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UNLOCKING SCIENTIFIC REASONING THROUGH ETHNO-STEM : MAPPING THE RESEARCH LANDSCAPE AND FUTURE DIRECTIONS

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ABSTRACT: The stagnation of global scientific literacy scores, as highlighted by PISA results, necessitates a paradigm shift toward culturally responsive pedagogies that foster holistic competencies. This study investigates the global trends of Ethno-STEM integration in facilitating Scientific Reasoning and 6C Skills (Character, Citizenship, Collaboration, Communication, Creativity, and Critical Thinking) through the lens of deep learning. Employing a mixed-method approach combining Systematic Literature Review (SLR) with PRISMA protocol and bibliometric analysis, we analyzed 2889 documents from the Scopus database spanning 2015 to 2026. The findings reveal an exponential growth in publications, predominantly driven by Indonesia and the United States, indicating a shift from a "western-centric" to a localized science education approach. VOSviewer visualization unveils a critical thematic evolution: research focus has transitioned from mere documentation of indigenous knowledge (e.g., ethnobotany) to complex pedagogical interventions aiming at cognitive development and digital integration. Theoretically, Ethno-STEM serves as an "epistemological bridge," reducing cognitive dissonance between students' native science and school science. Practically, the study recommends transforming curricula by embedding local wisdom as a core context for Project-Based Learning (PjBL) to nurture high-order thinking. Future research directions highlight the need for integrating immersive technologies (AI/AR/VR) and conducting empirical studies to measure the direct impact of Ethno-STEM on scientific reasoning.

Keywords: Bibliometric Analysis, Ethno-STEM, Science Education, Scientific Reasoning, Systematic Literature Review.

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INTRODUCTION

The transformation of global education in the 21st century demands a paradigm shift from mere content mastery to the development of holistic competencies, encompassing Scientific Reasoning and 6C Skills (Character, Citizenship, Collaboration, Communication, Creativity, and Critical Thinking). Within this increasingly complex educational landscape, the deep learning framework becomes crucial to ensuring that learners do not merely memorize scientific facts but construct profound understanding transferable to novel situations

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(van Laar et al., 2018). However, empirical reality demonstrates a significant gap between global curriculum expectations and student scientific literacy achievements, particularly in developing nations. The latest Programme for International Student Assessment (PISA) 2022 report reveals that average global science scores have stagnated, or even declined in many countries post-pandemic (OECD, 2024). This phenomenon is sharply evident in Indonesia, where students' average science and mathematics scores remain below the OECD average, indicating that conventional "one-size-fits-all" pedagogical approaches have failed to bridge the relevance of learning materials with students' cognitive and cultural contexts (Darta et al., 2021).

This low performance is often rooted in cultural alienation within science learning, where western science is taught in isolation from the local knowledge possessed by students. As a strategic response, the integration of Ethno-STEM (Science, Technology, Engineering, and Mathematics based on ethnoscience) has emerged as a pedagogical solution promising epistemological justice. Integrating indigenous knowledge into the STEM curriculum serves not only as cultural preservation but also as cognitive scaffolding that enhances learning relevance and student engagementt (Babaci-Wilhite, 2020; Listiyani et al., 2025). Previous studies confirm that when students learn through the lens of their own culture (culturally responsive teaching), cognitive barriers are reduced, enabling more effective assimilation of scientific concepts (Eldeen et al., 2016). Thus, Ethno-STEM is not merely a curricular supplement, but a fundamental bridge for creating an inclusive and meaningful learning ecosystem.

Furthermore, the urgency of strengthening scientific reasoning in STEM education is non-negotiable. Scientific reasoning ability is a primary predictor of student success in solving complex problems and making evidence-based decisions. However, developing this ability requires deliberate pedagogical intervention. Recent research indicates that innovative approaches such as Project-Based Learning (PjBL), the integration of computational thinking, and authentic assessment are effective catalysts for training student reasoning (Blancia, 2024; Tariq et al., 2025). In the context of Ethno-STEM, the inquiry process regarding local cultural phenomena for example, analyzing traditional fermentation techniques or vernacular architecture through physical principles provides a tangible context for students to practice inductive and deductive reasoning simultaneously (İzci, 2025). This asserts that the local context can serve as a natural laboratory for developing higher-order thinking skills.

The synergy between Ethno-STEM and the development of scientific reasoning inherently supports the mastery of 6C skills through a deep learning approach. The utilization of technology in culturally integrated STEM learning has been proven to accelerate the acquisition of collaboration and communication skills, as emphasized in recent findings on the effectiveness of digital learning innovations (Kiong et al., 2025; Zainil et al., 2024). The challenge, however, remains that literature on this topic is fragmented. Most research tends to proceed partially; focusing solely on ethnoscience, or solely on 21st-century skills, without examining the crucial intersection between the two. There is yet to be a comprehensive mapping that visualizes how global trends in Ethno-STEM contribute directly to

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the construction of specific deep learning competencies. As a next step, systematic research is needed to develop an integrative framework that not only links Ethno-STEM principles with the development of 6C skills but also maps their tangible impact on deep learning competencies across diverse educational contexts.

Therefore, this study aims to fill this gap through a Systematic Literature Review (SLR) approach using the PRISMA protocol combined with bibliometric analysis. This study will map the intellectual landscape, identify dominant topic clusters, and highlight research gaps in global publications related to the integration of Ethno-STEM, scientific reasoning, and 6C skills. This analysis is essential not only to provide theoretical insights for academics but also to offer data-driven recommendations for educational policymakers in Indonesia in designing curricula that are culturally adaptive yet globally competitive, to address the challenge of national scientific literacy stagnation.

METHOD

Research Design

This study adopts a mixed-method review approach, integrating a Systematic Literature Review (SLR) using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol with bibliometric analysis. The integration of these two methods was selected to generate a comprehensive analysis: SLR is employed to synthesize qualitative findings in depth, minimizing selection bias and ensuring study replicability (Page et al., 2021; Snyder, 2019). While bibliometric analysis is utilized to quantitatively map the intellectual structure, topic evolution, and collaboration trends on a large data scale (Donthu et al., 2021). This dual approach facilitates the precise identification of research gaps regarding the integration of Ethno-STEM in the development of scientific reasoning and 6C skills, which are often overlooked by traditional narrative reviews.

Data Source and Search Strategy

Data collection was conducted through the Scopus database, selected for its extensive coverage of high-quality journals in the fields of education and social sciences, as well as its rigorous metadata curation standards. The literature search was performed in October 2024 using complex Boolean Operators to capture the intersection between cultural aspects (Ethno), science education (STEM), and 21st-century competencies (Skills). Only peer-reviewed articles published in English were included to ensure the relevance and quality of the sources.

The search strategy was designed to select relevant documents while simultaneously filtering out the ambiguity of the term "deep learning" which is often conflated with artificial intelligence. The search string employed is as follows: TITLE-ABS-KEY (("ethno-STEM" OR "ethnoscience" OR "indigenous knowledge" OR "local wisdom" OR "culturally responsive teaching") AND ("STEM" OR "STEAM" OR "science education" OR "physics education" OR "biology education") AND ("scientific reasoning" OR "critical thinking" OR "6C skills" OR "deep learning competence" OR "collaboration")) AND NOT ("neural network" OR "machine learning" OR "algorithm"). This approach ensures that the retrieved literature focuses specifically on educational and cognitive aspects of STEM learning within indigenous and culturally responsive contexts.

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Literature Selection

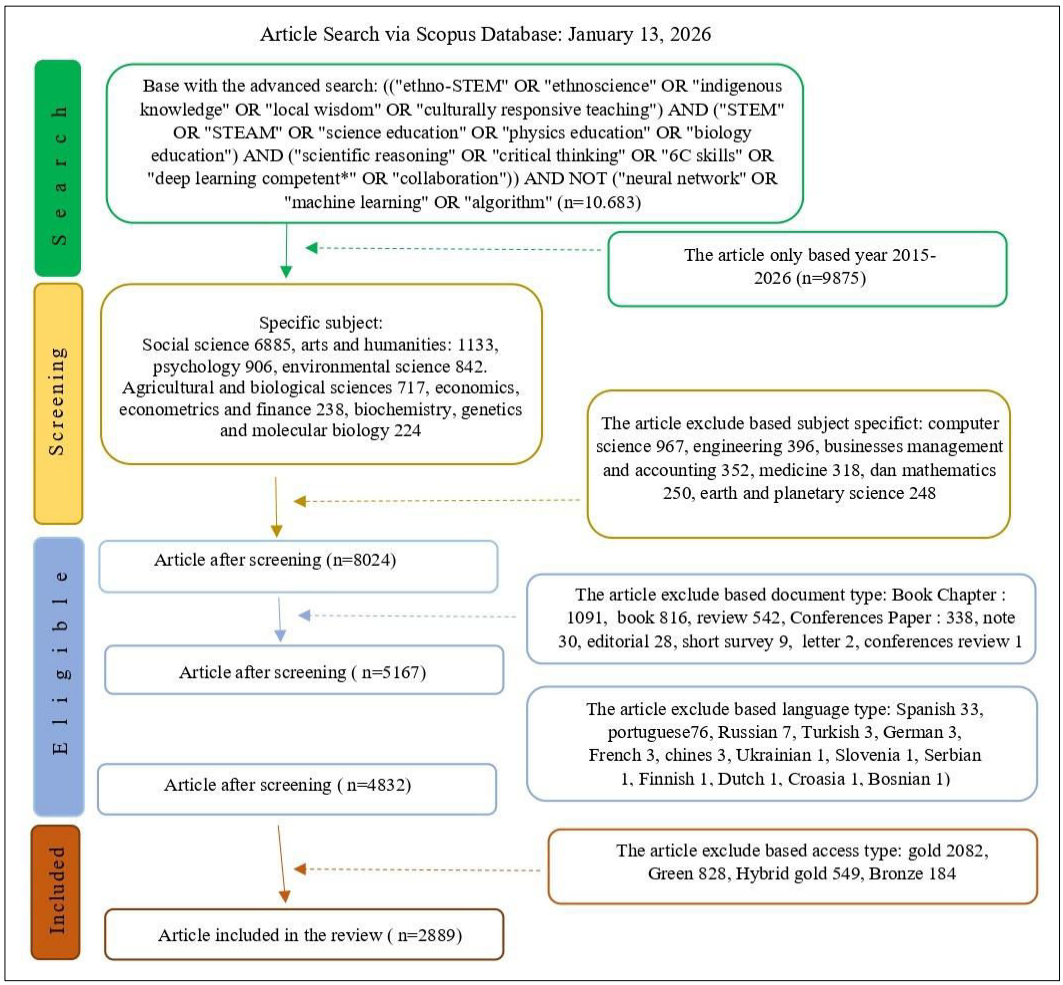

Figure 1. Literature Selection Process Using PRISMA.

Eligibility Criteria (Inclusion and Exclusion)

At this stage, to ensure data validity and relevance, the document selection process adhered to the PRISMA 2020 flow diagram. Articles were screened based on strict inclusion and exclusion criteria, and article metadata was accessed from Scopus on January 13, 2026, as detailed in Table 1. The focus was placed on recent literature (2015-2026) to capture educational trends post-implementation of the SDGs and Kurikulum Merdeka (in the Indonesian context), as well as to anticipate early access articles for the year 2026.

Only articles published in English and Indonesian were included to ensure accurate understanding of both local and global educational contexts. Eligible publication types comprised original research articles, systematic reviews, and empirical studies with clearly defined methodologies. Editorials, opinion pieces, conference papers without peer review, and duplicate publications were excluded to maintain data quality and integrity. This approach aimed to provide a comprehensive overview of educational practices and policies related to the SDGs and Kurikulum Merdeka in Indonesia.

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Table 1. Inclusion and Exclusion Criteria.

Category	Inclusion Criteria	Exclusion Criteria
Timeframe	2015-2026 (Current & Future Trends)	Before 2015
Document Type	Journal Article	Book Chapter, Review, Conference Proceeding, Editorial, Note, Short Survey
Subject Area	Social Sciences, Psychology, Arts and Humanities	Computer Science, Engineering, Medicine, Agriculture (Non-Educational Context)
Language	English (Global) & Indonesian (Local Context	Languages other than English and Indonesian
Publication Stage	Final	Article in Press (to Ensure Citation Stability)
Keywords	Relevant to Ethno-STEM & 6C Competencies	Purely Technical Focus (e.g., Pure Ethnobotany without Pedagogy)

Data Extraction and Analysis

Bibliographic data from eligible documents were extracted in .CSV and .RIS formats, encompassing citation information, bibliographic details, abstracts, and keywords. Data analysis was conducted in two stages:

Descriptive Analysis (Performance Analysis)

Utilizing Scopus analysis features and Microsoft Excel to calculate productivity metrics, such as annual publication distribution, most productive countries, primary target journals, and document access types (Open Access vs. Subscription). This aims to measure the impact and accessibility of Ethno-STEM research globally.

Bibliometric Analysis (Science Mapping)

Employing VOSviewer software version 1.6.20 to visualize bibliometric networks (van Eck & Waltman, 2023). The applied techniques include: 1) co-occurrence analysis, to map relationships between keywords and identify research thematic clusters (e.g., the relationship between indigenous knowledge and scientific reasoning); 2) overlay visualization, to detect topic novelty based on average publication time; and 3) co-authorship analysis, to observe collaboration patterns between countries and institutions.

VOSviewer parameters were set with a minimum keyword occurrence threshold of 5 to filter noise and ensure that the formed clusters were representative. The integration of these visualization results was then interpreted qualitatively to answer research questions regarding trends and future directions of Ethno-STEM integration.

RESULTS AND DISCUSSIONS

Based on a systematic search through the Scopus database, a total of 2889 documents relevant to the topic of Ethno-STEM integration, scientific reasoning, and 6C skills were identified. This data has undergone a rigorous screening process based on the PRISMA protocol to ensure analytical validity. This section presents a comprehensive bibliometric analysis to map the global scientific landscape and answer the formulated research questions. The researcher analyzed the results from the Scopus metadata into three Research Questions (RQs) as follows: 1) RQs 1,

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what are the current distribution and publication trends of research on Ethnoscience/Ethno-STEM integration for fostering scientific reasoning and 6C skills in academic literature?; 2) RQs 2, does the exploration of Ethnoscience/Ethno-STEM integration for fostering scientific reasoning and 6C skills remain a relevant and significant subject for future scientific inquiry?; and 3) RQs 3, what are the theoretical contributions and practical implications derived from existing studies on Ethnoscience/Ethno-STEM integration for fostering scientific reasoning and 6C skills, and how can these findings guide future research?

Global Publication Trends and Literature Distribution (Answering RQs 1)

Research Question 1 (RQs 1) aims to map the distribution and publication trends of Ethno-STEM literature. An analysis of the 2889 articles reveals a dynamic evolution of knowledge.

Annual Publication Growth

The data demonstrates an exponential growth trend over the last decade. In the initial period (prior to 2018), publications related to cultural integration and STEM were sporadic, with fewer than 50 documents per year. A significant surge occurred starting in 2019, continuing to increase through 2025. Regarding 2026, as the researcher retrieved data in early January 2026, the number of documents is expected to continue increasing until the end of the year (Figure 2).

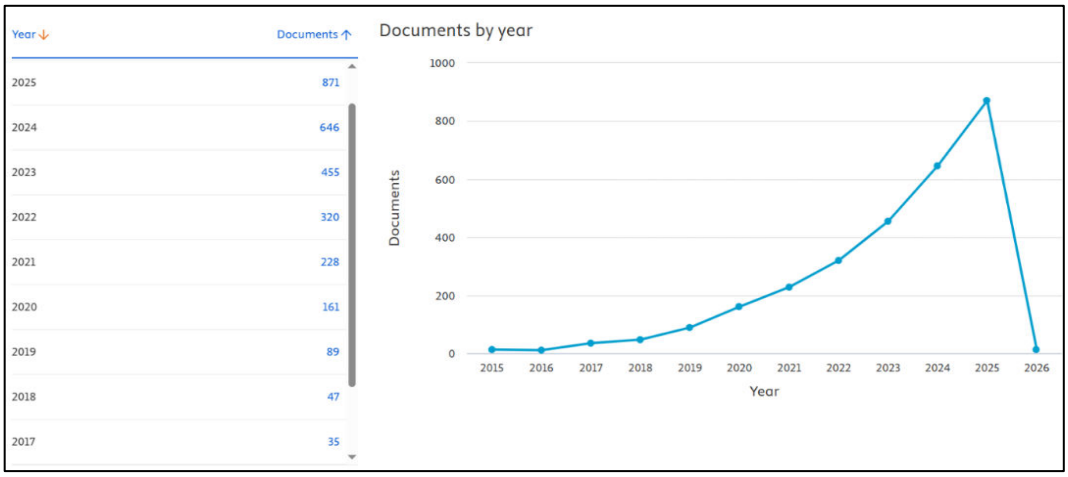

Figure 2. Distribution of Articles by Year. Source: Scopus Database.

Description:

Year	2026	2025	2024	2023	2022	2021	2020	2019	2018	2017	2016	2015
Document	13	871	646	455	320	228	161	89	47	35	11	13

This upward trend indicates a global education paradigm shift increasingly recognizing the urgency of Ethno-STEM as a solution to enhance science relevance. This increase also coincides with the adoption of the OECD Education 2030 framework, which emphasizes holistic competencies (6C), encouraging researchers to explore how local wisdom can serve as a vehicle for developing these competencies.

Top Influential Journals

Source analysis indicates that this discourse is dominated by highly reputable science education journals. Table 2 displays the top five journals based

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on citation counts and productivity. The International Journal of STEM Education and Jurnal Pendidikan IPA Indonesia (JPII) emerge as the primary outlets. The presence of Q1 and Q2 journals in this list confirms that Ethno-STEM has transformed from a "fringe" topic into a central issue in the global science education discourse.

Table 2. Top Five Journals with the Most Ethno-STEM Publications.

Rank	Journal Name	Quartile (Scopus)	Primary Focus
1	International Journal of STEM Education	Q1	Pedagogical Innovation & Policy
2	Jurnal Pendidikan IPA Indonesia	Q2	Science Education & Local Wisdom
3	Cultural Studies of Science Education	Q1	Sociocultural Aspects in Science
4	Journal of Research in Science Teaching	Q1	Methodology & Learning Theory
5	Eurasia Journal of Mathematics, Science and Technology Education	Q2	Technology Integration & STEM

Author Demographics and Country Affiliation

The geographical distribution reveals an intriguing polarization. Indonesia and the United States emerge as the largest contributors, followed by Australia and South Africa. The dominance of Indonesian researchers (e.g., Rahmawati et al.; Sudarmin & Selia) suggests that Indonesia serves as a "natural laboratory" for ethnoscience research due to its cultural diversity. Meanwhile, contributions from Western nations (USA & Australia) tend to focus more on theoretical frameworks regarding Indigenous Knowledge Systems (IKS) and social justice in education.

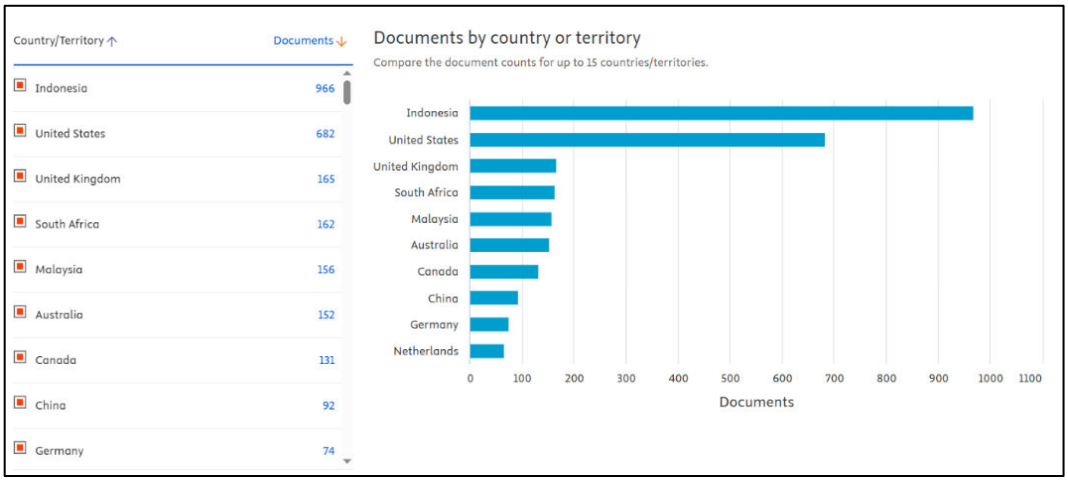

Figure 3. Distribution Article by Countries. Source: Scopus Database.

Figure 4 illustrates the inter-country relationships involved in research related to creative problem-solving, as analyzed using VOSviewer software. The distribution of scientific studies related to Ethno-STEM by country or region reveals a dominant presence of Indonesia with 966 manuscripts, followed by the United States with 682 manuscripts. Several other countries have also made

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significant contributions to this field, as detailed in Figure 3. These findings underscore the global relevance of ethnoscience, particularly its integration with Ethno-STEM, indicating that this topic has garnered significant attention not only in Asian and American countries but also in European and Australian nations. Analyzing these country relationships is a critical step in formulating a comprehensive and forward-looking research agenda.

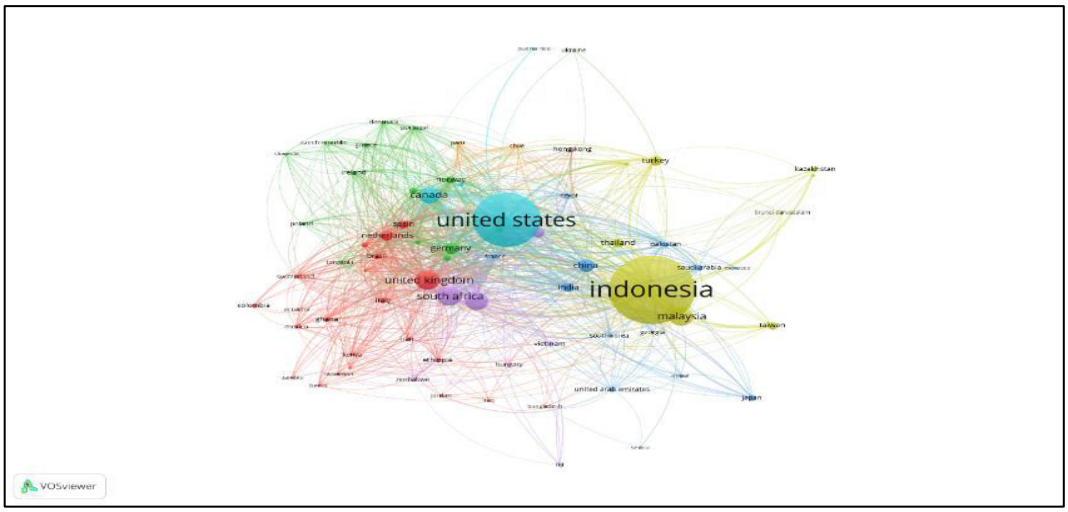

Figure 4. Visualization of Country Networks.

Figure 5 illustrates the distribution of studies on Indigenous Knowledge/Ethnoscience and Ethno-STEM by publication source. The findings indicate that scientific interest in Indigenous Knowledge/Ethnoscience and Ethno-STEM is not confined to academic institutions in Asian and Western nations (such as Indonesia, the United States, and Europe) but has also attracted significant attention from educational institutions in Australia. Regarding the top five publication sources, Jurnal Pendidikan IPA Indonesia leads with 96 articles, followed by Education Sciences with 87 articles, the International Journal of Evaluation and Research in Education with 75 articles, Frontiers in Education with 63 articles, and Sustainability (Switzerland) with 62 articles.

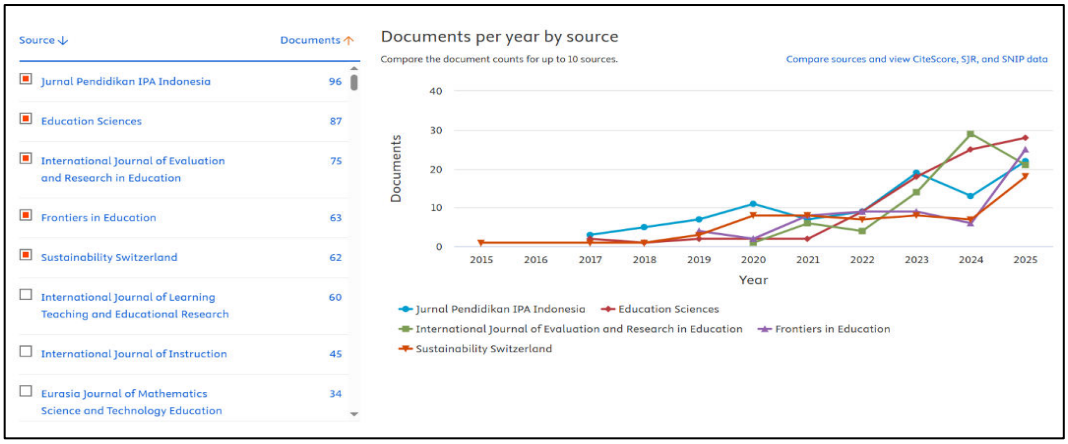

Figure 5. Distribution Article by Source. Source: Scopus Database.

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The Relevance of Ethno-STEM Exploration for Future Research (Answering RQs 2)

Research Question 2 (RQs 2) examines the significance of this topic for future inquiry. Based on a keyword co-occurrence analysis of 2,889 documents using VOSviewer, a crucial shift in research focus has been identified.

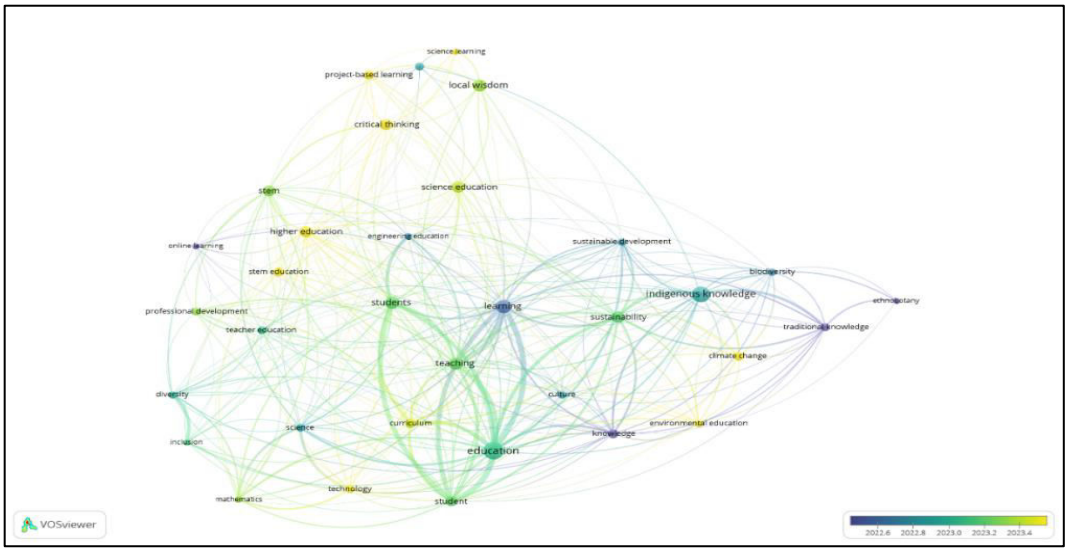

Figure 6. Network Visualization Keyword by Author.

The overlay visualization (topic novelty map) demonstrates a transition in keywords: 1) past trends (blue/purple), focused on "Indigenous Knowledge," "Traditional Knowledge," and "Ethnobotany." Early research tended to primarily document indigenous community science; 2) current trends (green), focused on "Local Wisdom," "STEM," and "Student."; and 3) future/emerging trends (yellow), focused on "STEM Education," "Environmental Education," "Deep Learning," and "Technology."

Regarding the subject areas of research on Ethnoscience and Ethno-STEM, the highest prevalence is found within the Social Sciences, followed by Pedagogy and other subject areas.

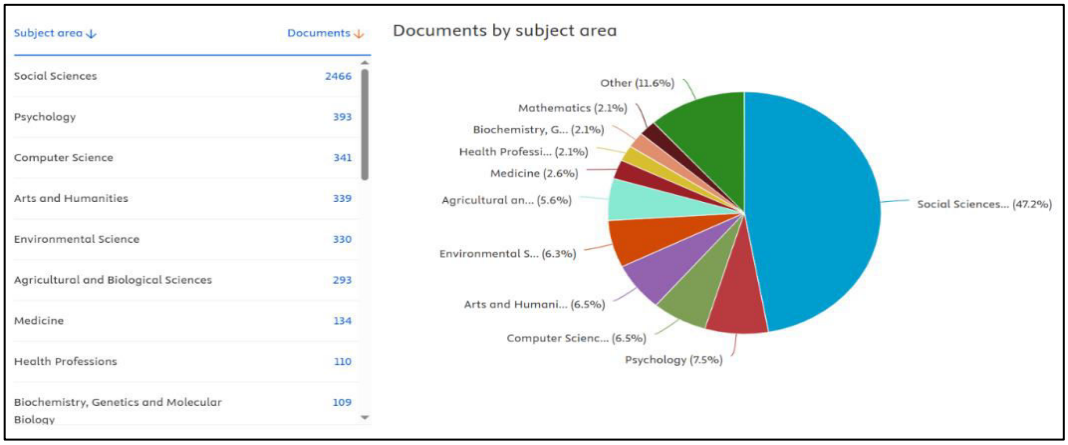

Figure 7. Distribution of Articles by Subject Area. Source: Scopus Database.

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The relevance of future research no longer lies merely in defining "what ethnoscience and STEM are" as an integrated entity (Ethno-STEM), but rather on "how Ethno-STEM enhances higher-order cognitive abilities, specifically scientific reasoning." These findings confirm that Ethno-STEM integration represents a fertile ground for future research, particularly in connecting cultural artifacts with the development of students' scientific reasoning and critical thinking, moving beyond the mere memorization of cultural facts (Sudarmin & Selia, 2023).

Theoretical Contributions and Practical Implications (Answering RQs 3)

Based on a content synthesis of high-impact articles within the dataset, RQs 3 is addressed through two primary dimensions:

Theoretical Contribution: Epistemological Bridge

The research within this dataset collectively contributes to the theories of social constructivism and situated learning. Ethno-STEM is proven to function as an "epistemological bridge" connecting students' everyday knowledge (native science) with school science (western science). Theoretically, these articles refute the view that culture and modern science are separate entities. Conversely, their integration fosters deep learning, as students process new information through cognitive schemas they already possess (their cultural background), thereby stimulating more complex scientific reasoning (Rahmawati et al., 2022).

Practical Implications: Developing 6C Skills

Practically, these findings provide a foundation for curriculum and pedagogical development:

1) Pedagogy

The utilization of Project-Based Learning (PjBL) models based on Ethno-STEM has proven effective in training collaboration and creativity. Students reconstructing traditional technologies (e.g., musical instruments or irrigation systems) must collaborate and think creatively to explain the underlying scientific principles.

2) Assessment

A shift in evaluation instruments is required. Research recommends the use of authentic assessment that measures critical thinking within the context of local problem-solving, rather than relying on culturally biased standardized tests.

3) Policy

For policymakers (including those in Indonesia implementing Kurikulum Merdeka), this data validates the importance of incorporating local content not as a supplementary subject, but as a core context in science learning.

The Trajectory of Ethno-STEM: From Periphery to Global Educational Mainstream

Data analysis reveals an exponential surge in Ethno-STEM publications, particularly during the 2018-2023 period. This phenomenon is not merely a quantitative increase but a strong indicator of a paradigm shift in global science education. While science was previously often taught as a value-free and "western-centric" entity, these data trends confirm that the global academic community is now moving toward a more inclusive Culturally Responsive Teaching (CRT) approach. This shift reflects a growing recognition of the importance of integrating local knowledge systems into mainstream STEM education.

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This surge correlates closely with global imperatives such as the OECD Education 2030 framework and the UNESCO SDGs to enhance the quality of socially and culturally relevant education. The finding that Indonesia is one of the largest contributors alongside the United States underscores the strategic position of developing nations in this discourse. In Indonesia, this integration is relevant to the challenge of stagnant PISA scores. The analyzed research indicates that student failure in scientific literacy is often not due to cognitive inability, but rather due to cognitive dissonance between their "school science" and "everyday science." Therefore, this upward trend in publications reflects a collective effort by researchers to dismantle this barrier through ethnoscience (Jannah et al., 2022).

Shifting Research Focus: From "Documentation" to "Cognitive Development"

One of the most critical findings from the VOSviewer overlay visualization is the distinct evolution of research themes.

Initial Phase (Past Trends)

Dominated by keywords such as indigenous knowledge, medicinal plants, and ethnobotany. In this phase, research tended to be descriptive-explorative, focusing solely on the inventory of local knowledge.

Transition Phase (Current Trends)

Moving toward the development of learning tools, such as module development and inquiry-based learning.

Future Phase (Emerging Trends)

The emergence of new, bright yellow clusters featuring keywords like critical thinking and digital technology.

This shift answers RQs 2 regarding future relevance. Ethno-STEM is no longer viewed merely as cultural preservation but has transformed into a pedagogical strategy to stimulate higher-order cognition. These findings imply that local wisdom provides rich and complex contexts ("ill-structured problems") that are ideal for training students in scientific reasoning. Students are no longer just memorizing the names of medicinal plants but are challenged to analyze the underlying phytochemistry, a process that demands critical analysis and deductive reasoning capabilities (Zidny & Eilks, 2020).

Theoretical Contribution: Ethno-STEM as an Epistemological Bridge for Deep Learning

Addressing RQs 3 regarding theoretical contributions, the synthesis of literature reinforces the theories of border crossing and social constructivism. The analysis confirms that Ethno-STEM functions as an "epistemological bridge" that facilitates deep learning. Within the deep learning framework, learning occurs when students are able to transfer knowledge to new situations. Ethnoscience enables this by providing scaffolding in the form of familiar cultural contexts. When students learn physics concepts (e.g., thermodynamics) through the process of traditional batik making or fish smoking, abstraction barriers are reduced. This process creates a "Third Space" where indigenous knowledge and scientific knowledge dialogue, resulting in a deeper and more durable conceptual understanding (Babaci-Wilhite, 2020). Furthermore, the data shows that this integration inherently cultivates 6C skills. Collaboration and communication are formed when students work in groups

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to reconstruct indigenous technologies, while creativity is honed when they must modify these technologies using modern STEM principles.

Practical Implications for Curriculum and Pedagogy

Bibliometric findings hold significant practical implications for policymakers and educational practitioners, particularly in the context of adaptive curricula such as Kurikulum Merdeka in Indonesia:

Curriculum Transformation

Ethno-STEM must not merely be an add-on or a separate local content subject. It must be integrated as a core context in science learning. Learning materials must be redesigned to initiate every learning unit from local phenomena before progressing to abstract global concepts.

Project-Based Pedagogy (Ethno-PjBL)

The dominance of the project-based learning keyword in the latest clusters suggests that lecture methods are ineffective for Ethno-STEM. Teachers need to design cultural engineering projects (e.g., designing water filtration systems based on local wisdom) to activate critical thinking and problem solving.

Assessment Redesign

A shift from standardized testing to performance assessment measuring reasoning abilities is required. Evaluation items must be contextualized with student culture to measure transfer of knowledge fairly.

Research Gaps and Future Directions

Although positive trends are evident, this analysis identifies several research gaps crucial for the future agenda:

Digital Technology Integration

Although the keyword digital has begun to appear, the volume of research combining Ethno-STEM with Augmented Reality (AR), Virtual Reality (VR), or Artificial Intelligence (AI) remains minimal. Immersive technologies hold great potential for visualizing abstract ethnoscience concepts or reconstructing extinct cultural artifacts.

Empirical Measurement of Scientific Reasoning

The majority of studies still focus on student perceptions or the validity of teaching tools. There are still few longitudinal or experimental studies that rigorously measure the impact of Ethno-STEM interventions on increasing scientific reasoning scores and Deep Learning Competencies (NPDL) quantitatively.

Cross-Cultural Studies

Research remains compartmentalized within specific cultural contexts. Comparative cross-cultural or cross-national studies are needed to formulate an Ethno-STEM framework that is more universal yet remains adaptive.

CONCLUSION

This study has presented a comprehensive bibliometric analysis of 2889 global scientific documents, confirming that Ethno-STEM integration has transformed from a mere cultural documentation effort into a mainstream pedagogical strategy in 21st-century science education. These findings decisively address doubts regarding the relevance of local wisdom in modern learning; the

data proves that Ethno-STEM is an effective catalyst for fostering Scientific Reasoning and 6C skills (Critical Thinking, Creativity, Collaboration, Communication, Citizenship, and Character) through the deep learning framework. Specifically, this study concludes three fundamental points:

Research Trend Evolution

A significant paradigm shift has occurred over the last decade. Research focus has moved from the inventory of indigenous knowledge (ethnobiology/medicinal plants) toward complex pedagogical implementation (inquiry-based learning & instructional design) aimed at stimulating students' higher-order cognition.

Epistemological Role

Theoretically, Ethno-STEM is proven to function as an "epistemological bridge" that reduces the gap between western science and students' native science. This integration provides contextual scaffolding that enables students to understand abstract scientific concepts more deeply and meaningfully.

Urgency of Adaptive Curricula

The dominance of publications from developing nations such as Indonesia underscores that this learning model is a strategic solution to address low scientific literacy (PISA scores) and educational access inequality, by utilizing local culture as an inclusive learning laboratory.

RECOMMENDATION

These findings recommend that policymakers and educational practitioners adopt the Ethno-STEM approach not as a supplement, but as the core of a contextual science curriculum. Learning should be designed based on Project-Based Learning (PjBL), challenging students to solve local problems using STEM principles. This analysis identifies urgent research gaps to be addressed. Future research is suggested to: 1) integrate immersive digital technologies (augmented reality/virtual reality) and Artificial Intelligence (AI) into Ethno-STEM learning to visualize complex ethnoscience concepts; 2) conduct longitudinal experimental studies to empirically measure the impact of Ethno-STEM on the improvement of scientific reasoning scores and student character dispositions; and 3) expand cross-national collaborations to formulate a global Ethno-STEM framework that is adaptive to diverse cultural backgrounds. In conclusion, this study asserts that the future of quality STEM education lies not in global standardization, but in education's ability to be rooted in local wisdom while reaching toward global competencies.

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