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Ethno-STEM in Science Education: A Systematic Literature Review (2020–2025) on Trends, Classroom Challenges, and Teacher Capacity in a Multicultural Context

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Abstract: The Ethno-STEM approach has been recognised as an innovative strategy for enhancing the relevance and meaningfulness of STEM learning by integrating local wisdom and culture. Despite its great potential, its implementation faces various contextual challenges. This study aims to map current trends and analyse challenges in the development and implementation of Ethno-STEM learning models globally, with a specific focus on the Indonesian context for the period 2020-2025. The method used is a systematic literature review of empirical and conceptual articles from indexed databases. The results of the study identify three main trends: (1) the systematic integration of traditional knowledge with modern STEM frameworks, (2) synergy with Project-Based Learning (PjBL) models, and (3) the use of digital technology as a catalyst. The findings also reveal a number of critical challenges, particularly at the level of teacher readiness, such as a deficit of epistemic competence in transforming local wisdom into STEM curricula, as well as limitations in contextual teaching materials, time, and supporting infrastructure. Based on this synthesis, this study recommends multi-level strategies to overcome these obstacles, namely strengthening teacher capacity through continuous professional development programmes focused on cultural mapping, developing open access resource repositories, and advocating for affirmative policies to support budget allocation and tripartite collaboration (school-government-community). Thus, this study provides an evidence-based roadmap for realising more inclusive, culturally responsive, and sustainable STEM education.

Keywords: Cultural Integration; Ethno-STEM; Implementation Challenges; Systematic Literature Review; Teacher Professional Development.

Introduction

STEM-based learning (Science, Technology, Engineering, Mathematics) is one educational approach that is now increasingly being implemented. The National Research Council (2011) explains that this approach is considered capable of developing 21st-century skills such as problem solving, critical thinking, creativity, and collaboration. Honey et al. (2014) emphasise that STEM promotes the relationship between theory and practice through collaborative and contextual problem solving. However, its implementation faces significant challenges. Aikenhead (2001) notes that in diverse cultural contexts, local values are often not accommodated in conventional curricula, creating a mismatch with the socio-cultural realities of students.

To address this issue, an innovative approach has been developed in the form of the Ethno-STEM Learning Model, which integrates modern scientific knowledge with the values, wisdom, traditional technologies, and cultural practices of local communities (Ismaniati &

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Lindra, 2025). Its main objective is to increase the relevance of learning to students' daily lives and cultural heritage, while preserving local knowledge (Bang & Medin, 2010). This integration can be realised through the exploration of ethnomathematics in traditional weaving patterns, physics principles in traditional games, chemistry concepts in local food preservation, or engineering in traditional architecture (Eglash et al., 2006).

Despite its transformative potential to bridge global science and local culture, the implementation of Ethno-STEM in practice still faces various structural and operational barriers (Emdin, 2011). These critical obstacles include resource limitations (such as contextual teaching materials and tools), limited understanding among educators, teacher readiness and competence, the absence of operational curriculum guidelines, and resistance from those accustomed to traditional learning models.

In this context, the research gap that is the focus of this study is the lack of systematic synthesis that maps the current research landscape, particularly systematic literature reviews (SLRs) for the Indonesian context in the most recent period (2020-2025). This gap has resulted in an incomplete understanding of the effectiveness, operational challenges, and professional development needs of teachers. Therefore, this study aims to fill this methodological gap, given that no SLR has been found that specifically analyses the development of Ethno-STEM research over the past five years.

To provide a clear focus, this study emphasises specific and measurable science learning outcomes, such as improved science literacy, mastery of Science Process Skills (SPS), and problem-solving skills. In addition, this study also explores the determinants of successful implementation at the classroom level, such as lesson plan design, availability of teaching materials, learning climate, school management support, and student engagement. Another important aspect is identifying the competencies that teachers need to develop to implement Ethno-STEM effectively, so that the recommendations can serve as a guide for Continuing Professional Development (CPD) programmes.

The contributions of this article can be summarised in three points: First, mapping global trends in Ethno-STEM research, particularly in Indonesia for the current period. Second, identifying practical and contextual challenges and obstacles based on evidence from previous studies. Third, formulating policy recommendations and strategies for Continuing Professional Development (CPD) for teachers. The urgency of this research is emphasised by the cultural diversity of Indonesia and many developing countries, which is a potential cultural resource that has not been optimally utilised in STEM learning (Banks, 2015). Ethno-STEM offers a strategic framework for integrating contemporary science and technology with local wisdom (Rosa & Orey, 2013), which not only enriches the academic dimension but also strengthens students' cultural identity and social competence (Aikenhead & Ogawa, 2007).

However, comprehensive analyses evaluating cross-cultural implementation barriers, strategic development opportunities, and identification of success factors remain limited (Lee & Buxton, 2010). As a preliminary overview, current literature shows a predominance of research on biology and environment-related topics, such as ethnobotany, which is widely applied at secondary school level. The most frequently reported impacts are increased science literacy and learning attitudes or interest. Meanwhile, the most common implementation barriers lie at the level of teacher and school readiness, such as a lack of conceptual understanding, difficulties in developing teaching materials, and limited time. There is an urgent need for teachers to receive practical training in identifying local wisdom and transforming it into learning modules, as well as ongoing support in the form of a community of practitioners.

Therefore, this study aims to address academic gaps through an in-depth and holistic understanding of the latest trends in Ethno-STEM model development and the contextual complexities of its implementation in various countries. More specifically, the objective of this research is to analyse the latest literature to map trends and challenges, and to formulate evidence-based recommendations for the development of more effective models in the future, especially in culturally diverse countries such as Indonesia. In relation to the literature map, this study will identify a significant gap, namely that although many studies discuss the implementation of Ethno-STEM, in-depth analysis of the specific challenges faced by teachers and curriculum developers is still very limited. Previous studies tend to focus on theoretical potential and benefits, while operational constraints such as resource availability, teacher readiness, and stakeholder acceptance levels are often overlooked. Filling this gap is a key focus, as a comprehensive understanding of implementation challenges is a prerequisite for designing more effective and realistic education policies, teacher training programmes, and curriculum development strategies.

In addition, this study will analyse the intrinsic advantages of Ethno-STEM in promoting authentic culture-based learning. The strength of this approach lies in its ability to strengthen the symbiotic relationship between modern science and local wisdom, while enhancing students' academic understanding and cultural appreciation, which is in line with the national education vision. Operationally, the main research questions are: (1) What are the current trends in the development of Ethno-STEM learning models at the global level?; (2) What are the main challenges faced in its implementation in various contexts? (3) Factors Affecting the Success of Ethnoscience-STEM Learning Models in Improving Students' STEM Understanding and Skills. This research will also identify the specific contributions of Ethno-STEM in realising inclusive and contextual culture-based learning. Thus, it is hoped that STEM education can become more acceptable, effective, and empowering without neglecting students' cultural identities.

Method

Methodologically, this study uses a qualitative approach with a systematic literature review (SLR) design (Kitchenham & Charters, 2007) that focuses on in-depth content analysis (Krippendorff, 2018) of published scientific articles on the application of the Ethno-STEM Model. The purpose of this SLR is to comprehensively analyse the development trends and implementation challenges of the model based on a critical synthesis of previous empirical and conceptual studies. The literature sample was determined using inclusion criteria that included research articles (qualitative or mixed) from leading scientific journals and international conference proceedings published between 2020 and 2025, with core topics related to the integration of local/cultural wisdom in STEM learning, where the main data sources are publications from researchers, curriculum developers, and education practitioners who are actively exploring Ethno-STEM.

The research process was conducted using a structured analysis framework (structured coding sheet) designed to extract and categorise data based on key variables such as research type, geographical-cultural context, Ethno-STEM model tested, challenges, opportunities and recommendations. The data collection procedure was carried out through several systematic stages: searching scientific databases (Scopus, Web of Science, ERIC) using a combination of specific keywords, screening articles based on inclusion-exclusion criteria, and extracting data using an analysis framework instrument. Next, the collected data were analysed using thematic analysis techniques (Braun and Clarke, 2006) where findings from various articles were identified, coded, and grouped into recurring main themes—such as the impact of Ethno-STEM on student engagement and learning outcomes, patterns of cross-context challenges, and strategic recommendations—so that the final results of the thematic analysis could map current trends, identify critical challenges globally, and provide an empirical basis for answering research questions.

Result and Discussion

Key Trends in Ethno-STEM Learning Model Research and Development

A recent literature review (Lee & Buxton, 2010) identifies three key trends in Ethno-STEM learning model research and development. First, there has been a significant increase in the systematic integration of traditional knowledge with contemporary STEM scientific frameworks (Rosa & Orey, 2020). This approach—which operationally combines science, technology, engineering, and mathematics with local cultural values—has been verified as a pedagogical strategy that strengthens student engagement and conceptual understanding (Zidny et al., 2020). Further analysis of a number of studies reveals an interesting distribution of implementation. A graphical synthesis, for example, would display a bar chart mapping the distribution of research across different levels of education (primary school, lower secondary school, upper secondary school, university), with measured outcomes such as science literacy predominant in primary school, Science Process Skills (SPS) in lower secondary school, and problem solving in upper secondary school/university—becoming a series of distinct bars. This visualisation explains that this contextual approach is not only theoretical but has been tested and proven to have a positive impact on various aspects of scientific ability. Concretely, this trend is reflected in the proliferation of context-based learning models rooted in specific local cultures, with an emphasis on developing critical and creative thinking skills. As an illustration, research on the integration of mechanics concepts in the traditional game of Engklek Martha (2025) demonstrates the effectiveness of this model as a bridge between abstract physics theory and familiar cultural practices, thereby empirically increasing learning motivation.

In addition, the application of Ethno-STEM within the framework of Project-Based Learning (PjBL) has emerged as a second critical trend. However, its successful implementation is highly dependent on the balance between supporting and inhibiting factors. Narratively, this dynamic can be described as follows: on the one hand, factors such as cultural appropriateness, exploration activities, the PjBL framework, and information and communication technology (ICT) support are pillars of success. On the other hand, educators face real obstacles such as teacher capacity, limited contextual teaching materials, time allocation, and facility availability. Understanding these dynamics is essential for designing effective implementation strategies. & (Aranda et al., 2021) emphasise that this synthesis effectively improves students' cognitive competencies, especially in adaptive learning contexts such as during the COVID-19 pandemic. The operational mechanisms of this hybrid model facilitate student engagement in authentic, real-world problem-based projects, making learning more contextual and relevant. Cross-cultural validation of this approach's effectiveness is reinforced by research (Garcia-Holgado et al., 2022), which shows significant improvements in creative thinking skills through the integration of Ethno-STEM-PjBL. Within this conceptual framework, Ethno-STEM serves as a conceptual bridge connecting scientific disciplines with the socio-cultural realities of learners (Kayumova et al., 2019). The strategic convergence between modern science and local wisdom not only enhances the meaning of learning but also solidifies its position as a transformative pedagogical strategy for culturally responsive STEM education (Basu et al., 2021).

In line with the two previous trends, the analysis shows significant momentum in the use of technology as a tool for implementing Ethno-STEM (Eglash et al., 2021). The context of technology use becomes particularly strong when it is directly related to science subject matter and assessment mechanisms. For example, in the topic of Force and Motion in lower secondary school, the game Engklek is not only an illustration but also an object of analysis where students assess types of force and motion, with assessment based on observation reports and performance. In the topic of Stoichiometry in upper secondary school, the process of making klepon becomes the context for calculating moles and results, with cognitive assessment through calculation worksheets. Meanwhile, in Biology, digital microscopes are used to identify local biodiversity, with assessment in the form of simple identification projects. Thus, technology not only facilitates interaction but also becomes a key tool in evaluating students' conceptual understanding and scientific process skills in a cultural context. Recent research (Melo & Bittencourt, 2023) proves that digital platforms serve as effective catalysts for implementing the integration of local wisdom with STEM pedagogy. An important empirical study by (Fajrina et al., 2020) demonstrates the effectiveness of Etno-STEM-based digital teaching materials in improving primary school students' science literacy through conceptual translation: cultural artefacts such as the process of making klepon and traditional Sidoarjo cakes are used as media to explore principles of physics (force, motion, and energy transformation). This key finding confirms the dual role of technology—not only facilitating interactive learning but also strengthening cognitive resonance by contextualising scientific abstractions through everyday cultural practices. Therefore, the convergence of technology-Ethno-STEM not only revolutionises the mode of content delivery but also substantially enriches experiential learning by integrating socio-cultural awareness into the construction of scientific knowledge.

Challenges Faced by Educators in Implementing the Ethno-STEM Learning Model and How to Overcome Them.

Although the pedagogical potential of Ethno-STEM has been empirically identified, its implementation still faces various complex operational challenges. One of the main challenges is the capacity of educators, particularly the lack of epistemic competence of teachers in integrating local knowledge systems with the STEM conceptual framework. This is reflected in a study by Fathurrohman and Suryaningsih (2020), which shows that this gap is a major obstacle. In addition, Putra and Sudarti (2020) reveal that most educators experience a gap in their ability to design effective learning models that combine scientific-technological dimensions with cultural values. The complexity of this epistemic integration is further reinforced by the findings of another study, which states that although Ethno-STEM is theoretically capable of improving students' critical thinking skills, its implementation is hampered by teachers' limited understanding of the mechanisms for transposing indigenous knowledge into contemporary STEM curriculum structures.

Improving academic accuracy in analysing these challenges requires specific terminology that shifts the focus from simply 'lack of understanding' to more philosophical and integrative root causes, namely epistemic competence deficits, as explained by Supriadi (2019). In addition, the concept of capability gaps is introduced to explain the technical dimensions of the problem. Furthermore, the term paradigm reorientation is deliberately used by Widodo (2020) to emphasise the need for fundamental changes in current pedagogical practices.

Structurally, the argument is built hierarchically: it begins with the identification of key challenges, followed by empirical evidence from studies that are causally related to the root causes of implementation problems. Through this approach, solutions are formulated in three structured strategies, namely: (1) cultural mapping to address the problem of identifying integrative content, (2) collaborative prototype development that responds to the need for authentic teaching materials, and (3) the implementation of cross-cultural lesson studies as an effort to reduce the professional isolation of teachers. The use of technical terms such as CPD (Continuing Professional Development), lesson studies, and curriculum transformation agents not only complies with education policy standards but also strategically positions teachers as key actors in the change process.

In this context, strengthening the capacity of educators through context-based Continuous Competency Improvement (PKB) programmes is an operational necessity. As stated by Nurhidayah (2021), training that is systematically designed to teach techniques for integrating local cultural knowledge into STEM pedagogy can improve technical competence while building teachers' confidence in applying innovative models. Comparatively, the findings of this systematic literature review (SLR) are in line with previous reviews that confirm the dominant trend of integrating Project-Based Learning (PjBL) and Information and Communication Technology (ICT). This dominance can be traced to the effectiveness of PjBL in creating active contextual learning, while ICT acts as a catalyst that facilitates access to learning resources and digital cultural exploration. Synergistically, the availability of curated educational resources—including contextual modules, culturally relevant practical tools, and supporting digital tools—is a critical prerequisite for successful learning transformation.

In terms of implementation, these findings have specific practical implications for each stakeholder. For science teachers, this means designing authentic learning and assessment plans that are integrated with local wisdom. Schools are required to allocate sufficient time for curriculum collaboration, while local governments need to allocate a special budget for the procurement of low-cost cultural kits. For researchers, there are methodological opportunities to explore mediator variables such as intrinsic motivation. For example, Prasetyo et al. (2021) showed that the use of locally based gas sensors in chemistry learning through the Ethno-STEM approach significantly improved students' conceptual understanding. However, despite individual challenges, the infrastructure gap between schools remains a serious problem. According to Santoso and Wijaya (2021), this inequality is particularly evident in access to technology and the availability of facilities that support the PjBL model, which ultimately creates a learning opportunity gap between regions.

Therefore, to address the systemic complexities in the implementation of Ethnoscience-STEM—including time constraints, infrastructure deficiencies, and resource limitations—this study recommends three interrelated strategies. First, the development of a national repository of open access resources to facilitate the exchange of practices among educators, as proposed by Agussuryani (2022). Second, the integration of dedicated blocks of time into the academic structure of schools to support cross-disciplinary curriculum collaboration, as described by Reffiane (2021). Third, the advocacy of affirmative policies that allocate specific budgets for the procurement of low-cost technology and locally-based experiment kits, as found in a study by Wulandari (2024). However, it is important to acknowledge several limitations in this study, such as the potential for publication bias towards positive findings, the dominance of certain country contexts that may limit generalisation, and the diversity of Ethno-STEM definitions that may affect the consistency of data interpretation. Collectively, the implementation of these multi-level strategies, taking these limitations into account, is expected to create an environment that supports inclusive and culturally responsive STEM education transformation.

From a methodological perspective, this solution framework is designed hierarchically to map systemic challenges diagnostically, with key terms such as self-efficacy (replacing the term 'confidence' which refers to Bandura's theory), enjoyable learning experiences as enrichment of psychopedagogical constructs, and major obstacles to visualising systemic impacts as catalysts for analytical accuracy. Furthermore, regarding empirical evidence, a study by Sudarmin et al. (2023) specifically reinforces the psychopedagogical aspects of enjoyable learning, while Mansur's (2018) findings validate the existence of systemic barriers in terms of material. In terms of solutions, this layered design encompasses three levels: institutional (repository), structural (time blocks), and policy (affirmative allocation)—where technical precision in low-cost technology overcomes affordability challenges, while culture-based kits address material gaps. Through argumentative transition mechanisms such as 'synergistic' and 'transcending individual capacity challenges,' cohesion between phases is maintained. Its academic significance lies in its dual contributions: (a) a theoretical model of micro-macro challenge interaction; (b) a multi-level implementation framework; (c) an evidence-based technical roadmap focused on equity; and (d) global relevance through low-cost solutions applicable in developing countries—collectively transforming descriptive findings into implementable propositions for policymakers.

Factors Affecting the Success of the Ethnoscience-STEM Learning Model in Improving Students' STEM Understanding and Skills

The successful application of the Ethnoscience-STEM learning model in improving students' STEM understanding and skills is influenced by four determining factors. First, the integration of relevant cultural contexts acts as a catalyst for learning engagement, as seen in the use of locally-based cultural modules in Denpasar, which have been proven to facilitate the independent integration of culture and science (Ekayanti et al., 2023). The main mechanism lies in epistemic scaffolding: connecting scientific knowledge with cognitive schemas based on students' life contexts facilitates the internalisation of abstract concepts. Therefore, the selection of cultural elements that are ontologically aligned with the material is a prerequisite for successful learning (Juliantara et al., 2024).

Additionally, the second determining factor relates to the intensity of student engagement in experience-based learning. In this case, the Ethnoscience-STEM model with a problem-based learning approach through e-modules has been proven to improve students' critical thinking skills (A'yun, 2025), while in the context of Dayak culture through PjBL, mathematical problem-solving abilities showed a significant improvement (Priyani, 2024). The empirical implications are clear: students' direct involvement in contextual practices promotes deep internalisation of STEM concepts. Therefore, learning design should prioritise discovery- and experience-based activities over passive theory transmission.

In addition, the third factor that is no less important relates to the epistemic fluency of educators. As revealed in science teacher mentoring, the effectiveness of Ethnoscience-STEM greatly depends on the ability of teachers to perform two-way translation between local knowledge and the STEM framework (Sartika et al., 2023). Specifically, teachers who have mastered dual literacy are able to develop pedagogically cohesive learning pathways. Therefore, continuous professional training based on the development of ethno-pedagogical capacity is essential.

Finally, the fourth factor is systemic: institutional support and policy. Research in border schools shows that Ethnoscience-STEM supported by digital microscopes successfully improves students' scientific process skills (Priyani, 2024), confirming that technological infrastructure and responsive policies are critical enablers. Furthermore, disparities between schools in terms of digital support have the potential to create learning opportunity gaps. Therefore, a three-way synergy between schools, government, and communities to provide a support ecosystem that includes resources, regulations, and stakeholder collaboration is key to creating a sustainable implementation environment (Wulandari & Hanim, 2023).

Conclusion

The Ethno-STEM learning model has proven to be a transformative approach that enhances the relevance of STEM education through the integration of local wisdom with modern science, particularly through three main trends: culture-based design (such as the Engklek game for physics mechanics), synergy with Project-Based Learning (PjBL), and the use of digital technology as a catalyst. This approach not only strengthens conceptual understanding and 21st-century skills, but also fosters a sense of ownership and preserves cultural heritage.

However, its implementation faces complex challenges, both at the micro level, such as a lack of teachers' epistemic competence (a gap in the ability to transform local knowledge into STEM), and at the macro level, such as a lack of infrastructure, limited time for integrated curriculum development, and a scarcity of contextual teaching materials. As a result, these systemic challenges have the potential to widen the learning opportunity gap, especially in resource-constrained areas.

Therefore, the success of this model requires a multilevel integrated strategy. First, at the educator level, strengthening epistemic fluency through culture mapping-based training and cross-cultural lesson studies is key to overcoming competency gaps. Second, at the institutional level, developing open access resource repositories and allocating dedicated blocks of time for curriculum development collaboration supports sustainability. Third, at the policy level, advocacy for affirmative budgets for low-cost technology and culture-based experiment kits is necessary to address material gaps.

Concretely, tripartite synergy (school-government-community) in building a supportive ecosystem that includes resource support, regulation, and collaboration is the foundation for realising inclusive, culturally responsive, and sustainable STEM education, especially in a multicultural country such as Indonesia.

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