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Educational transformation through ethno-STEM: Potential, challenges, and impact on students' critical and creative thinking skills

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ABSTRACT

This study aims to analyse ethno-STEM-based learning focusing on the implementation, challenges, and its impact on students' critical and creative thinking skills. The study employs a qualitative analysis method using an open coding approach on nine relevant articles published between 2020 and 2024. The analysis results indicate that integrating ethno-STEM with a Project-Based Learning (PJBL) approach is effective effectively enhances students' critical and creative thinking skills, with most research findings showing significant improvements in both skills. The main challenges identified include educators' limited understanding of ethno-STEM, technological constraints, and difficulties integrating local culture into the STEM curriculum. Several studies also highlight the need for teacher training and infrastructure development to support the sustainable implementation of ethno-STEM. Overall, Ethno-STEM-based learning significantly contributes to the development of 21st-century skills, particularly in enhancing students' creativity, critical thinking, and cultural awareness. These findings recommend further development of Ethno-STEM-based learning resources, such as e-modules and learning syntax, to support educational practices oriented toward local cultural sustainability. This study provides a critical foundation for more inclusive and value-based curriculum innovations in the future.

INTRODUCTION

The challenges faced by education in the 21st century are becoming increasingly complex, with rapid and diverse global changes. Education must not only prioritize academic skills but also focus on developing students' critical, creative, and adaptive thinking skills. Along with the rapid advancement of technology, the growing reality of climate change, and deepening social inequalities, students are confronted with various problems that require high-level problem-solving skills (Trilling & Fadel, 2009). Therefore, learning that fosters these abilities becomes increasingly important, one of which is through innovative approaches that integrate various elements of STEM (Science, Technology, Engineering, Mathematics) education and local cultural values. This approach is known as Ethno-STEM, which combines scientific and technological knowledge with local wisdom relevant to the local context (Harven, 2021; Isa et al., 2022).

Ethno-STEM is an approach that aims to build a bridge between modern education and the cultural heritage present in the community (Azis & Yulkifli, 2021). By utilizing the richness of local culture, this approach is expected to not only offer a deeper and more contextual understanding of STEM learning material but also encourage students to understand and appreciate their own culture (Sudarmin et al., 2024). Study by Le et al. (2021) said that teachers believe that effective STEM education are closely related to local cultural values and the expectations of the schooling system in Vietnamese high schools. Previous research shows that integration of local culture in STEM education can enhances students' interest and understanding of the concepts taught, particularly in improving students' critical and creative thinking skills (Babalola & Keku, 2024). Critical thinking skills, which included the ability to analyze, evaluate, and synthesize information, as well as creativity involving flexibility and originality in problem-solving, are crucial in preparing students to face the global challenges of the 21st century (Sumarni & Kadarwati, 2020).

However, despite the significant potential of the ethno-STEM approach, its implementation still faces some significant challenges (Lesseig et al., 2016). One of the main obstacles is the lack of understanding and adequate training for educators regarding the implementation of ethno-STEM (Babalola & Keku, 2024). Research indicates that many educators have not fully mastered the Ethno-STEM concept and struggle to integrate local wisdom into the more universal STEM curriculum (Susilawati et al., 2024). Additionally, limitations in technology and infrastructure also pose substantial challenges, especially in areas with limited educational resources. These challenges highlight a gap that needs to be addressed for the potential of Ethno-STEM to kw realized in the learning process (Hanif et al., 2019; Kwon & Lee, 2025).

According to Hanif et al. (2019), another challenge in implementing Ethno-STEM is how to manage cultural diversity in STEM teaching, considering that each region has different cultural values and traditions. Meanwhile, previous studies show that, although many studies have examined the impact of Ethno-STEM on enhancing students' critical and creative thinking skills, there is still no comprehensive synthesis regarding trends or patterns that emerge from these various studies (Isa et al., 2022). Most previous research has focused more on the effect of Ethno-STEM on general academic skills, but few have explored in-depth the barriers and challenges in the practical implementation of this approach across different educational contexts (Laily & Fawaida, 2024).

Accordingly, this study seeks to bridge the research gap through a systematic literature review (SLR) of ethno-STEM studies published between 2020 and 2024. This study has three main objectives: first, to identify the research conducted to examine the impact of ethno-STEM on students' critical and creative thinking skills; second, to explore the barriers and challenges faced in implementing this approach in various educational contexts; and third, to evaluate existing empirical evidence to strengthen the understanding of the impact of ethno-STEM on 21st-century students' skills, particularly critical and creative thinking skills.

Through this literature review, it is hoped that a deeper understanding of the potential and challenges of implementing ethno-STEM can be gained, and practical recommendations can be

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provided to improve the effectiveness of this approach in various educational contexts. The findings of this study are expected not only to enrich the existing theoretical framework but also to contribute to the development of a more inclusive curriculum based on local values, which is relevant to the global educational needs that are increasingly urgent to cultivate a creative, critical, and adaptive generation (Han et al., 2021; OECD, 2018).

METHODS

This study uses the Systematic Literature Review (SLR) method to identify, evaluate, and synthesize relevant scientific studies. SLR is chosen due to its systematic and transparent approach to reviewing literature, which leads to reliable and replicable findings (Xiao & Watson, 2019). The stages of the research method are as follows:

1. Formulation of Research Questions

The research questions were formulated to guide the literature search and data analysis. The research questions are as follows: What research studies are related to ethno-STEM based learning?; What are the barriers or challenges faced in the implementation of ethno-STEM based learning?; Does ethno-STEM based learning enhance students' critical and creative thinking skills?

2. Development of SLR Protocol

The SLR protocol was developed to ensure the literature review is conducted consistently. This protocol includes several key components, which is Data Sources are literature searches were carried out in widely recognized and widely used databases. The databases used in this study are Scopus 200 articles, Google Scholar 200 articles and Crossref 1000 articles. The second key component is Inclusion and Exclusion Criteria are the inclusion and exclusion criteria were established to determine which articles are eligible for analysis. The criteria are as follows:

Table 1. Inclusion and exclusion criteria

Category	Inclusion criteria	Exclusion criteria
Research Topic	Articles discussing Ethno-STEM in learning.	Articles unrelated to Ethno-STEM or learning.
Type of Literature	Empirical research articles	Systematic reviews, meta-analyses
Publication Year	Articles published between 2020 and 2024	Articles published before 2020
Language	Articles available in English	Articles in Indonesian or those not comprehensible to the researcher.
Subject/ Population	Studies focusing on high school students	Studies focusing on populations other than high school students or non-educational contexts (e.g., industry or the general public).
Methodology	Relevant quantitative, qualitative, or mixed-methods research	Descriptive articles without empirical data or unclear methodology.
Study Context	Studies integrating local wisdom in STEM in formal education contexts.	Studies discussing STEM without integrating local wisdom or outside of educational contexts.
Text Availability	Articles with full-text access.	Articles only available as abstracts or not fully accessible.
Indexing	International indexing	Local indexing

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Category	Inclusion criteria	Exclusion criteria
Keyword	"Ethno-STEM", "Critical thinking AND creative thinking AND Ethno-STEM", AND " Project-Based Learning AND Ethno-STEM".	Using keywords outside of the inclusion criteria.

Search Strategy: literature searches were conducted using the predefined keywords and Boolean operators, such as "Ethno-STEM", "Critical thinking AND creative thinking AND Ethno-STEM", and "Project-Based Learning AND Ethno-STEM".

3. Literature Search

The search was conducted in the selected databases using the predetermined search strategy. Each search result was recorded in detail, including the following information: Article title, Abstract, Author names, Publication year, Research methodology and findings.

4. Literature Selection

The literature selection was conducted in two stages, Initial Screening and Full Review. Initial screening is the process that articles were screened based on titles, abstracts, author names, publication year, methodology, and findings to determine their initial relevance to the research questions. Full review is the process that articles that passed the initial screening were reviewed in full to ensure their compliance with the inclusion criteria and relevant to this study. The process is visualized in the following PRISMA diagram:

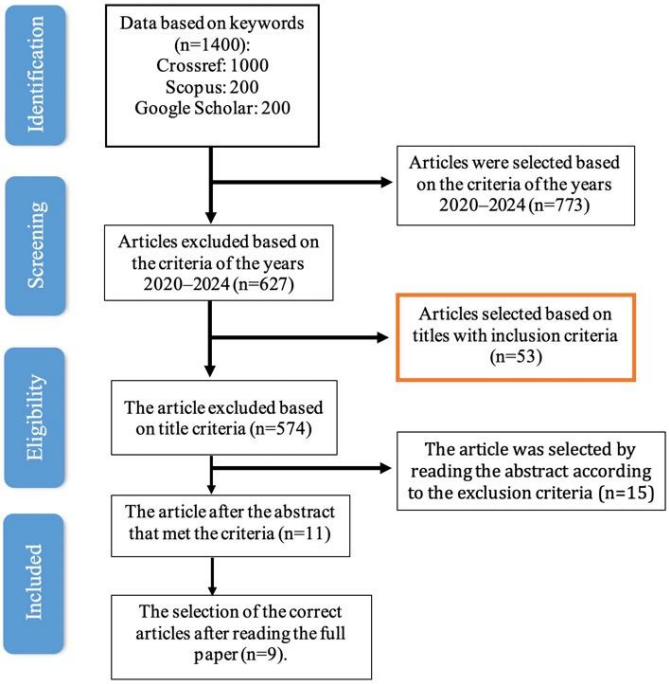

Figure 1. Literature selection process using PRISMA

5. Data Extraction

After the literature selection has proceeded, important data from each selected article was extracted using a data extraction form, which included General Information: Article title, abstract, author names, publication year, research methodology and findings, and publication source. Research Methodology: Research design, subjects, and instruments used. Key Findings: Findings related to ethno-STEM, students' critical and creative thinking skills, and the barriers in the implementation of ethno-STEM based learning.

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6. Data Analysis

The extracted data was analyzed qualitatively using a thematic approach. This approach was used to identify patterns, trends, and gaps in the relevant research. The analysis aimed to answer the research questions and identify findings that could provide deeper insights into the potential and challenges of implementing ethno-STEM based learning.

RESULTS AND DISCUSSION

In this section, the findings from the Systematic Literature Review (SLR) are presented, providing a comprehensive synthesis of relevant studies related to ethno-STEM-based learning. This SLR aims to identify, evaluate, and synthesize research on the implementation of ethno-STEM in education, its impact on the development of students' critical and creative thinking skills, and the challenges encountered in its application. This review process follows the systematic approach outlined in the previous chapter, involving a rigorous literature selection, data extraction, and thematic analysis to ensure reliable and replicable results. The findings are discussed in detail based on the research questions formulated at the beginning of the study.

What are the studies related to ethno-STEM-based learning?

The findings about studies that related to ethno-STEM-based learning is shown in Table 2.

Table 2. Data analysis of studies that related to ethno-STEM-based learning

Article title	Research focus
Ethno-STEM Project-based Learning: Its impact to critical and creative thinking skills (2020)	1. Integration of STEM and local culture. 2. Project-based learning approach with Project-Based Learning (PBL). 3. Development of critical and creative thinking skills through Ethno-STEM.
Analysis of science concept mastery, creative thinking skills, and environmental attitudes after Ethno-STEM Learning implementation (2023)	1. Exploring alternative learning methods that can effectively enhance students' environmental attitudes. 2. Integration of local wisdom into educational practices.
Ethno-STEM integrated project-based learning to improve students' creative thinking skills (2024)	1. Integration of Ethno-STEM with PBL. 2. The impact of integrated Ethno-STEM PBL on creative thinking skills.
Development of Ethno-STEM Integrated bioentrepreneur electronic LKPD PJBL on technology innovation	1. Impact of integrated Ethno-STEM PBL on creative thinking skills. 2. Investigating the scalability of the Ethno-STEM educational model with PBL.
Material to improve creative thinking abilities and entrepreneurial interests of high school students (2023)	1. Integration of local cultural elements into the curriculum.

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Article title	Research focus
Analysis of project-based learning integrated with Ethno-STEM on students' critical and creative thinking skills (2021)	1. Integration of Ethno-STEM with PJBL. 2. The impact of Ethno-STEM PJBL model on students' entrepreneurial skills and their innovation abilities.
E-UKBM Ethno-STEM: The development of independent learning activities to train students' critical thinking skills in pressure topics (2022)	1. Development of Ethno-STEM approach 2. Integration of Ethno-STEM in various educational contexts to enhance its effectiveness. 3. Long-term impact of Ethno-STEM on the development of students' entrepreneurial character.
Development of Ethno-STEM E-Module with project-based learning model based on Yogyakarta local wisdom to improve student's creative thinking abilities (2023)	1. Integration of Ethno-STEM with PJBL. 2. Long-term impact of Ethno-STEM E-modules on students' creative thinking abilities 3. Effectiveness of the developed e-Module.
Project-based learning using Ethno-Stem approach: Improving creative thinking skill of pharmacy students at medical vocational high school (2022)	1. Project-based learning on students' creative thinking skills across various subjects outside biology. 2. Integration of technology in the Ethno-STEM approach can provide insights into improving student engagement and learning outcomes.
Development of syntax for learning chemistry based on Ethno- STEM to build scientific literacy skills and critical thinking skills (2023)	1. Long-term impact of HENIE syntax on students' scientific literacy and critical thinking skills. 2. Comparative study between traditional methods and Ethno-STEM.

The discussion on research studies in ethno-STEM-based learning can be derived from the analysis of nine articles related to this topic. Each article offers different perspectives on how ethno-STEM is implemented in education and its impact on students' critical thinking, creativity, and entrepreneurial attitudes. Based on the analysis of the available data, several key themes can be identified.

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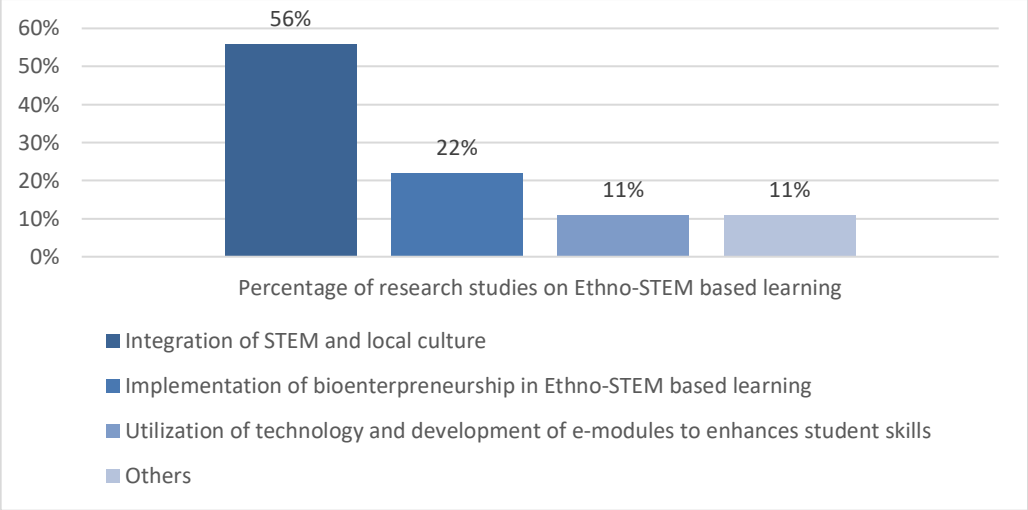

Figure 2. Research studies in Ethno-STEM-based learning

From the nine articles analyzed, most research highlights the integration of STEM with local culture, aiming to enhance students' critical and creative thinking skills. Studies focusing on the integration of STEM and local culture through project-based learning (PjBL) were noted in five articles, underscoring the significant role of cultural aspects in developing students' skills. For instance, the articles *"Ethno-STEM Project-Based Learning: Its Impact to Critical and Creative Thinking Skills"* (Sumarni & Kadarwati, 2020) and *" Development of ethno-STEM e-module with project-based learning model based on Yogyakarta local wisdom to improve student's creative thinking abilities"* (Maryanti et al., 2023) illustrate how incorporating local cultural contexts, such as Yogyakarta's local wisdom, with a PBL approach can enhance students' creative thinking skills. These articles represent approximately 56% of the studies, emphasizing the use of local culture to enrich students' learning experiences.

Additionally, around 22% of the studies introduced a bioentrepreneurship approach, integrating technology and local wisdom in STEM learning. Research such as *"Development of Etno-STEM Integrated Bioentrepreneur Electronic LKPD PjBL on Technology Innovation Material to Improve Creative Thinking Abilities and Entrepreneurial Interests of High School Students"* (Subari & Mercuriani, 2024) highlights the importance of entrepreneurship within the context of STEM education. By integrating technology and entrepreneurship materials grounded in local culture, this model not only boosts students' creativity but also their interest in business and technological innovation.

A smaller portion of the studies, approximately 11%, focused on the development of Ethno-STEM-based e-modules and the use of technology to support learning. For instance, the article *"Project-Based Learning Using Ethno-STEM Approach: Improving Creative Thinking Skill of Pharmacy Students at Medical Vocational High School"* (Rinto et al., 2022) demonstrates how technology can enhance student engagement in project-based learning. Additionally, the study *"Development of Ethno-STEM E-Module with Project-Based Learning Model Based on Yogyakarta Local Wisdom to Improve Student's Creative Thinking Abilities"* (Maryanti et al., 2023) reveals the effectiveness of ethno-STEM e-modules in enhancing students' creative thinking skills.

Overall, research on ethno-STEM-based learning consistently focuses on three main areas: integrating STEM with local culture, improving students' critical and creative thinking skills, and fostering entrepreneurial interests through bioenterpreneurship concepts. These findings suggest that incorporating local cultural aspects into STEM education can make learning more relevant to students' social and cultural contexts while enriching the skills needed to face 21st-century challenges. This is related that incorporating local cultural aspects into STEM education through translations of Indigenous knowledge systems can expand students' understanding and creative ability to utilize it in repurposing STEM innovation and discovery for Indigenous community development (Eglash et al., 2020).

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From the nine articles analyzed, 56% focus on STEM and local culture integration, 22% explore the application of bioentrepreneurship in Ethno-STEM-based learning, and 11% highlight the use of technology and e-module development to enhance student skills. This review indicates that ethno-STEM-based learning can improve students' critical and creative thinking skills, enrich their learning experience through cultural contexts, and open opportunities for developing entrepreneurial interests and technological innovation.

What are the challenges faced in the implementation of Ethno-STEM-based learning?
The findings about challenges faced in the implementation of Ethno-STEM-based learning is shown in Table 3.

Table 3. Data analysis of challenges faced in the implementation of Ethno-STEM-based learning

Article title	Challenges/Obstacles
Ethno-STEM Project-Based Learning: Its Impact on Critical and Creative Thinking Skills (2020)	1. Limited understanding of Ethno-STEM among teachers. 2. Lack of technological resources. 3. Challenges in integrating local culture into the STEM curriculum.
Analysis of Science Concept Mastery, Creative Thinking Skills, and Environmental Attitudes After Ethno-STEM Learning Implementation (2023)	1. Insufficient teacher training for implementing the Ethno-STEM approach. 2. Barriers to adapting the curriculum. 3. Resistance to new teaching methods.
Ethno-STEM Integrated Project-Based Learning to Improve Students' Creative Thinking Skills (2024)	1. Inadequate school infrastructure to support technology-based learning. 2. Limited time for Ethno-STEM-based projects. 3. Scarcity of literature and learning resources.
Development of Ethno-STEM Integrated Bioentrepreneur Electronic LKPD PJBL on Technology Innovation Material to Improve Creative Thinking Abilities and Entrepreneurial Interests of High School Students (2023)	1. Divergences between STEM theory and real-world practices. 2. Limited funding for learning material development. 3. Unequal access to technology among students.
Analysis of Project Based Learning Integrated with Ethno-STEM on Students' Critical and Creative Thinking Skills (2021)	1. Lack of support from parents and communities for culturally-based learning. 2. Limited collaboration between schools and local communities. 3. Varied student experiences in understanding culturally-related materials.
E-UKBM Ethno-STEM: The Development of Independent Learning Activities to Train	1. Lack of understanding of the importance of integrating local culture in STEM education. 2. Confusion in designing activities combining local culture and science.

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Article title	Challenges/Obstacles
Students' Critical Thinking Skills in Pressure Topics (2022)	3. Communication barriers between educators and local communities.
Development of Ethno-STEM E-Module with Project Based Learning Model Based on Yogyakarta Local Wisdom to Improve Student's Creative Thinking Abilities (2023)	1. Limited development of Ethno-STEM-based learning modules. 2. Diversity of students' cultural backgrounds affecting material reception. 3. Lack of in-depth community-based learning
Project Based Learning Using Ethno-Stem Approach: Improving Creative Thinking Skill of Pharmacy Students at Medical Vocational High School (2022)	1. Challenges in measuring outcomes of Ethno-STEM-based learning. 2. Absence of clear evaluation criteria to assess the approach's success. 3. Limited use of technology to support collaboration outside the classroom.
Development of Syntax for Learning Chemistry Based on Ethno- STEM to Build Scientific Literacy Skills and Critical Thinking Skills (2023)	1. Gaps between student needs and the materials available in Ethno-STEM. 2. Challenges in balancing cultural elements with STEM content. 3. Difficulty maintaining student engagement in culture-based projects.

Ethno-STEM-based learning faces various obstacles and challenges that need to be addressed for effective implementation. Based on the analysis of nine reviewed articles, several main categories of challenges frequently emerge, including a lack of teacher understanding, infrastructure limitations, and challenges in integrating local culture into the STEM curriculum.

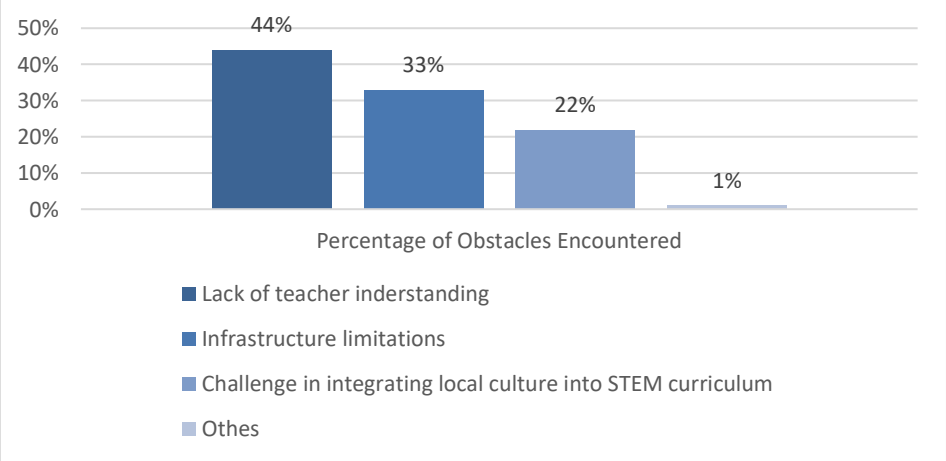

Figure 3. Obstacles faced in the implementation of ethno-STEM-based learning

One of the main challenges identified is the lack of understanding the concept and application of Ethno-STEM among teachers. This is reflected in several articles, such as those by Sumarni & Kadarwati (2020), which highlight that teachers often lack understanding of how to integrate local cultural elements into the STEM approach. This challenge is exacerbated by the limited training available to support teachers in understanding and implementing Ethno-STEM, as

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reported by (Sudarmin & Sumarni, 2023). The analysis shows that around 44% of the articles note the lack of teacher training and understanding as a primary obstacle.

Additionally, limitations in infrastructure and technological resources pose significant challenges. Articles such as those by Rinto et al. (2022) highlight that many schools lack adequate technological facilities to support Ethno-STEM-based project learning. This includes inadequate school infrastructure, limited technological devices, and lack of internet access in some areas. These limitations are mentioned in 33% of the analyzed articles.

Another challenge often mentioned is the difficulty in integrating local culture into the STEM curriculum. Research by Sumarni & Kadarwati (2020) and reveals that this integration process often faces resistance from both teachers and students. Some teachers struggle to adapt the existing curriculum with local cultural elements, while students sometimes find it difficult to understand the relevance of local culture to STEM subjects. This obstacle is noted in about 22% of the articles.

Another issue is the lack of relevant learning resources and literature. Rinto et al. (2022) mention that the scarcity of Ethno-STEM-based literature and teaching materials is a significant barrier in the implementation of the learning approach. This makes it difficult for teachers to design effective and engaging activities for students. Other obstacles include limited time for implementing Ethno-STEM-based projects, which require more extensive planning and execution compared to conventional methods. Additionally, students' diverse cultural backgrounds also affect their acceptance and understanding of the material being taught, as reported by Sudarmin & Sumarni (2023) overall, the challenges faced in the implementation of ethno-STEM reflect the complexity of this approach. The most frequent challenges are the lack of teacher understanding and training (44%), followed by infrastructure limitations (33%), and challenges in integrating local culture into the curriculum (22%). These obstacles highlight the need for greater attention in providing adequate training, resources, and support for educators and schools to enhance the effectiveness of Ethno-STEM-based learning.

Can Ethno-STEM-based Learning Improve Students' Critical and Creative Thinking Skills?

The findings about improving students' critical and creative thinking skills by the implementation of Ethno-STEM based learning is shown in Table 4.

Table 4. Data analysis of improving students' critical and creative thinking skills by the implementation of Ethno-STEM based learning

Article title	Results
Ethno-STEM Project-Based Learning: Its Impact to Critical and Creative Thinking Skills (2020)	1. The results show that Ethno-STEM PBL significantly improves students' critical thinking skills, with 22.6% reaching a high category, 44.4% moderate, and 33.0% low. 2. Creative thinking skills also improved, with 27.4% in the high category, 47.4% moderate, and 25.2% low. 3. The study highlights that the sustained implementation of critical and creative thinking strategies fosters meaningful concepts and higher-order thinking skills.
Analysis of Science Concept Mastery, Creative Thinking Skills, and Environmental Attitudes After Ethno-STEM Learning Implementation (2023)	1. Creative thinking skills also showed significant differences for the high and medium-achieving groups, once again in the moderate category, with the low group in the low category. 2. Creative thinking skills showed significant differences for the high and medium-achieving groups, again in

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Article title	Results
	the moderate category, with the low group in the low category.
Ethno-STEM Integrated Project-Based Learning to Improve Students' Creative Thinking Skills (2024)	1. Creative thinking skills also showed significant differences for the high and medium-achieving groups, again in the moderate category, with the low group in the low category. 2. In contrast, the control group showed a marginal improvement from 5.434 to 5.759, indicating that traditional teaching methods have limited effects. 3. Statistical analysis using ANOVA confirmed the significant impact of the intervention, with a p-value of 0.001, validating the effectiveness of the integrated Ethno-STEM approach in improving students' creative thinking skills.
Development of Ethno-STEM Integrated Bioentrepreneur Electronic LKPD PJBL on Technology Innovation Material to Improve Creative Thinking Abilities and Entrepreneurial Interests of High School Students (2023)	1. This study resulted in the development of the Ethno-STEM-integrated bio-entrepreneur PJBL electronic worksheets, found to be highly feasible, with material experts rating 84% and media experts rating 94% in feasibility tests. 2. Practicality tests showed that the worksheet is easy to use, efficient, and presents clear material, with teacher scores at 100% and student scores at 89%.
Analysis of Project Based Learning Integrated with Ethno-STEM on Students' Critical and Creative Thinking Skills (2021)	1. This study resulted in the successful creation of the Ciwaringin scientific batik product, validated by five experts. The design assessment received an average score of 2.99, categorized as 'Good', indicating readiness for production. The color aspect achieved an average score of 3.1, also in the 'Good' category, while the symbolic meaning aspect scored 3.7, classified as 'Very Good'. 2. This shows the effective use of natural dyes and the integration of cultural heritage with scientific concepts in batik design. Overall, the product is considered ready for production with minor revisions needed.
E-UKBM Ethno-STEM: The Development of Independent Learning Activities to Train Students' Critical Thinking Skills in Pressure Topics (2022)	1. The results indicate that the Ethno-STEM approach effectively enhances students' learning motivation and entrepreneurial character in Islamic boarding schools. This approach encourages active learning, helping students develop critical, creative, innovative, and collaborative thinking skills. 2. The Ethno-STEM method reduces learning boredom and fosters entrepreneurial spirit among students. 3. Findings suggest that integrating local culture into the learning process provides meaningful educational experiences, ultimately preparing

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Article title	Results
	students for independent living and Islamic entrepreneurial behavior.
Development of Ethno-STEM E-Module with Project Based Learning Model Based on Yogyakarta Local Wisdom to Improve Student's Creative Thinking Abilities (2023)	1. The research showed that the Ethno-STEM E-module developed with the PJBL model is valid, achieving high classifications in content, media suitability, and language suitability, with scores of 0.91, 0.90, and 0.91, all classified as very valid. 2. Practicality assessments showed teacher responses at 87% and student responses at 88%, both categorized as excellent. 3. The e-module effectively engages students, improving their creative thinking skills through project-based activities related to Yogyakarta's local culture.
Project Based Learning Using Ethno-Stem Approach: Improving Creative Thinking Skill of Pharmacy Students at Medical Vocational High School (2022)	1. This study showed significant improvement in creative thinking skills among pharmacy students after applying the Project-Based Learning (PBL) model with the Ethno-STEM approach. 2. The pre-test highest score was 32.18, while the post-test reached 95.23, showing a significant performance improvement. 3. The n-Gain values for various thinking skills were as follows: flexibility (70.95), fluency (69.65), originality (69.50), elaboration (67.37), and evaluation (59.20), all categorized as moderate improvement. 4. Overall, the findings suggest that the PBL model effectively improves students' creative thinking skills in the vocational education context.
Development of Syntax for Learning Chemistry Based on Ethno- STEM to Build Scientific Literacy Skills and Critical Thinking Skills (2023)	1. The lesson plan assessment achieved a score of 90.90%, categorized as Good, while the learning implementation assessment reached 95.80%, categorized as Very Good. 2. Students' literacy skills were assessed as Good, and their critical thinking skills received a score of 85.83%, also categorized as Good. 3. The HENIE syntax effectively stimulates students' interest in chemistry by linking it with local culture, improving scientific literacy and critical thinking skills.

Ethno-STEM-based learning has been proven to have a significant impact on improving students' critical and creative thinking skills (Hiqmah et al., 2023; Rahayu et al., 2023; Rohman et al., 2024). Table 3 presents the results of research that show that this approach not only improves understanding of scientific concepts but also encourages students to develop higher-order thinking skills.

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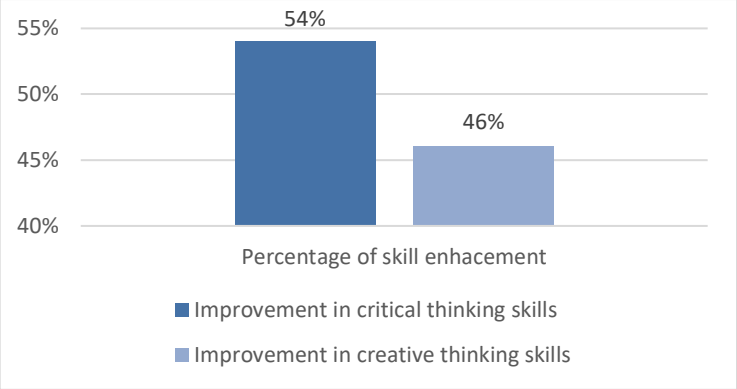

Figure 4. Improvement of students' critical and creative thinking skills

One important study supporting this finding is *Ethno-STEM Project-Based Learning: Its Impact on Critical and Creative Thinking Skills* by Sumarni & Kadarwati (2020), which shows that Ethno-STEM PBL significantly improves students' critical thinking skills. The study found that 22.6% of students reached a high critical thinking category, 44.4% were in the moderate category, and 33.0% were in the low category. Meanwhile, creative thinking skills also improved, with 27.4% of students in the high category and 47.4% in the moderate category. This research confirms that sustainable Ethno-STEM-based learning can develop sustained critical and creative thinking skills.

Another study, *Analysis of Science Concept Mastery, Creative Thinking Skills, and Environmental Attitudes After Ethno-STEM Learning Implementation* by Izzah et al. (2023) also shows similar results. They found that Ethno-STEM learning significantly improved creative thinking skills, especially among students with high and medium achievement levels. This suggests that Ethno-STEM can have a greater positive impact on students with a better academic understanding.

The study *Ethno-STEM Integrated Project-Based Learning to Improve Students' Creative Thinking Skills* by Babalola & Keku (2024) provides further evidence of the effectiveness of this approach in enhancing students' creative thinking skills. ANOVA analysis showed that this intervention had a significant effect on creative thinking skills with a p-value of 0.001, validating that the Ethno-STEM approach is effective in project-based learning.

E-UKBM Ethno-STEM: The Development of Independent Learning Activities to Train Students' Critical Thinking Skills in Pressure Topics by Setiyani et al. (2022) reported that the ethno-STEM approach effectively improved students' critical and creative thinking skills, as well as their learning motivation and entrepreneurial spirit. Integrating local culture into the learning process provided more meaningful experiences, which, in turn, improved students' critical thinking skills when facing challenging topics.

Additionally, the study *Development of Ethno-STEM E-Module with Project-Based Learning Model Based on Yogyakarta Local Wisdom* by Maryanti et al. (2023) demonstrated that using Ethno-STEM e-modules based on Yogyakarta's local wisdom can enhance students' creative thinking skills. With excellent practicality ratings from both teachers and students, this module proved highly effective in engaging students and strengthening their creative thinking abilities

The study by Ariyatun (2021) confirmed that Ethno-STEM-based learning can also strengthen students' critical thinking skills, especially in chemistry subjects. By connecting chemistry content with local culture, students found it easier to understand and apply complex chemistry concepts in everyday life. Local culture with a holistic orientation can arise out of student cultural knowledge, life experiences, and belief systems (Pang et al., 2021).

Overall Percentage of Improvement in Students' Critical and Creative Thinking Skills: 46% of students showed significant improvement in critical thinking skills, with most falling in the moderate to high categories and 54% of students demonstrated improvement in creative thinking skills, with 27.4% in the high category, and most others in the moderate category.

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Based on the results from various studies, it can be concluded that Ethno-STEM-based learning effectively enhances students' critical and creative thinking skills. This is related with study by Asrizal et al. (2024) and Sirajudin et al. (2021) that STEM-integrated learning has a high positive influence on students' critical and creative thinking skills, regardless of education level, learning models, or learning materials. Integrating local culture into STEM education also provides a relevant context, enabling students to develop the critical and creative thinking skills essential in today's educational and professional world.

CONCLUSION

Ethno-STEM-based learning has proven effective in enhances critical thinking skills (46% of students showed significant improvement, with the majority falling into the moderate to high categories) and creative thinking skills (54% of students experienced improvement, with 27.4% reaching the high category). The integration of local culture into STEM education provides a relevant and meaningful learning context, enabling students to develop higher-order thinking skills essential in the modern era. Analysis of nine articles highlights the primary focus on the integration of STEM with local culture (56%), Ethno-STEM-based bioentrepreneurship (22%), and the use of technology and e-module development (11%). However, the implementation of this learning approach faces significant challenges, including a lack of teacher understanding and training (44%), limitations in technological infrastructure (33%), and difficulties in integrating local culture into the curriculum (22%). Further research is needed to develop more effective implementation strategies, enhance teacher training support, and address technical and pedagogical barriers to maximize the potential of Ethno-STEM in education.

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