Bridging Local Wisdom and Global Science: Policy Insights for Integrating Ethno-STEM Into Indonesian Science Education

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Abstract

Despite Indonesia's rich cultural heritage, its students continue to struggle with science literacy, as reflected in consistently low PISA scores. This study investigates whether integrating ethnoscience bridging scientific concepts with local knowledge can enhance science education by making it more culturally relevant and engaging. Using a qualitative-exploratory approach, the research analyzes literature, case studies, and policies to assess the viability of Ethno-STEM learning modules in Indonesia's national curriculum. Results indicate that embedding local wisdom into science education boosts student engagement, critical thinking, and real-world application of knowledge. However, successful implementation requires structured teacher training and policy alignment, guided by Patton and Sawicki's alternative policy criteria theory. The study also highlights socio-economic and cultural benefits tied to SDGs, particularly quality education (SDG 4) and cultural preservation (SDG 11), while addressing challenges like standardization and resource gaps. Practical recommendations are provided to support classroom integration, offering a roadmap for transforming science education through Ethno-STEM in Indonesia.

Keywords: scientific literacy, ethnoscience, Ethno-STEM, sustainable education, local wisdom preservation

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Introduction

Scientific literacy is a strategic objective in science education, equipping future generations to navigate local and global challenges (Istyadji & Sauqina, 2023). In Indonesia, science literacy is crucial for fostering scientific thinking applicable to everyday decision-making. However, the 2022 PISA results revealed that Indonesian students' average science literacy scores remain below the Organisation for Economic Co-operation and Development (OECD) average, reflecting significant gaps in connecting scientific concepts to real-world applications (OECD, 2023).

One contributing factor to this issue is the lack of culturally relevant teaching approaches that link science to students' daily lives. Traditional teaching methods often fail to contextualize scientific concepts within the realities and experiences of students, leaving many unable to see the relevance of science in their communities (Jones & Burrell, 2022). Data from the 2018 PISA report shows that fewer than 50% of Indonesian students can effectively apply scientific knowledge to practical situations in their lives, underscoring the need for innovative teaching strategies (Wang et al., 2023).

Ethnoscience, an innovative approach integrating traditional local knowledge with science education can address these challenges. This approach incorporates values, knowledge, and skills from local communities into science curricula, enhancing relevance and engagement (Morris et al., 2021). For instance, students could explore scientific principles embedded in traditional agricultural practices or local biodiversity management, making learning more meaningful and accessible.

The urgency of this issue is further heightened by findings that link low science literacy to broader developmental challenges. Students with poor scientific understanding struggle to make informed decisions on environmental, health, and technological issues, which are vital in today's globalized world. This highlights the critical need for educational reforms that emphasize culturally relevant and context-driven learning (Mahatma Gandhi Institute of Education for Peace and Sustainable Development, 2019).

Aligned with Sustainable Development Goals (SDGs), ethnoscience supports global citizenship and cultural literacy. Integrating Ethno-STEM into education, as proposed by Sudarmin et al. (2022), allows students to apply scientific knowledge through culturally relevant projects. This fosters active, independent learning and appreciation for local heritage while promoting global diversity values. Moreover, by embedding Ethno-STEM in science curricula, Indonesia can address the dual goals of improving science literacy and preserving its rich cultural heritage.

Method

This study was conducted following a systematic framework to ensure a comprehensive evaluation of the role of Ethno-STEM in enhancing science literacy. The steps followed are outlined below:

Protocol Development

The study employed a qualitative-exploratory approach combined with case study methods through literature reviews to evaluate the feasibility of implementing Ethno-STEM-based

learning modules. Patton et al. (2012) alternative policy criteria theory provided the conceptual framework for assessing feasibility, effectiveness, efficiency, and equity of Ethno-STEM integration.

To maintain a structured and critical review, the PROMPT mnemonic was applied (Santos-Hermosa & Sánchez, 2010):

- Presentation: Findings were organized clearly, providing actionable recommendations.
- Relevance: Focused on Indonesian contexts, aligning with national and global educational goals.
- Objectivity: Both opportunities and challenges of Ethno-STEM integration were considered.
- Method: Rigorous qualitative methods and case studies ensured validity.
- Provenance: Only peer-reviewed and validated sources were included.
- Timeliness: The review incorporated studies published between 2015 and 2024.

Eligibility Criteria

Studies included in this review met the following PICOS criteria by Thapa et al. (2024):

- Population: Focused on school and university students in Indonesia.
- Intervention: Integrated Ethno-STEM and local wisdom into science education.
- Comparison: Evaluated against traditional methods, such as textbook-based instruction.
- Outcomes: Reported measurable impacts on students' science literacy, critical thinking, or cultural appreciation.
- Scope: Included peer-reviewed studies published between 2015 and 2024.

Information Sources and Search Strategy

A comprehensive search strategy was applied using databases such as Scopus and PubMed. Search terms included "Ethno-STEM," "ethnoscience," and "local wisdom education." Boolean operators (AND, OR) were used to refine search results. The initial search was conducted in November 2024, followed by a secondary search in December 2024 to include recently published studies. Relevant studies were imported into Mendeley for reference management. Duplicate records were removed, and titles and abstracts were screened for relevance. A manual review of references from selected articles was also conducted to identify additional sources (Jamarani et al., 2024).

Data Extraction and Charting

Data were extracted using a standardized charting form to ensure consistency. Key information collected included:

- Study design (e.g., exploratory or quasi-experimental).
- Sample size and characteristics of participants.
- Intervention details, such as Ethno-STEM modules and cultural practices integrated.
- Outcomes, including impacts on science literacy, critical thinking, and alignment with SDGs.

Data were synthesized qualitatively to identify themes, patterns, and gaps, linking findings to the criteria outlined by Patton et al. (2012).

Synthesis of Results

The extracted data were analyzed qualitatively to:

1. Highlight the effectiveness of Ethno-STEM in improving science literacy and fostering cultural preservation.
2. Evaluate the feasibility of embedding these modules into Indonesia's "*Kurikulum Merdeka*."
3. Identify challenges, such as resource constraints, and propose actionable solutions.

Policy Recommendations

Policy recommendations were derived using Patton et al. (2012) alternative policy criteria theory. The criteria included:

- Feasibility: Examining how Ethno-STEM modules align with the curriculum structure and local content mandates.
- Effectiveness: Assessing measurable improvements in student engagement, critical thinking, and cultural appreciation.
- Efficiency: Evaluating resource allocation and teacher preparedness.
- Equity: Ensuring accessibility of Ethno-STEM resources across diverse regions.

This systematic and structured methodology ensured a robust evaluation of the integration of Ethno-STEM into science education in Indonesia, producing actionable insights for curriculum reform and alignment with the Sustainable Development Goals (SDGs).

Results and Discussion

Synthesis of Findings on Ethno-STEM Integration in Indonesian Science Education

a. Screening Details

- Number of Titles and Abstracts Reviewed: A total of 30 studies were screened based on relevance to Ethno-STEM integration in Indonesian science education. For example, the study by Zidny and Eilks (2022) on integrating green chemistry with local wisdom was selected for its focus on culturally relevant science education, while Wahyudi et al. (2023) provided insights into the impact of Ethno-STEM on junior high school students.
- Year of Publications: The studies range from 2018 to 2024, reflecting a growing interest in Ethno-STEM during this period. Early works, such as Melyasari et al. (2018), laid the groundwork by validating Ethno-STEM frameworks, whereas more recent studies like Misbah et al. (2024) addressed bibliometric trends.
- Country of Publication: Most studies were conducted in Indonesia or focused on Indonesian educational contexts, such as Kusumah et al. (2022) and Tresnawati et al. (2021), which explored science learning aligned with local cultural contexts. A significant limitation is the scarcity of Ethno-STEM studies conducted exclusively in Indonesia. To compensate, this review incorporates findings from Malaysia and other regions where cultural and pedagogical conditions share similarities with Indonesia (e.g., emphasis on local wisdom in STEM, collectivist educational approaches). However, differences in national curricula and cultural specifics (e.g., distinct indigenous knowledge systems) suggest caution when generalizing results.

- Article Types: The collection includes journal articles, conference proceedings, and case studies, emphasizing empirical and theoretical research. For instance, Tresnawati et al. (2021) focused on pre-service teacher training through conference proceedings, while Sudarmin, Zahro, et al. (2019) provided empirical findings in journal articles.

b. Study Design and Methodology

- Sampling Methods: Studies used purposive and cluster random sampling to select participants, often targeting specific groups such as teachers, students, or pre-service educators. For instance, Prayogi et al. (2023) employed purposive sampling to assess the impact of digital Ethno-STEM inquiry projects, while Tresnawati et al. (2021) used cluster sampling for PGSD (primary school teacher education) students.
- Study Designs: Mixed-methods, quasi-experimental, and qualitative descriptive designs were predominant, providing both quantitative data and in-depth qualitative insights. Zidny and Eilks (2022) used mixed-methods to integrate green chemistry and local wisdom, while Kusumah et al. (2022) employed a quasi-experimental design to validate e-modules.
- Data Collection Tools: Tools included interviews, questionnaires, pre-and post-tests, observation sheets, and content validity assessments to ensure comprehensive data collection. For example, Wahyudi et al. (2023) utilized pre- and post-tests to measure student outcomes, and Sudarmin, Sumarni, et al. (2019) relied on observation sheets to evaluate essential oil production activities.
- Participant Profile: Participants were diverse, including elementary, junior high, and high school students, as well as teachers and pre-service educators. Tresnawati et al. (2021) focused on pre-service PGSD students, whereas Dewi et al. (2019) studied chemistry students across multiple levels.

Table 1

Summary of Included Publications

Author(s), Year	Country	Article Type	Sampling Methods	Study Design	Participant Profile
(Anggaryani et al., 2024)	Indonesia	Conference Proceedings	Mixed-method	Survey and Interviews	Indonesian students in Taiwan
(Melyasari et al., 2018)	Indonesia	Conference Proceedings	Purposive	4D Model Validation	Junior High School students in Tulungagung
(Abdurrahman et al., 2020)	Indonesia	Conference Proceedings	Purposive	Mixed-method	Science teachers in Indonesia
(Kusumah et al., 2022)	Indonesia	Conference Proceedings	R&D	Experimental (Validation Phases)	Elementary School students in Seluma
(Sudarmin, Sumarni, et al., 2022)	Indonesia	Conference Proceedings	Descriptive	Ethno-STEM Project-Based	Chemistry students in UNNES
(Yuliana et al., 2021)	Indonesia	Journal Article	Quasi-experimental	Context-based Learning	Elementary School students in Indonesia
(Prayogi et al., 2023)	Indonesia	Journal Article	Experimental	Digital Inquiry-Based Ethnoscience	Pre-service science teachers

Author(s), Year	Country	Article Type	Sampling Methods	Study Design	Participant Profile
(Irfandi et al., 2023)	Indonesia	Journal Article	R&D	Blended Learning Implementation	Physics students in East Coast Malay
(Bisono et al., 2022)	Indonesia	Conference Proceedings	R&D	E-module Development	Junior High School students near Merapi
(Dewi et al., 2019)	Indonesia	Journal Article	Descriptive	Ethnoscience Pedagogy	Chemistry students at multiple levels
(Kurniawan et al., 2019)	Indonesia	Journal Article	Quantitative	Contextual Learning Design	Primary school students
(Wati et al., 2021)	Indonesia	Conference Proceedings	Mixed-method	Literature Research	Research articles from 2015–2020
(Lightner et al., 2021)	Multiple	Journal Article	Ethnographic Text Analysis	Qualitative Analysis	55 Cultures Worldwide
(Sudarmin, Zahro, et al., 2019)	Indonesia	Journal Article	R&D	PBL with Green Chemistry	High school chemistry students
(Nadzirin et al., 2024)	Indonesia	Conference Proceedings	Qualitative	Ethnophysics Study	High school physics students in East Java
(Rinto et al., 2020)	Indonesia	Conference Proceedings	Descriptive	Pharmacognosy Learning	Vocational Pharmacy students
(Tresnawati et al., 2021)	Indonesia	Conference Proceedings	R&D	Ethno-STEM PjBL	Pre-service PGSD students
(Zidny & Eilks, 2022)	Indonesia	Journal Article	Mixed-method	Green Chemistry Integration	Chemistry students at multiple levels
(Wahyudi et al., 2023)	Indonesia	Journal Article	Experimental	Hybrid Ethno-Project Based	Physics students at Lombok University
(Atmojo et al., 2019)	Indonesia	Journal Article	Quasi-experimental	Ethnoscience Integrated Learning	Primary education pre-service teachers
(Sudarmin et al., 2019)	Indonesia	Journal Article	R&D	Essential Oil Learning Models	Chemistry education students
(Tresnawati et al., 2021)	Indonesia	Conference Proceedings	Mixed-method	Ethno-STEM in Biotechnology	PGSD Students
(Ardianti et al., 2023)	Indonesia	Journal Article	R&D	Ethnoscience-Based Smart Modules	Primary school students
(Misbah et al., 2024)	Indonesia	Conference Proceedings	Bibliometric Analysis	Literature Trends Analysis	Research articles
(Putra, 2021)	Indonesia	Conference Proceedings	Theoretical or conceptual	Theoretical Literature Review	Research articles
(Khusniati et al., 2023)	Indonesia	Journal Article	Qualitative approach	Ethnoecological	Students and Villagers

Author(s), Year	Country	Article Type	Sampling Methods	Study Design	Participant Profile
(Mulyono et al., 2024)	Indonesia	Journal Article	literature study with in-depth analysis	Ethnoscience with Inquiry	All students level
(Ardianti et al., 2019)	Indonesia	Journal Article	R&D	Edutainment Modules	Elementary school students
(Hariyono et al., 2023)	Indonesia	Journal Article	Non-equivalent control group	4D model (Define, Design, Develop, Dissemination)	29 high school students in grade XI
(Risdianto et al., 2021)	Indonesia	Conference Proceedings	Observation and surveys	Direct instruction-based ethnoscience	Physics students in Bengkulu

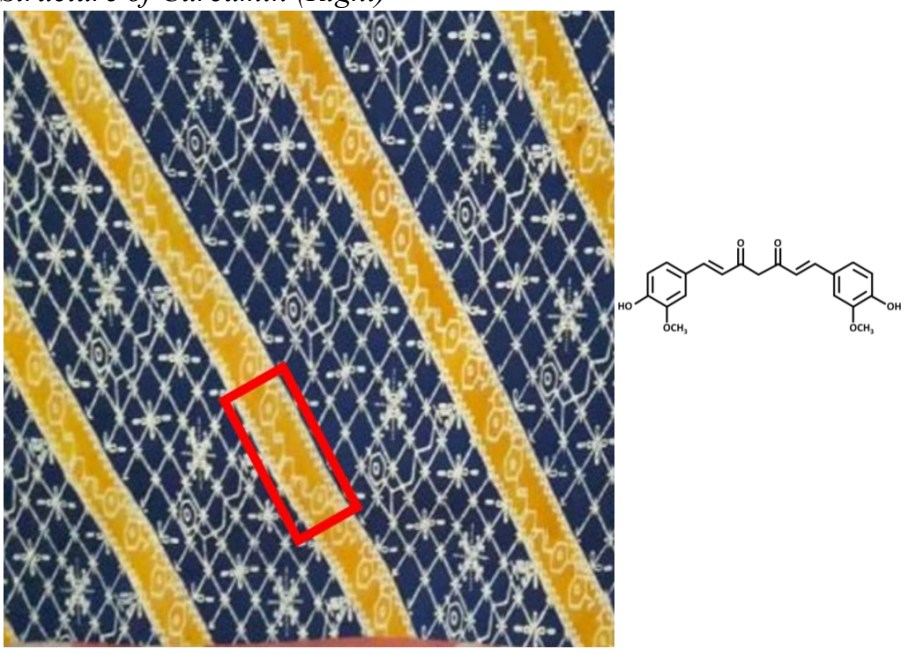
Findings and Implications

a. Integration of Ethnoscience Into Science Education

The integration of ethnoscience into Indonesian science education has been shown to enhance culturally relevant science literacy. By embedding local wisdom within science learning frameworks, students gain a deeper appreciation of their cultural heritage while developing critical scientific skills. For example, Sudarmin et al. (2020) demonstrated that incorporating traditional practices, such as "*Batik chemistry*," into science classes improved both cultural understanding and the application of scientific concepts. This approach aligns with global efforts to create contextually relevant education and has proven to be a feasible strategy for the Indonesian educational context.

Figure 1

Chemical Striated Batik Products With Curcumin/Turmeric Patterns (Left) and Chemical Structure of Curcumin (Right)



Source. Sudarmin et al. (2020); Zhai et al. (2020)

b. Feasibility of Ethno-STEM-Based Learning Modules

The feasibility of incorporating Ethno-STEM-based modules into the national curriculum has been demonstrated in multiple studies. For instance, Dewi et al. (2019) developed an ethnoscience based chemistry learning module by using local traditions like "*Terasi*" (traditional shrimp paste), revealing improved student science literacy. Additionally, Khusniati et al. (2023) found that Ethno-STEM-based worksheets on production of *Troso* woven fabric activities around Jepara increased students' understanding of science concepts while fostering environmental awareness. These outcomes strongly support the scalability of these modules across schools in Indonesia.

Figure 2

The Process of Binding Troso Woven Fabric

Source. Khusniati et al. (2023)

c. Student Engagement and Critical Thinking

Ethno-STEM approaches have led to significant improvements in student engagement. Activities like traditional Batik-making, exploring essential oils in Sudarmin, Sumarni, et al. (2019) research, and analyzing local agricultural practices by Dewi et al. (2019) have increased student motivation by linking science to everyday cultural experiences. These culturally relevant activities also stimulate critical thinking by encouraging students to solve problems and innovate within their own contexts. For instance, Prayogi et al. (2023) reported that digital Ethno-STEM inquiry projects significantly enhanced students' problem-solving skills.

d. Teacher Training and Policy Support

Teacher training has emerged as a cornerstone for the successful implementation of Ethno-STEM in classrooms. Tresnawati et al. (2021) highlighted the effectiveness of pre-service training programs that focus on creating Ethno-STEM-based lesson plans. Additionally, Wahyudi et al. (2023) emphasized that consistent policy support is critical for institutionalizing these practices. The alignment of Ethno-STEM initiatives

with Indonesia's educational goals, such as the "*Kurikulum Merdeka*," has further enabled teachers to implement these methods effectively.

e. Alignment With Sustainable Development Goals (SDGs)

The integration of Ethno-STEM in Indonesian education contributes directly to SDG 4 (Quality Education) by improving the quality and relevance of science instruction. For example, Zidny and Eilks (2022) found that integrating green chemistry principles with local wisdom supported SDG 15 (Life on Land) by promoting environmental sustainability. Similarly, Putra (2021) highlighted how people interpret and relate to nature through cultural knowledge, thereby preserving intangible cultural heritage particularly ecological wisdom and local classification systems which aligns with SDG 11 (Sustainable Cities and Communities) and demonstrates the socio-environmental relevance of Ethno-STEM.

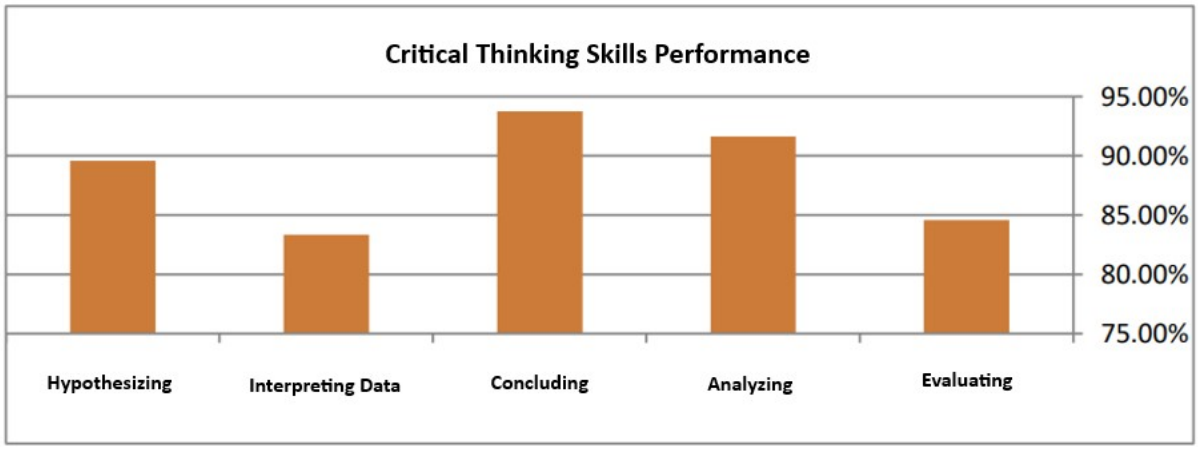
f. Socio-Cultural and Economic Benefits

Ethno-STEM practices offer socio-cultural benefits by preserving local traditions and promoting cultural pride. Economically, these practices can inspire innovation in local industries. For instance, Dewi et al. (2019) explored how students could apply chemical principles to traditional food preservation techniques, fostering entrepreneurial opportunities. Similarly, Sudarmin, Sumarni, et al. (2019) showed how essential oil production linked chemistry concepts with sustainable economic practices. This dual impact strengthens community resilience and fosters a sense of ownership among students and educators.

Figure 3

Students' Conservation Character Outcomes and Improvements in Critical Thinking Through Ethno-STEM Interventions

No	Soft skill in conservation	Pretest Score	Postest Score	N-Gain Score	Category
1	Environmental loving	78	89	0,50	Average
2	Environmental caring	75	93	0,72	High
3	Responsibility	79	93	0,67	Average



Source. Sudarmin et al. (2022); Zakiyah et al. (2022)

g. Challenges and Limitations

Despite its promise, the integration of Ethno-STEM faces challenges, including:

- Standardization Issues: Creating uniform modules that are adaptable to diverse local contexts is difficult, as noted by Lightner et al. (2021).
- Resource Constraints: Schools in rural areas may lack access to the necessary resources and teacher training programs (Wahyudi et al., 2023).
- Sustainability: Ensuring long-term support for these programs requires consistent funding and policy commitment, as highlighted by Misbah et al. (2024).

Policy Recommendations

Based on the qualitative-exploratory approach and literature case studies, the following policy recommendations are proposed:

a. Feasibility and Effectiveness

- Developing Guidelines for Ethno-STEM Implementation: Create comprehensive national guidelines to standardize the integration of Ethno-STEM modules across Indonesia. The guidelines should outline practical steps for embedding cultural wisdom, such as Batik-making or herbal medicine, into science curricula.
- Pilot Programs: Implement pilot programs in diverse regions to test the effectiveness of Ethno-STEM modules in improving science literacy and student engagement. For instance, Kusumah et al. (2022) demonstrated how e-modules based on local tools like "*Robyong*" enhanced learning outcomes in physics.

b. Efficiency and Resource Allocation

- Equitable Resource Distribution: Allocate resources, including funding for teacher training and development of Ethno-STEM teaching materials, to underserved regions. Sudarmin, Sumarni, et al. (2019) emphasized the importance of providing essential tools for practical science education, such as materials for essential oil experiments.
- Digital Integration: Develop digital platforms for Ethno-STEM modules, making them accessible for remote and underserved schools. Prayogi et al. (2023) highlighted the success of digital Ethno-STEM inquiry projects in improving engagement and problem-solving skills.

c. Equity and Inclusivity

- Localized Content Development: Collaborate with local communities to ensure that Ethno-STEM modules are inclusive and reflective of regional cultural practices. Bisono et al. (2022) illustrated how collaboration with local experts enriched the development of worksheets on volcanic activities around Merapi.
- Teacher Capacity Building: Expand professional development programs to equip teachers with the knowledge and skills to implement Ethno-STEM effectively. Tresnawati et al. (2021) showed that targeted training improved the ability of pre-service teachers to design culturally relevant lesson plans.

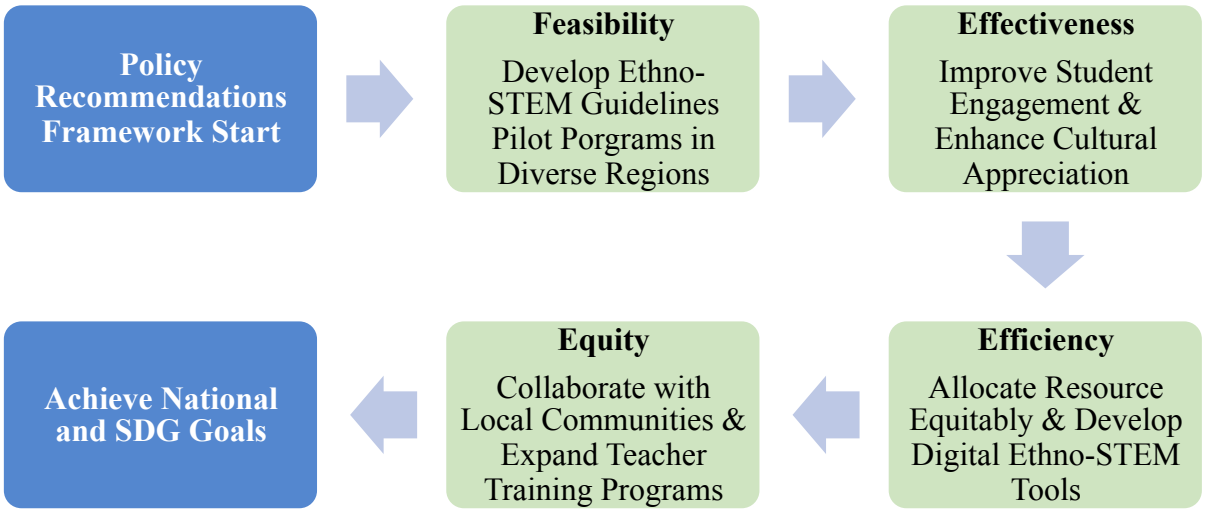
d. Alignment With National and Global Goals

- Integration with "*Kurikulum Merdeka*": Embed Ethno-STEM within the "*Projek Penguatan Profil Pelajar Pancasila*" (Pancasila Student Profile Strengthening Projects) to align with the goals of contextual, competency-based learning (Kemendikbudristek, 2024).
- Sustainability Goals: Use Ethno-STEM to support Indonesia's commitments to SDGs, such as promoting sustainable land use and biodiversity conservation through culturally relevant science education (Zidny & Eilks, 2022).

e. Monitoring and Evaluation

- Long-Term Impact Studies: Conduct longitudinal research to evaluate the sustained impacts of Ethno-STEM modules on students' competencies and communities.
- Feedback Mechanisms: Establish feedback loops involving teachers, students, and policymakers to continually refine the Ethno-STEM framework based on implementation outcomes.

Figure 4
The Progression From Feasibility to Achieving National and SDG Goals



Conclusion

The integration of Ethno-STEM into Indonesian science education shows strong potential to improve students' scientific literacy, critical thinking, and cultural awareness. This review affirms the feasibility of Ethno-STEM approaches and their alignment with national priorities such as the *Kurikulum Merdeka* and global targets like the Sustainable Development Goals (SDGs). While the benefits are clear, successful implementation requires overcoming key challenges, particularly in resource allocation, teacher training, and content standardization. With supportive policies and strategic investment, Ethno-STEM can serve as a transformative framework for delivering culturally relevant and sustainable science education across Indonesia.

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