Tirta, 2023; Lestari & Kurniati, 2025a; Muharromah & Kristiana, 2024).

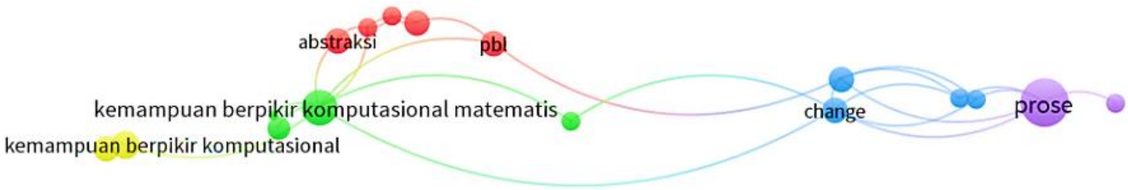
However, the implementation of STEM across various educational contexts often fails to account for learners' social and cultural contexts, resulting in a learning process that is abstract and less relevant to their daily experiences. In fact, contextualizing learning materials to align with the local environment and culture can significantly enhance the relevance and meaningfulness of the learning experience. Ethnomathematics, introduced by D'Ambrosio, refers to mathematical ideas and practices embedded in specific cultural traditions such as number systems, measurements, patterns, and problem-solving techniques transmitted across generations (Mariatul, 2019; Octaviani et al., 2021). Its central premise is that mathematical reasoning is culturally situated, rather than uniform across societies. This perspective makes ethnomathematics highly relevant for contextualising STEM learning, as it connects abstract scientific concepts with students' cultural experiences. When integrated into instruction, ethnomathematical activities provide authentic contexts for exploring patterns, structures, and procedures, thereby supporting the development of computational thinking through culturally meaningful problem-solving.

Previous studies have shown that implementing STEM learning has significant potential to enhance students' computational thinking skills. Through a research-based approach, students can be actively engaged in solving complex problems occurring in their surroundings, such as river erosion, while simultaneously increasing their motivation and engagement in the learning process (Lestari & Kurniati, 2025b). Muharromah et al. (2024) reported that applying Research-Based Learning (RBL) to problem-solving using Convolutional Neural Networks (CNNs) can strengthen students' computational thinking skills through a structured, meaningful learning process.

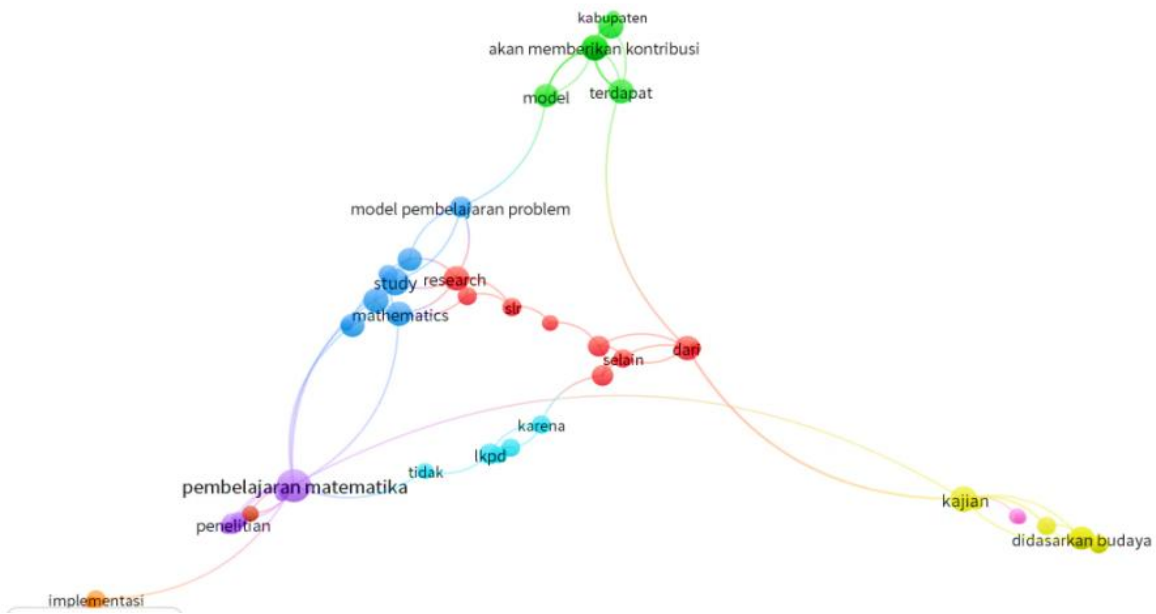
Furthermore, integrating ethnomathematical elements into STEM learning is considered to enrich students' learning context. For instance, through local cultural practices incorporated into learning media such as Papan Gekola, students not only learn mathematical and scientific concepts but also understand the relationship between scientific knowledge and their own cultural practices. It has been proven to improve problem-solving skills while also strengthening the relevance of learning to students' daily lives (Dwi Sari & Setiawan, 2020). In addition, research by Sumardi et al. (2023) showed that STEM learning that utilises cultural contexts, such as batik motifs, not only impacts conceptual understanding but also enhances historical literacy and students' awareness of preserving local cultural heritage.



Picture 1. Visualization Map of STEM Learning Using VOSviewer



Picture 2. Visualization Map of Computational Thinking Skills Using VOSviewer



Picture 3. Visualization Map of Ethnomathematics Using VOSviewer

The three visualisation maps generated by VOSviewer analysis illustrate the thematic relationships among keywords frequently used in research on STEM learning, computational thinking skills, and ethnomathematics. These maps reveal that the topics are interconnected and form clusters that indicate the current directions and focal points of research. The concepts of learning, STEM, and skills are strongly connected within the educational literature, while computational thinking skills are often associated with problem-based learning approaches. On the other hand, ethnomathematics appears within the context of culture-based mathematics learning, highlighting a strong potential to integrate local values into modern teaching approaches.

Although these three topics appear to be interconnected, the direct relationship between ethnomathematics and computational thinking remains relatively weak. It indicates that researchers have not deeply explored the integration of these two concepts within the STEM learning framework. In other words, studies that combine cultural contexts through ethnomathematics with STEM learning to enhance computational thinking skills are still rare. This finding highlights a research gap that can serve as a foundation for further investigation.

Most existing studies have focused on implementing STEM learning tools or producing instructional products. Yet, they rarely examine the cultural responsiveness of STEM learning processes, particularly in the development of students' computational thinking (CT). Research that incorporates cultural elements often prioritises cultural preservation or aesthetic appreciation over examining how local cultural contexts can serve as cognitive resources for fostering higher-order thinking, including CT applicable to real-world problem-solving (Dwi Sari & Setiawan, 2020; Sumardi et al., 2023). Consequently, there remains a clear gap in understanding how culturally grounded STEM learning, particularly through ethnomathematical practices, can be systematically leveraged to strengthen students' CT in complex, meaningful learning situations.

Based on this research gap, the present study aims to examine the implementation of culturally responsive STEM learning integrated with ethnomathematics in a high school mathematics classroom. Specifically, this study focuses on understanding how local cultural elements are incorporated into learning activities and how such integration supports the development of students' computational thinking skills.

Research Method

This study employed a descriptive qualitative approach to provide an in-depth description of the process and implementation of culturally responsive STEM (Science, Technology, Engineering, and Mathematics) learning integrated with ethnomathematics to enhance students' computational thinking skills. This approach was chosen because the study focused on phenomena in the field rather than on developing teaching materials or testing the effectiveness of learning interventions. The research design followed the stages outlined by Miles and Huberman (2014), which include research planning, data collection, data analysis, and conclusion. In the initial stage, a literature review and research trend mapping were conducted using VOSviewer to identify relationships among relevant concepts and topics, thereby providing a strong theoretical understanding while also helping to determine the research focus.

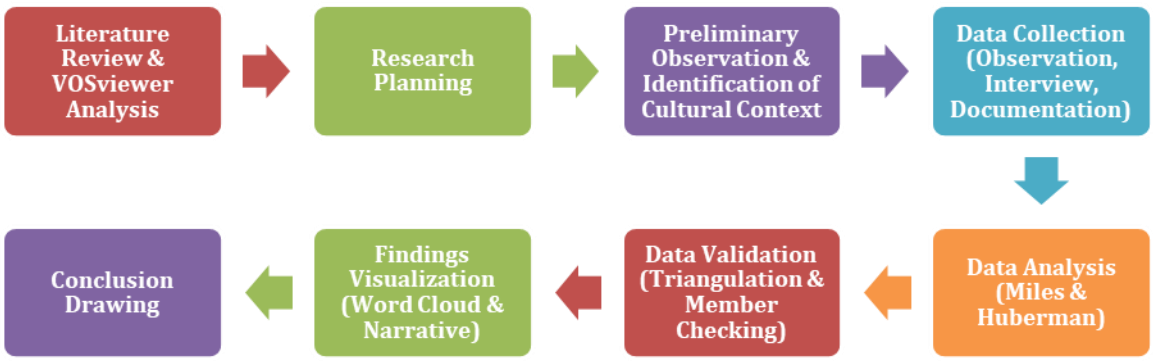
This study was conducted at SMA Zainul Hasan Genggong, Probolinggo Regency, East Java. The research subjects consisted of 30 students from class X-A and one mathematics teacher who acted as the facilitator of culturally based STEM learning. The selection of subjects was based on their involvement in the learning process and their relevance to the research objectives.

Data collection was carried out in several stages. First, participatory observation was used to directly observe the process of STEM learning that integrates local cultural elements, including teacher-student interactions, student engagement levels, and the application of cultural contexts in learning activities. The observations were documented using structured observation sheets and field notes. Second, semi-structured interviews were conducted with the teacher and several selected students to explore perceptions, experiences, challenges, and opportunities in implementing culturally based STEM learning. The interviewed students were selected using purposive sampling based on varying levels of engagement, differences in the demonstration of computational thinking indicators, and their participation in cultural exploration activities, ensuring representation of diverse learning experiences. The interview guidelines were designed to explore students' and teachers' understanding of the relationship between mathematical concepts and local culture, as well as its impact on computational thinking skills. Third, documentation was conducted by collecting teaching materials, lesson records, photographs of activities, and cultural artefacts used during the learning process. Fourth, a literature review using VOSviewer was conducted at the beginning of the study to map research trends related to STEM, ethnomathematics, and computational thinking through keyword co-occurrence analysis of reputable international publications. The results of this visualization strengthened the theoretical foundation and identified a research focus relevant to the local context.

Data analysis in this study followed the interactive model of Miles and Huberman (2014), which consists of three main stages. First, data reduction, which is the process of selecting, simplifying, and focusing on relevant data obtained from observations, interviews, and documentation. The collected data were coded and grouped based on themes such as cultural integration, student participation, and indicators of computational thinking. To ensure analytic transparency, several coding examples were applied. Words such as culture, traditional, batik, and carving were coded as cultural contextualization, forming the category Cultural Integration. Terms such as independently, discussion, and learning were coded as active engagement, which then developed into the category Student Participation.

Meanwhile, words such as patterns, symmetry, formula, and algorithm were coded as conceptual and computational reasoning, forming the category Computational Thinking Indicators. Second, data display was carried out in the form of narratives, matrices, and visualizations such as Word Clouds to help the researcher understand patterns and relationships among the themes. Third, conclusion drawing and verification were conducted by interpreting the analyzed data and verifying it through source triangulation, technique triangulation, and member checking to ensure the accuracy and validity of the research findings.

The success of this research was measured through several qualitative indicators, namely the achievement of local cultural integration in STEM learning by the teacher, the level of active student participation in the learning process, the improvement of computational thinking skills as reflected in problem-solving abilities, pattern recognition, and algorithmic thinking, as well as the students' ability to connect mathematical and scientific concepts with their daily lives. The following Picture presents the research workflow illustrating the implementation steps.



Picture 4. Implementation Steps

Field data analysis was carried out through data reduction, data display, and conclusion drawing, as explained by Miles and Huberman (2014). Data validity was maintained through source triangulation and technique triangulation, as well as member checking to ensure the accuracy of data interpretation. Furthermore, to strengthen the qualitative findings and illustrate the frequency and intensity of key themes emerging from interviews and observations, this study also employed Word Cloud visualization techniques. This visualization was generated using text analysis software to display the words most frequently mentioned by teachers and students, thereby facilitating the identification of keywords that reflect students' cognitive, affective, and psychomotor engagement in culturally based STEM learning.

Results and Discussion

Integration of Local Cultural Context in STEM Learning

Observations and interviews revealed that STEM (Science, Technology, Engineering, and Mathematics) learning at SMA Zainul Hasan Genggong has been implemented by incorporating local cultural practices as relevant ethnomathematical contexts. This strategy is evident in the learning activities designed by teachers, such as exploring symmetrical motifs in Madurese batik, geometric patterns in bamboo weaving, and comparing measurements in the preparation of traditional foods like *dodol* and *apem*. The teacher used this approach to help students better understand mathematical and scientific concepts through contexts that are familiar and tangible in their daily lives. One mathematics teacher stated:

> "*All this time, students felt that mathematics was distant from their lives. But when we started using examples from local culture, they became more enthusiastic and understood better. Batik, weaving, and traditional foods actually hold many mathematical concepts that can be taught.*" – Mathematics Teacher, SMA Zainul Hasan Genggong.

Integrating local culture also provided students with more meaningful learning experiences. They not only learn cognitively but also affectively and psychomotorically, as they were directly involved in observing and exploring their surrounding culture. A student from class X-A shared:

> "*I just realized that Madura batik can be related to symmetry lessons. So, math lessons aren't just about calculations on the board; we can see and try them ourselves.*" – Grade XI Science Student.

The integration of local culture into STEM learning represents ethnomathematical practice, combining academic knowledge with traditional wisdom. It supports a constructivist approach that emphasises the importance of contextual learning experiences. According to Ismail et al. (2023), ethnomathematics expands students' learning spaces and strengthens their cultural identity.

The bibliometric analysis conducted with VOSviewer also supports the relevance of this strategy. The interconnection of keywords such as learning, skills, science, and the STEM approach in the knowledge visualisation map underscores the importance of contextual, meaningful learning in developing 21st-century skills, including critical thinking, problem-solving, and creativity.

Thus, incorporating local cultural contexts not only reinforces STEM learning concepts but also serves as a bridge between cultural heritage and scientific knowledge, while significantly enhancing students' interest and engagement in the learning process.

Enhancement of Computational Thinking Skills

The analysis of students' assignments, observation results, and teacher reflections revealed that STEM learning contextualized with local cultural values successfully enhanced students' computational thinking skills across several key aspects, including problem decomposition, the use of simple algorithms, abstraction, and pattern recognition. This improvement was evident in students' ability to break down cultural problems into mathematical sub-problems, such as calculating material requirements for local crafts or identifying symmetrical and rotational patterns in traditional batik motifs.

Based on interviews and an analysis of students' activity records, four main aspects of computational thinking were identified:

1. Decomposition – Students were able to break down cultural problems into smaller sub-problems, such as identifying geometric elements in batik patterns.
2. Pattern Recognition – Students recognized patterns and structures in cultural artefacts, such as rotational symmetry in traditional motifs.
3. Abstraction – Students began to generalize concepts from cultural contexts into formal mathematical concepts.
4. Algorithmic Thinking – Students designed systematic steps to solve culturally based problems, such as creating an algorithm to calculate the materials needed to produce traditional crafts.

During the learning activities, students were not only asked to solve mathematical problems but also to understand the cultural context behind them. Through group discussions, exploration of local materials, and direct observation of cultural objects, students demonstrated more systematic, structured thinking. This process followed a computational thinking cycle, including understanding the problem, visually representing data, selecting problem-solving strategies, and critically evaluating solutions.

Observation results also indicated that students began to identify smaller components of a cultural problem, such as the step-by-step process for creating local wooden carving patterns, and then structured them into systematic mathematical and algorithmic models. In an interview, one student stated:

> "*In the past, I only memorized formulas, but now I think about why and how those formulas can be applied to real life, like in batik patterns*." — Student.

Meanwhile, the mathematics teacher confirmed that students appeared more active and critical during the lessons:

> "*When I connected mathematics to their surrounding culture, students became more enthusiastic and understood more easily. They even started asking questions on their own.*" — Mathematics Teacher.

These findings are consistent with those of Lestari and Kurniati (2025b) and Muharromah et al. (2024), who showed that implementing the RBL-STEM model strengthens computational thinking skills by engaging students in solving contextual problems closely related to their daily lives.

The use of VOSviewer to analyze supporting literature further reinforced these findings. The visualisation map revealed that keywords such as problem-solving, pattern recognition, critical thinking, and contextual learning are strongly interconnected with computational thinking and STEM education. It indicates that computational thinking in STEM learning is inseparable from critical thinking activities based on real-world contexts, including local culture. These findings highlight that culturally responsive STEM learning with an ethnomathematical approach not only enhances conceptual mastery but also develops systematic, reflective, and creative thinking, which is essential for addressing the challenges of the 21st century.

Teacher and Student Responses to Culturally Responsive STEM Learning

The results of interviews, observations, and questionnaires indicate that STEM learning contextualised within local culture received positive responses from both teachers and students. This approach is seen as an innovative strategy that not only enhances the understanding of mathematical concepts but also fosters a sense of ownership over the learning process.

a. Teacher Responses

In-depth interviews with mathematics teachers revealed that this approach is more flexible and context-specific than conventional methods. Teachers found that integrating local culture into mathematics lessons made students more active and engaged. One teacher stated:

> *"I see that students are much more enthusiastic when mathematics material is connected to things they encounter in their daily lives, such as batik, weaving, and local irrigation systems. They find it easier to understand and don't get bored quickly."*

The teacher also added that project-based activities in this learning model improved students' collaboration and initiative:

> *"Usually, they are passive and just wait for questions from me. But this time, they were more proactive in discussions and even divided group tasks on their own."*

b. Student Responses

Students reported that this approach made it easier for them to understand the material because it was contextual and closely related to their daily lives. They felt more confident and motivated to participate actively in the learning process. One student expressed:

> *"When mathematics is explained through cultural elements like batik or traditional building patterns, I can understand it faster. It's not just numbers, but there's meaning behind it."*

Another student added:

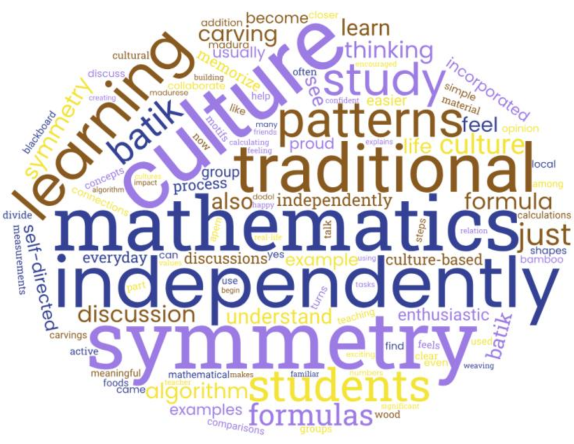
> *"We now discuss more often, and group work becomes more exciting because we talk about our own culture. It's different from the usual lessons where we only solve problems."*

These findings reinforce previous research (Hadiyanto et al., 2020; Jumriani et al., 2021) that emphasises the importance of locally contextualised learning in fostering student engagement. In this context, culturally responsive STEM learning provides students with opportunities to understand mathematics more concretely and meaningfully.

Moreover, this model strengthens 21st-century competencies, such as collaboration through group work in project-based learning, communication through active discussions and cultural project presentations, problem-solving by analyzing real-world issues related to local culture, and creativity in connecting mathematical concepts with cultural heritage. By linking learning to students' cultural identity, this approach not only supports cognitive understanding but also builds affective and social bridges between students, teachers, and the learning environment.

Word Cloud Visualization of Teacher and Student Responses to Culturally Responsive STEM Learning

To visualise the qualitative data from interviews and observations, a Word Cloud was created to identify the most frequently occurring keywords in teacher and student responses regarding the implementation of STEM learning in the local context. This Word Cloud represents the frequency and intensity of the main concepts expressed by the research subjects.



Picture 5. Word Cloud of Teacher and Student Responses to STEM Learning Based on Local Culture

Based on the Word Cloud visualization, words such as culture, learning, mathematics, students, study, patterns, traditional, symmetry, formula, and independently were the most dominant terms identified in the interviews and observations. The prominence of these words indicates that a STEM approach integrating local culture effectively fosters active student engagement in the learning process, as reflected in the frequent use of words such as independently, discussion, and thinking. In addition, words such as culture, traditional, batik, and carving emphasize the importance of a learning experience that is contextual and closely related to students' everyday lives. Mathematics and science concepts such as patterns, symmetry, algorithms, and formulas also stand out, showing that learning remains rooted in systematic scientific structures. Moreover, words such as enthusiasm, experience, and enjoyment reflect students' positive affective and motivational responses to this learning model. Thus, the Word Cloud provides visual evidence that a STEM learning approach grounded in local culture not only strengthens cognitive skills but also fosters deeper emotional and social engagement in students' learning processes.

Discussion

Based on the research findings presented, this study reinforces prior research while offering a new perspective on culturally responsive STEM education through the integration of ethnomathematics. Overall, the results indicate that implementing STEM learning grounded in local culture can enhance students' computational thinking skills, their understanding of mathematical and scientific concepts, and their emotional and social engagement in the learning process.

These findings align with the studies of Lestari and Kurniati (2025b) and Muharromah et al. (2024), which found that the Research-Based Learning (RBL)-STEM model can strengthen computational thinking skills through contextual problem-solving. In this study, students not only understood formulas and abstract concepts but also applied them in real-life contexts, such as Madurese batik patterns, bamboo weaving, and traditional food preparation. It supports the concept of contextual learning discussed by Dwi Sari and Setiawan (2020), who emphasise the importance of learning experiences closely aligned with students' daily lives to increase motivation and active engagement.

Furthermore, these findings are consistent with research by Sumardi et al. (2023), which demonstrated that integrating local culture into STEM learning can enhance cultural literacy and 21st-century skills such as collaboration, creativity, and problem-solving. In this study, culturally grounded learning also strengthened students' critical thinking and algorithmic skills, as evidenced by their abilities in problem decomposition, pattern recognition, abstraction, and algorithm design.

However, this research provides a novel contribution that has not been widely explored in previous studies. While earlier studies primarily focused on developing teaching materials or cultural literacy, this study shows that integrating ethnomathematics into STEM learning can directly improve students' computational thinking skills. It creates a bridge between local cultural values and the mastery of technological and scientific concepts, enabling students to learn not only cognitively but also to internalize cultural meaning throughout the learning process.

Thus, the findings of this research both reinforce existing theories and extend the understanding of the importance of contextual and culturally based learning. These results highlight that culturally responsive STEM learning is not only relevant for enriching cultural literacy but is also strategic for developing computational thinking as a core skill in the digital era. It has direct implications for teachers and educational practitioners in designing meaningful, contextual learning that addresses the challenges of the 21st century.

Although the study's findings resonate with prior research, they also offer a deeper, more critical perspective. While earlier works often emphazise either STEM tools or cultural preservation, this study highlights that local cultural practices can serve as cognitive scaffolding that explicitly foster computational thinking. This insight aligns with the broader discourse in computational thinking and culturally responsive pedagogy. Indeed, Ye et al. (2023), in their systematic review of CT in K-12 mathematics, show that CT-based instruction supports a reciprocal relationship between mathematical and computational reasoning.

Moreover, culturally responsive mathematics instruction is not merely about embedding local contexts for affective engagement; rather, culture can serve as a structural and conceptual resource. Nielsen et al. (2008) argue that culturally responsive pedagogy, viewed through the lens of complexity theory, provides a framework in which culture, cognition, and learning dynamically interact.

Finally, from a theoretical standpoint, this study adds to the emerging dialogue on ethnocomputing where cultural practices are not neutral backgrounds, but computationally rich environments in themselves (Tedre & Sutinen, as discussed in Wikipedia, 2025). This perspective shifts the view of culture in STEM from a passive context to an active computational terrain, underscoring a unique scientific contribution: culturally embedded STEM learning can directly scaffold higher-order thinking rather than serving merely as a motivational add-on.

Conclusion

This study emphasizes that integrating local cultural contexts into STEM education effectively enhances the quality of mathematics and science learning, particularly in developing students' computational thinking skills. By utilising ethnomathematics derived from cultural heritage, such as Madurese batik motifs, bamboo weaving patterns, and traditional food measurement practices, students can understand academic concepts more meaningfully while strengthening their connection to their own cultural values. The findings reveal that culturally responsive STEM learning not only improves conceptual understanding but also fosters essential components of computational thinking, including problem decomposition, pattern recognition, abstraction, and algorithmic thinking. Thus, this approach plays a vital role in preparing students to face 21st-century challenges that demand problem-solving, creativity, and collaboration.

The implications suggest that teachers should develop culturally grounded learning strategies to teach science and mathematics in innovative ways. Instructional. However, this study is limited by its single-region scope and reliance on descriptive qualitative methods, which constrain generalizability and prevent measurement of the magnitude of learning gains. Therefore, future research is recommended to implement cross-regional or cross-cultural studies to compare how different local cultural contexts contribute to STEM learning outcomes.

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