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Insights into Artificial Intelligence and Ethnoscience in STEM: Systematic Literature Review (SLR) for Pre-Service Physics Teachers

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Abstract

Background: Integrating Artificial Intelligence (AI), ethnoscience, and STEM education is increasingly important for preparing pre-service physics teachers to address technological, interdisciplinary, and culturally responsive demands. However, research in Indonesia remains fragmented, with AI, STEM, and ethnoscience investigated as separate domains, limiting integrated approaches to physics teacher preparation.
Aims: This study identifies publication trends, dominant themes, methodological characteristics, and gaps in integrating AI, ethnoscience, and STEM within Indonesian pre-service physics teacher education.
Methods: Guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, an integrative literature review examined publications from 2015 to 2026 from Google Scholar, IEEE Xplore, Scopus, and ERIC. Following title, abstract, and full-text screening, 51 articles were selected. Data were analyzed using descriptive bibliometrics, thematic analysis, and gap analysis.
Results: Three trends emerged. First, research emphasizes AI- and STEM-enhanced learning, conceptual understanding, and 21st-century competencies. Second, ethnoscience studies promote local wisdom, contextual learning, cultural literacy, and instructional resources, but remain disconnected from AI-supported STEM learning. Third, comprehensive frameworks integrating AI, ethnoscience, and STEM for pre-service physics teacher education remain scarce. Developmental and qualitative approaches dominate existing studies, while mixed-methods, longitudinal, and intervention-based research remains limited. Gaps persist in examining pre-service teachers' AI literacy, TPACK, prior knowledge, and capacity to design culturally contextualized STEM learning supported by AI.
Conclusion: The findings reveal a research gap and provide a foundation for developing empirically validated, culturally responsive frameworks integrating AI, STEM, and ethnoscience to strengthen AI literacy, TPACK, STEM competencies, and contextual pedagogical practice in physics teacher education.

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INTRODUCTION

The integration of Artificial Intelligence (AI), STEM, and ethnoscience holds critical importance for pre-service physics teachers in the 21st century, since together they form a complementary foundation for delivering physics instruction that is intelligent, interdisciplinary, contextual, and meaningful. AI functions both as an enabling technology and a cognitive partner to support analysis, conceptual exploration, problem-solving, and timely feedback; STEM offers an integrative framework that connects physics principles with engineering design, technological applications, mathematics, creativity, and authentic real-world problem-solving; and ethnoscience grounds learning in local cultural knowledge, practices, and phenomena (Beege et al., 2024; Weldeana et al., 2023). Collectively, these three pillars reinforce digital literacy, critical thinking, creativity, collaboration, and problem-solving skills, while equipping future educators to design physics learning that is culturally responsive and attentive to diverse student needs. This combination Artificial Intelligence with STEM and ethnoscience, thus emerges as a strategic blueprint for preparing pre-service physics teachers to become capable future learning designers (Holtbrügge et al., 2025; Nowak, 2026; Yolanda, Arini, Fauziah, et al., 2025). It empowers them to seamlessly integrate technology, sound pedagogy, physics subject content, and local cultural wisdom, thereby fully addressing both the expectations and the challenges of twenty-first-century education.

In addition, the STEM (Science, Technology, Engineering, and Mathematics)-based learning approach is gaining increasing attention as a strategy for improving the quality of science education (Shahat et al., 2025). This approach emphasizes the integration of various disciplines and the application of concepts in real-life situations (Parviz, 2024). For prospective physics teachers, mastering the STEM approach is essential to designing contextual learning experiences that are relevant to the needs of students in the modern era.

In addition, the STEM (Science, Technology, Engineering, and Mathematics)-based learning approach is gaining increasing attention as a strategy for improving the quality of science education(Lohakan & Seetao, 2024; Tripp & Waight, 2024). This approach emphasizes the integration of various disciplines and the application of concepts in real-life situations. For prospective physics teachers, mastering the STEM approach is essential to designing contextual learning experiences that are relevant to the needs of students in the modern era (Yang et al., 2025).

On the other hand, integrating local knowledge through ethnoscience is one way to connect science learning with the surrounding cultural and environmental context. Ethnoscience enables students to understand scientific concepts through local experiences and practices that have developed within their communities (Ammar et al., 2024). In the culturally rich context of Indonesia, this approach has great potential to enhance the relevance and meaning of physics education (Govender et al., 2025).

Several studies indicate that the use of AI in education can enhance learning effectiveness through personalization (Iqbal & Campbell, 2023), data analysis, and the automation of learning processes (Yolanda, Arini, Pribadi, et al., 2025). Other research also confirms that a STEM approach can improve conceptual understanding and higher-order thinking skills (Prihatiningtyas et al., 2025). Meanwhile, studies in ethnoscience suggest that integrating local knowledge can strengthen the connection between science and students' daily lives (Permanasari et al., 2024).

However, most research still focuses on each of these aspects separately. Studies on AI tend to emphasize the technological aspect, while STEM research focuses more on the integration of disciplines, and ethoscience on the cultural context (Maryna et al., 2025; Simpson et al., 2025). This has led to a lack of research that comprehensively examines the integration of these three aspects within a single learning framework (Govender et al., 2025; Valeri et al., 2025).

Furthermore, studies specifically examining prospective physics teachers' prior knowledge regarding the integration of AI, STEM, and ethnoscience remain very limited. Yet, prior knowledge is a critical factor influencing prospective teachers' readiness to design and implement instruction. The scarcity of empirical research examining the implementation of the integration of these three aspects in Indonesia also represents a gap that warrants attention (Maryna et al., 2025b).

Given these gaps, a comprehensive study is needed to map research trends, areas of focus, characteristics, and existing gaps. This study is essential as a foundation for understanding research developments and identifying opportunities for more innovative and context-based learning (Ammar et al., 2024; Boneva & Dimitrov, 2024). Consequently, the integration of AI, STEM, and ethnoscience can be carried out more systematically and effectively.

Therefore, this study aims to analyze publication trends, identify research foci, examine research characteristics, and identify research gaps related to the integration of AI, ethnoscience, and

STEM in the education of prospective physics teachers in Indonesia. The results of this study are expected to contribute to the development of integrative learning models and support the improvement of physics education quality in line with the demands of the 21st century.

METHOD

This study employs an integrative review using the PRISMA method to identify, analyze, and synthesize various research findings related to prospective physics teachers' prior knowledge regarding local wisdom-based STEM education in Indonesia. A systematic literature review (SLR) allows researchers to combine various types of studies, both qualitative and quantitative, thereby providing a more comprehensive understanding of research developments in a specific field (Blackwell, 2019). This approach was chosen because it can identify research trends, areas of focus, and research gaps that still exist in the existing literature (Campbell, 2021).

Table 1. Article Search Characteristics

Characteristics	Explanation
Research Questions	1. What are the trends in research publications regarding the integration of Artificial Intelligence (AI), ethnoscience, and STEM education in the training of prospective physics teachers in Indonesia? 2. What topics or research focuses have been most frequently studied in research on AI, ethnoscience, and STEM in the training of prospective physics teachers in Indonesia? 3. What are the characteristics of the research conducted in these studies, in terms of research methods, publication sources, and research institutions? 4. What research gaps still exist in studies on the integration of AI, ethnoscience, and STEM in the education of prospective physics teachers in Indonesia?
Data Source	The data sources for this study were drawn from scientific articles published in national and international journals relevant to the research topic. The literature search was conducted using several scientific databases, including Google Scholar, IEEE, Scopus, ERIC, and Garuda (Garba Rujukan Digital). The selected articles focused on research addressing STEM education, local wisdom, and the education of prospective physics teachers in Indonesia.
Strategi Pencarian Literatur	The literature search for this study was conducted using a combination of several keywords relevant to the research focus. The keywords were formulated into a Boolean algebraic expression as follows: ("STEM education" OR "ethno-STEM" OR "local wisdom-based STEM") AND ("local wisdom" OR "kearifan lokal") AND ("pre-service physics teacher" OR "physics teacher education" OR "prospective physics teacher") AND ("prior knowledge" OR "initial knowledge") AND ("Artificial Intelligence" OR "AI").
Inclusion criteria:	1. Research articles discussing STEM education, local knowledge, or ethno-STEM. 2. Research involving prospective teachers or physics education students. 3. Articles published in scientific journals or conference proceedings. 4. Articles published between 2015 and 2025. 5. Research conducted in the context of education in Indonesia.
Exclusion criteria	1. Articles that do not address physics education or teacher education. 2. Articles that are solely opinion pieces, editorials, or non-scientific reports. 3. Articles for which the full text is not available. 1. Articles that do not address physics education or teacher education. 4. Articles that are solely opinion pieces, editorials, or non-scientific reports.

	5. Articles for which the full text is not available.
Article selection process	The article selection process consists of several stages, namely: 1. Identification: Collecting articles retrieved from various databases using predetermined keywords. 1. 2. Screening: Selecting articles based on their titles and abstracts to ensure relevance to the research topic. 3. Eligibility: Reviewing the content of the articles in greater depth to ensure they meet the inclusion criteria. 4. Inclusion: Articles that meet all criteria are then selected for further analysis.

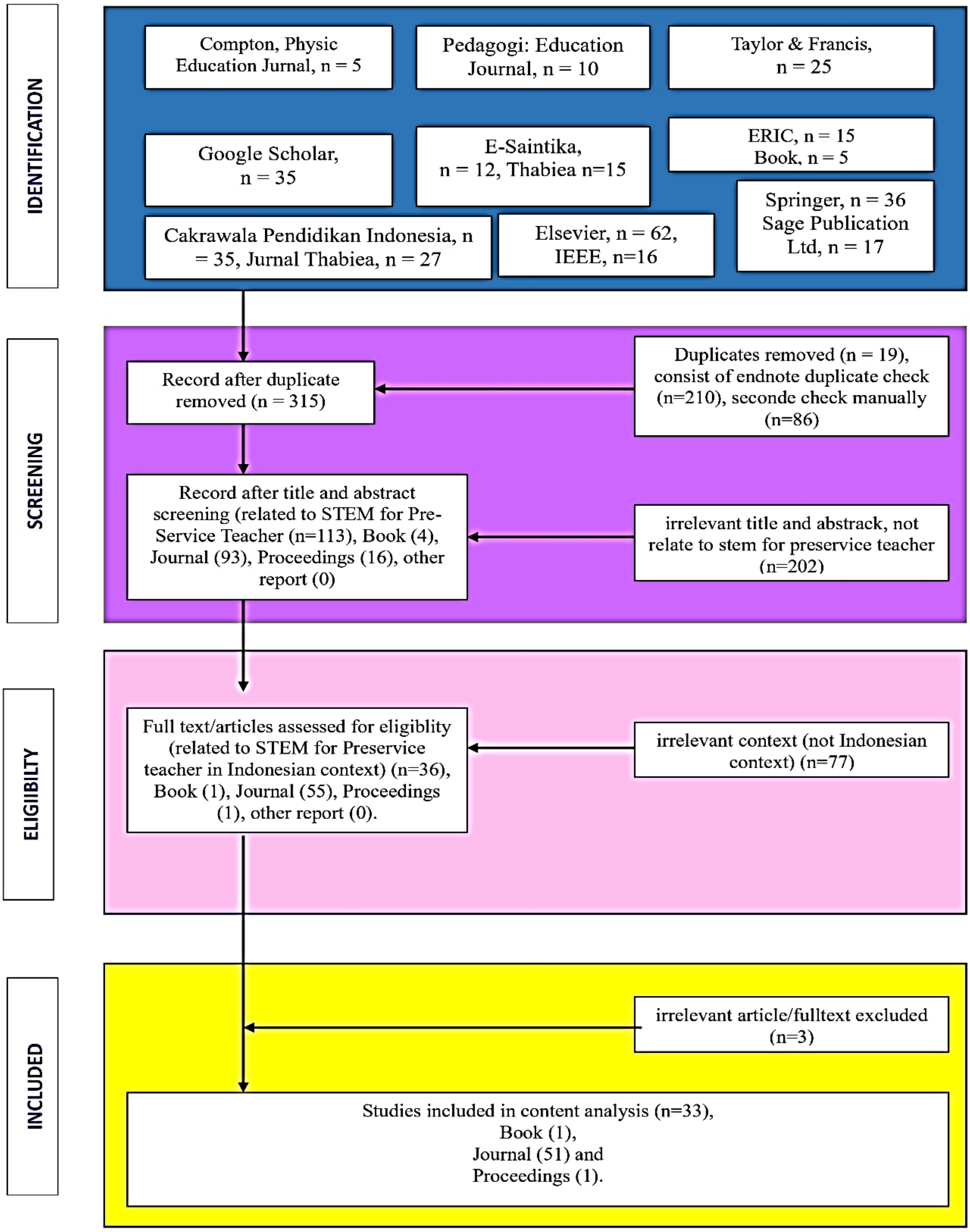

Figure 1. PRISMA stages

Table 2. Analysis and Validity of the Article

Characteristics	Explanation
Data Analysis	Data from the selected articles were analyzed using descriptive content analysis to identify research patterns and trends. The analysis was conducted by classifying the articles based on the following aspects: • Year of publication • Type of research (qualitative, quantitative, mixed methods) • Focus of the study • Research subjects • STEM learning approach used • Context of local wisdom examined • Key research findings Furthermore, the results of the analysis were used to identify research trends and gaps that still exist in studies on the prior knowledge of prospective physics teachers regarding STEM education based on local wisdom in Indonesia.
Validity	To enhance the validity of the research findings, the analysis process was conducted systematically by cross-checking the articles under analysis. In addition, data classification and interpretation were carried out consistently based on the established analytical framework, ensuring that the results of the literature synthesis objectively reflect the research context.

RESULTS

The results of the review on trends in research publications regarding the integration of Artificial Intelligence (AI), ethnoscience, and STEM education in the training of prospective physics teachers in Indonesia are presented in Table 3.

Table 3. Trends in STEM Research in Ethnoscience

Period	The Development of Ethnoscience	Developments in STEM	Research Characteristics
2015–2017	Ethnoscience research increasingly entered science education, particularly through local wisdom and culturally contextual learning.	STEM approaches became increasingly adopted in science education research.	Studies focused on integrating local knowledge with science concepts and developing contextual learning approaches.
2018–2019	Ethnoscience-based learning expanded into learning models, teaching materials, and contextual science education.	STEM research increasingly emphasized interdisciplinary and problem-based learning.	Research focused on developing ethnoscience-based instructional materials and STEM learning models.
2019–2020	Integration of ethnoscience with STEM became increasingly explicit, leading to the emergence and strengthening of Ethno-STEM research.	STEM research increasingly incorporated digital technology, scientific literacy, and 21st-century skills.	Studies emphasized culturally contextual STEM learning, scientific literacy, and development of learning tools.

2020–2021	Ethnoscience research increasingly moved toward integration with digital technology and contemporary educational approaches.	STEM research increasingly incorporated AI, digital learning, and innovative pedagogies.	Research trends emphasized technology-enhanced, culturally responsive, and competency-oriented learning.
2021–2022	Strengthening of research on local wisdom-based learning	STEM became recognized in educational research in Indonesia	Integration of scientific approaches with contextual learning
2022–2024	Strengthening the integration of ethnoscience in teacher education	Integration of STEM with digital technology	Focus on scientific literacy, 21st-century skills, and contextual learning
2024–2026	Ethnoscience studies began to be linked with modern technology	Integration of STEM, digital technology, and Artificial Intelligence (AI) in deep learning	Research trends toward innovation in culture- and technology-based learning

The results of the review regarding the topics or areas of focus most frequently studied in research on AI, ethnoscience, and STEM in the education of prospective physics teachers in Indonesia are presented in Tables 4 and 5.

Table 4. Ethnoscience Topics in the Context of Local Wisdom and Physics Concepts

No	Ethnoscience Focus	Description of Research Focus	Examples of Local Wisdom Context	Related Physics Concepts	Researchers
1	Traditional community technology	Studies examine how simple technologies developed within communities can be used as contexts to understand physics concepts in STEM learning	Traditional houses, farming tools, traditional transportation, local household tools	Force, balance, mechanics, energy, simple machines	(Yolanda & Pribadi, 2026),(Sutaphan & Yuenyong, 2023)
2	Agricultural activities and environmental management	Studies utilize community agricultural practices as learning resources to explain the relationship between natural phenomena and scientific concepts	Determining planting and harvesting seasons, traditional irrigation systems, land cultivation	Solar energy, water cycle, temperature, weather changes	(Nirmala et al., 2025),(Yolanda, Arini, Pribadi, et al., 2025),(Anggita et al., 2024)
3	Cultural traditions and rituals	Local traditions are used as learning contexts	Traditional ceremonies, communal	Energy, sound, waves, motion	(Nehru et al., 2024),(Evans, 2024)

		to connect cultural practices with scientific concepts, making learning more contextual	feasts, cultural rituals, traditional games		
4	Traditional games	Traditional games are analyzed to identify physics concepts that can be used as contexts in STEM learning	Hopscotch, spinning tops, kites, other folk games	Motion, force, momentum, rotation	(Hambali et al., 2026),(Thinnakorn et al., 2026b)
5	Natural phenomena in local knowledge	Community knowledge in observing natural phenomena is used as a source to understand physics and science concepts	Wind direction determination, seasonal change indicators, tides	Air pressure, fluid dynamics, natural energy	(Ainur et al., 2025),(Pardosi et al., 2026), (Kunioshi et al., 2019)
6	Daily community activities	Daily activities are analyzed to identify the relationship between cultural practices and scientific concepts	Traditional cooking, drying agricultural products, handicraft production	Heat, heat transfer, energy	(Yolanda, Arini, Pribadi, et al., 2025),(Rahardjanto et al., 2025)

Table 5. Research Topics or Focus Areas

No	Topic / Focus Area	Description	Example of Research Form	Researchers
1	Integration of Ethnoscience in Physics Learning	Examines how local knowledge or local wisdom can be connected to physics concepts in the learning process	Exploratory studies of local cultural phenomena containing physics concepts	(Simpson et al., 2025),(Maryna et al., 2025b),(Yolanda & Pribadi, 2026)
2	Development of Ethno-STEM Learning Models	Develops learning models that integrate STEM approaches with local cultural contexts	Development of Project-Based Learning, Inquiry, or Problem-Based Learning models based on Ethno-STEM	(Valeri et al., 2025),(Govender et al., 2025),(Lohakan & Seetao, 2024)
3	Development of STEM and Local Wisdom-Based Learning Materials	Develops learning tools such as modules, teaching materials, worksheets, or media based on STEM and ethnoscience	Research and Development (R&D) studies	(Tripp & Waight, 2024),(Yang et al., 2025), (Yolanda, Arini, Fauziah, et al., 2025)
4	Analysis of Pre-Service Physics	Examines pre-service teachers' initial	Surveys or diagnostic studies involving	(Boneva & Dimitrov,

	Teachers' Prior Knowledge	understanding of physics concepts, STEM, and local wisdom	physics education students	2024),(Ammar et al., 2024)
5	Integration of Digital Technology in STEM Learning	Examines the use of digital technology to support culturally contextual STEM learning	Use of virtual labs, simulations, or digital learning platforms	(Iqbal & Campbell, 2023), (Shahat et al., 2025)
6	Utilization of Artificial Intelligence in Physics Education	Examines the use of AI to support learning, learning analytics, or the development of physics learning media	Use of AI tools, learning chatbots, or learning data analysis	(Beege et al., 2024),(Parviz, 2024)
7	Pre-Service Teachers' Competence in STEM Learning	Examines the readiness and competence of pre-service physics teachers in implementing STEM approaches based on local wisdom	Studies on pedagogical content knowledge (PCK) and STEM literacy	(Prihatiningtyas et al., 2025),(Nkopodi et al., 2024),(Yolanda, Arini, Fauziah, et al., 2025)
8	Integration of Local Culture in Teacher Education	Examines the role of local culture in shaping scientific understanding and teaching approaches of pre-service teachers	Conceptual studies and field studies	(Hakim et al., 2023),(Mezinska et al., 2024)

The results of the review regarding the characteristics of the research conducted in the study, as examined in terms of research methods, publication sources, and research institutions, are presented in Table 6.

Table 6. Research Characteristics

Aspect	Category	Description of Findings	Researchers
Research Method	Research and Development (R&D)	Widely used to develop learning tools such as modules, teaching materials, instructional media, and STEM or Ethno-STEM-based learning models.	(Amalu et al., 2023), (Permanasari et al., 2024)
	Quantitative Research	Used to measure the effect of implementing STEM or ethnoscience learning models on learning outcomes, scientific literacy, and critical thinking skills.	(Bardoe et al., 2023).
	Qualitative Research	Used to explore local knowledge, community cultural practices, and how physics concepts can be explained through these cultural phenomena.	(Otto et al., 2025)
	Mixed Methods	Combines quantitative and qualitative approaches to analyze the implementation of STEM learning based on local wisdom more comprehensively.	(Bui et al., 2023),(Nehru et al., 2024)
Publication Sources	Physics Education Journals	The most dominant publication source, as studies focus on physics learning and physics teacher education.	(Skowronek et al., 2022)
	Science Education Journals	Contains research related to STEM integration, scientific literacy, and contextual learning based on local culture.	(Mansour et al., 2025),(Gusman & Yulina, 2023)

	General Education Journals	Presents studies on learning innovation, educational technology, and the development of prospective teacher competencies.	(Santos et al., 2025)
	National / International Conference Proceedings	Serve as an initial platform for research publication before being developed into journal articles.	(Aguayo et al., 2023)
Researcher Institutions	Public Universities	Most studies are conducted by academics from universities with physics education or science education programs.	(Malele & Ramaboka, 2023)
	Private Universities	Also contribute to research on STEM learning development and the integration of local wisdom in science education.	(Yolanda, Arini, Fauziah, et al., 2025),(Dhany & Yulianti, 2025),(Shofiyah et al., 2021)
	Inter-institutional Collaboration	Some studies are conducted through collaboration between universities or between science education researchers and experts in culture and educational technology.	(Yolanda & Pribadi, 2026),(Suyono & Azizah, 2020),(Yanti et al., 2025)

The results of the review regarding the research gaps that still exist in studies on the integration of AI, ethnoscience, and STEM in the education of prospective physics teachers in Indonesia are shown in Table 7.

Table 7. Research Gaps

No	**Aspect**	**Current Research Condition**	**Research Gap**	**Future Research Opportunities**
1	Integration of AI in Ethnoscience-Based Learning	Most studies still focus on integrating ethnoscience and STEM without directly involving AI technology.	Research that explicitly integrates AI with Ethno-STEM is still very limited.	Development of AI-supported Ethno-STEM learning models in physics teacher education.
2	Research Subject Focus	Many studies are conducted on secondary school students.	Research specifically examining pre-service physics teachers is still relatively limited.	Studies on the readiness, competencies, and AI literacy of pre-service physics teachers.
3	Research Methodological Approach	Research is dominated by development (R&D) studies and learning experiments.	There is still limited use of mixed methods, longitudinal studies, or meta-analyses.	Research using more diverse and in-depth methodological approaches.
4	Variation of Local Wisdom Context	Most studies only highlight a few specific examples of local cultures.	Exploration of local wisdom from various regions in Indonesia is still limited.	Broader identification of local knowledge related to physics concepts.
5	Integration of Digital Technology and AI	Digital technology has begun to be used in STEM learning.	The use of AI as a learning analysis tool or culture-based	Development of AI-based learning tools that integrate local culture.

			learning media is still rare.	
6	Study of Pre-service Teacher Competencies	Research mostly assesses student learning outcomes.	In-depth studies on prior knowledge, STEM literacy, and AI literacy of pre-service physics teachers are still limited.	Research on developing professional competencies of pre-service teachers in integrating AI and Ethno-STEM.

Table 3 illustrates that the evolution of STEM research within the ethnoscience context from 2015 to 2026 has shifted from merely using local knowledge as a learning context toward deeper integration between ethnoscience, STEM, digital technology, and Artificial Intelligence (AI). Between 2015 and 2017, research primarily centered on merging local wisdom and scientific concepts through contextual instruction; this expanded in 2018–2019 to develop interdisciplinary, problem-based STEM curricula, models, and teaching materials. By 2019–2021, the link between ethnoscience and STEM became more explicit through the advancement of Ethno-STEM frameworks, scientific literacy, 21st-century skills, and digital adoption, while 2021–2024 placed greater emphasis on local wisdom, teacher preparation, and technology-enhanced STEM education.

DISCUSSION

Collectively, these developments trace three sequential phases: contextualization, integration, and technological transformation. Initially, ethnoscience functioned as a contextual foundation; it then became fully integrated through interdisciplinary strategies, literacy building, and resource development; and now progresses toward AI-driven and deep learning-based approaches that are culturally responsive. This trajectory signals a shift from treating local culture as supportive background to building cohesive learning ecosystems that unite local knowledge, scientific understanding, STEM proficiency, digital tools, and AI. At the same time, it exposes a meaningful research gap: few studies have systematically combined ethnoscience, STEM, AI, and deep learning within a single pedagogical framework that has been fully validated and empirically tested for effectiveness.

The results presented in Tables 4 and 5 indicate that research on ethnoscience in physics education in Indonesia is highly diverse and closely connected to local wisdom. As shown in Table 4, frequently studied topics include traditional community technology, agricultural practices, cultural traditions, traditional games, natural phenomena, and daily community activities. Studies by (Yolanda & Pribadi, 2026) and (Sutaphan & Yuenyong, 2023) demonstrate how traditional technologies can explain physics concepts such as force and mechanics. Similarly, research by (Nirmala et al., 2025), (Yolanda, Arini, Pribadi, et al., 2025), and (Anggita et al., 2024) shows how agricultural activities help explain solar energy and weather changes. Cultural contexts are also widely used, as seen in studies by (Nehru et al., 2024), and (Evans, 2024), while traditional games are explored by (Hambali et al., 2026), and (Thinnakorn et al., 2026a) to illustrate motion and momentum. In addition, local knowledge of natural phenomena has been studied by (Ainur et al., 2025), (Pardosi et al., 2026), and (Kunioshi et al., 2019), while daily activities are examined by (Rahardjanto et al., 2025). These findings show that ethnoscience-based learning effectively connects physics concepts with students' real-life cultural experiences, making learning more meaningful and contextual.

Meanwhile, Table 5 reveals that research topics have expanded toward more structured, pedagogical, and technology-integrated approaches. The integration of ethnoscience in physics learning has been explored by (Simpson et al., 2025) and (Maryna et al., 2025a), while the development of Ethno-STEM learning models has been carried out by (Valeri et al., 2025), (Govender et al., 2025), and (Lohakan & Seetao, 2024). Research on learning materials has been conducted by (Tripp & Waight, 2024) and (Yang et al., 2025), while studies on pre-service teachers' knowledge and competencies involve , (Ammar et al., 2024), (Prihatiningtyas et al., 2025), and (Nkopodi et al., 2024).

Furthermore, the integration of digital technology and Artificial Intelligence has been investigated by (Iqbal & Campbell, 2023), (Beege et al., 2024), and (Parviz, 2024), while the role of local culture in teacher education is discussed by (Hakim et al., 2023) and (Mezinska et al., 2024). Overall, these findings indicate a shift toward integrating ethnoscience, STEM, and advanced technologies, highlighting the importance of preparing prospective physics teachers who are both culturally responsive and technologically competent.

The results presented in Table 6 show that research on the integration of ethnoscience, STEM, and Artificial Intelligence in physics education is characterized by diverse methodological approaches. The most dominant method is Research and Development (R&D), which is widely used to design and develop learning tools such as modules, instructional media, and Ethno-STEM-based learning models, as demonstrated by studies conducted by (Amalu et al., 2023) and (Permanasari et al., 2024). In addition, quantitative research is frequently employed to measure the effectiveness of these learning models on students' learning outcomes, scientific literacy, and critical thinking skills, as seen in studies by (Bardoe et al., 2023). Qualitative approaches are also utilized to explore local knowledge and cultural practices, particularly in understanding how physics concepts can be explained through cultural contexts, as highlighted by (Otto et al., 2025). Furthermore, mixed methods research, as conducted by (Nehru et al., 2024), provides a more comprehensive analysis by combining both quantitative and qualitative data.

In terms of publication sources, the findings indicate that physics education journals are the most dominant outlets, reflecting the strong focus on physics learning and teacher education, as shown in studies by (Skowronek et al., 2022). Science education journals also play a significant role by publishing studies on STEM integration and scientific literacy, such as those by (Mansour et al., 2025), (Gusman & Yulina, 2023). Additionally, general education journals contribute by addressing broader themes such as educational innovation and teacher competence development, as seen in studies by (Santos et al., 2025), while conference proceedings, such as those by (Aguayo et al., 2023), serve as initial dissemination platforms. From an institutional perspective, most research is conducted by academics from public universities, as indicated by (Malele & Ramaboka, 2023), although private universities also contribute significantly, as shown by (Yolanda, Arini, Fauziah, et al., 2025), (Dhany & Yulianti, 2025), and (Shofiyah et al., 2021). Moreover, collaborative research across institutions, such as those conducted by (Yolanda & Pribadi, 2026), (Suyono & Azizah, 2020), and (Yanti et al., 2025), highlights the growing trend of interdisciplinary and cross-institutional cooperation in advancing ethnoscience and STEM-based physics education research.

The results presented in Table 7 reveal several important research gaps in studies on the integration of ethnoscience, STEM, and Artificial Intelligence in the education of prospective physics teachers in Indonesia. One of the main gaps lies in the limited integration of AI within ethnoscience-based learning, as most existing studies still focus primarily on combining ethnoscience and STEM without explicitly incorporating AI. This indicates that the development of AI-supported Ethno-STEM learning models remains underexplored. In addition, the majority of research has been conducted on secondary school students, while studies focusing specifically on pre-service physics teachers are still relatively scarce. This suggests a need for further investigation into the readiness, competencies, and AI literacy of future physics teachers to better prepare them for technology-enhanced learning environments.

Another significant gap relates to research methodologies and the scope of study contexts. Current research is largely dominated by Research and Development (R&D) and experimental approaches, with limited use of more comprehensive methods such as mixed methods, longitudinal studies, or meta-analyses. Furthermore, most studies tend to focus on a narrow range of local cultural contexts, indicating that the diversity of local wisdom across different regions in Indonesia has not been fully explored. In terms of technology integration, although digital tools have begun to be utilized in STEM learning, the application of AI as a tool for learning analysis or as a medium for culturally based learning is still rare. Additionally, research has predominantly emphasized student learning outcomes, while in-depth studies on the prior knowledge, STEM literacy, and AI literacy of pre-service physics teachers remain limited. Therefore, future research should focus on developing more diverse methodological approaches, expanding cultural contexts, and designing innovative AI-based learning tools, while also strengthening the professional competencies of prospective physics teachers in integrating ethnoscience, STEM, and AI.

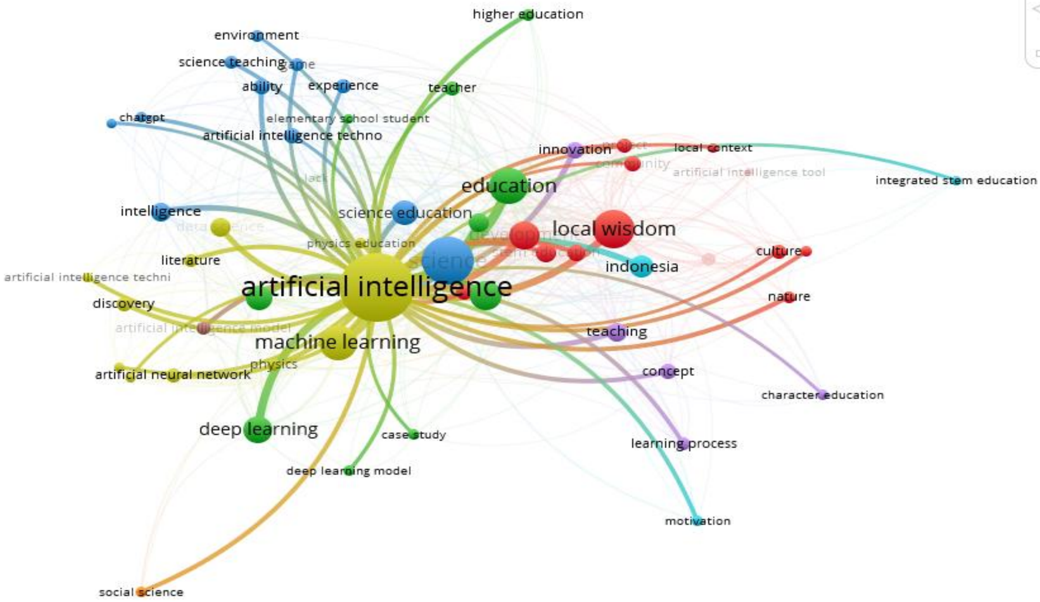

Figure 2. Network Visualization

The keyword network visualization ini figure 2, demonstrates a strong dominance of *artificial intelligence* as the central and most interconnected theme, indicating that current research in science education is heavily driven by technological advancement, particularly AI integration. This is reinforced by its close links with related concepts such as machine learning, deep learning, and artificial neural networks, which form a dense cluster representing modern computational approaches in education. At the same time, the visualization reveals the presence of a distinct yet less connected cluster centered on *local wisdom*, which is associated with terms such as culture, Indonesia, and local context, highlighting efforts to contextualize science learning within cultural frameworks. However, the relatively weak connections between these two major clusters suggest that the integration of AI-driven approaches with local wisdom-based education remains limited and underexplored. Additionally, while nodes like education, science education, and teaching act as bridges between clusters, the absence of strong linkages to concepts such as prior knowledge or prospective physics teachers indicates a gap in research focusing on teacher readiness. Overall, this pattern reflects an imbalance where technological innovation advances rapidly, but its meaningful integration with culturally relevant and pedagogically grounded approaches, particularly in the Indonesian context still requires deeper and more systematic investigation.

The overlay visualization in Figure 3 highlights the temporal evolution of research topics, where color gradients indicate the relative recency of keyword emergence. It is evident that *artificial intelligence* remains the central and most influential theme, consistently connected to both earlier and more recent topics, demonstrating its sustained importance in science education research. Keywords such as machine learning, deep learning, and artificial neural network appear in relatively earlier phases, reflecting the foundational development of AI-based approaches. Meanwhile, more recent trends are indicated by the emergence of terms such as local wisdom, integrated STEM education, innovation, and local context, which are shown in lighter colors. This shift suggests a growing research interest in contextualizing technological advancements within cultural and educational settings. However, despite this positive trend, the connections between newer topics and established AI concepts remain relatively limited, indicating that the integration between advanced technologies and locally grounded educational approaches is still developing. Overall, the visualization suggests a transition from purely technology-driven research toward more integrative and context-aware studies, although deeper synthesis between these domains is still needed.

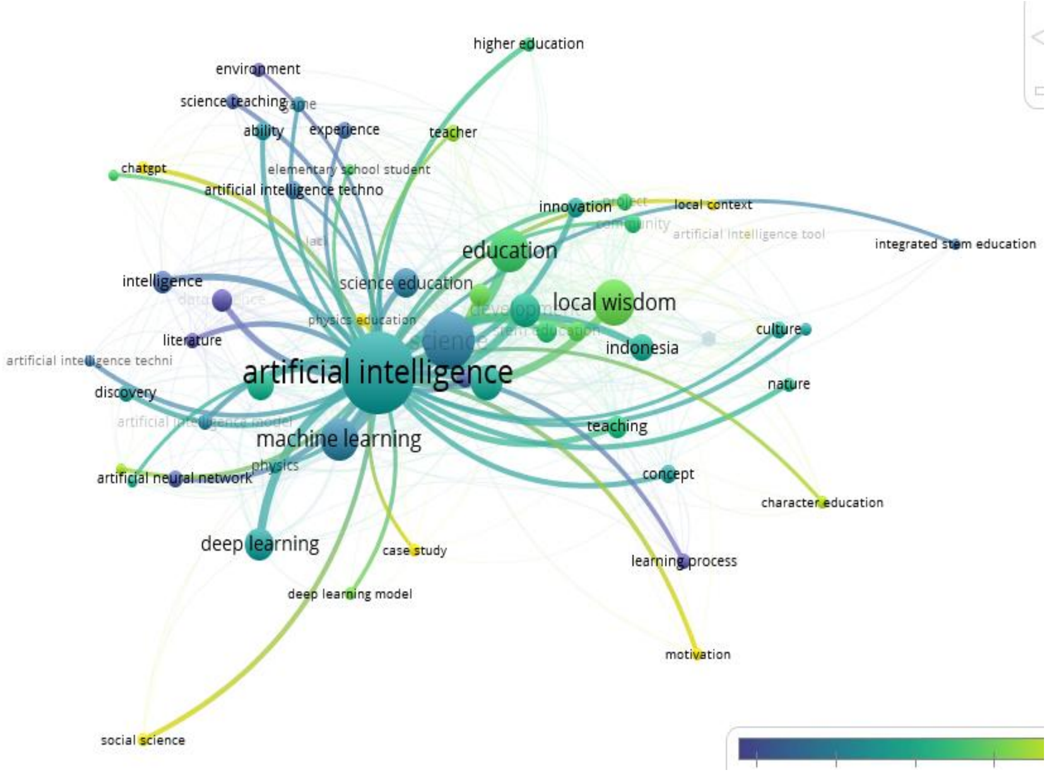

Figure 3. Overlay Visualization

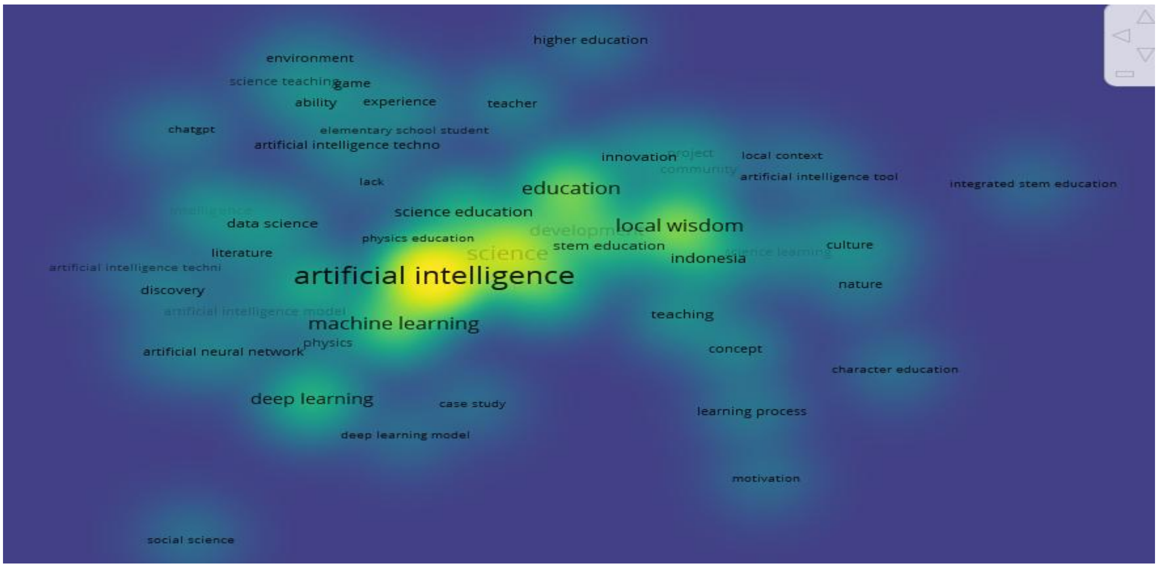

Figure 4. Density Visualization

The density visualization in Figure 4 reveals the concentration and intensity of research focus within the mapped topics, where brighter areas indicate higher keyword density and stronger research activity. The most prominent hotspot is centered on *artificial intelligence*, highlighting it as the core and most extensively studied theme within the field. This central density is closely surrounded by related concepts such as machine learning, deep learning, science, and science education, indicating a well-established and highly integrated body of research on AI-driven approaches in science learning. In contrast, areas associated with *local wisdom*, Indonesia, culture, and STEM education appear with lower density levels, suggesting that although these topics are present, they have not yet reached the same level of research intensity. Additionally, peripheral concepts such as learning process, motivation, and character education are more sparsely distributed, indicating limited exploration and weaker integration into the main research discourse.

Overall, this visualization underscores a significant imbalance in the research landscape, where technology-oriented studies dominate, while the integration of cultural context and pedagogical depth, particularly those related to local wisdom and learner characteristics, remains underdeveloped and presents substantial opportunities for future research.

Implications

The findings of this study indicate that the integration of artificial intelligence, STEM approaches, and local wisdom has significant potential to enhance the quality of science learning, making it more contextual, innovative, and relevant to 21st-century needs. These results imply the need to develop learning models that are not only technology-oriented but also capable of incorporating local cultural values as meaningful learning resources. Furthermore, educational institutions and teacher education programs are expected to strengthen the conceptual and pedagogical readiness of prospective teachers, particularly in integrating advanced technologies with ethnoscience approaches. Thus, learning should not only focus on conceptual understanding but also on the development of character and contextual awareness among students.

Limitations

This study has several limitations that should be acknowledged. First, the analysis is based on bibliometric data, making it highly dependent on the availability and quality of data within the selected database, which may result in the exclusion of relevant publications. Second, the keyword network visualization approach only represents general conceptual relationships and does not fully capture the depth of each study's content. Third, this research does not examine the empirical implementation of integrating artificial intelligence, STEM, and local wisdom in classroom practice; therefore, the findings remain descriptive and exploratory.

Research Contributions

This study makes an important contribution by mapping research trends and identifying gaps in the field of science education related to the integration of artificial intelligence, STEM, and local wisdom. Theoretically, it enriches the discourse on ethnoscience by positioning it within the context of modern technological developments. Practically, the findings can serve as a reference for researchers and educators in designing more innovative and contextual learning approaches. In addition, this study opens opportunities for further, more integrative research, particularly in examining the prior knowledge of prospective physics teachers as a crucial factor in the successful implementation of STEM and local wisdom-based learning.

Suggestions

Based on the findings of this study, several recommendations can be proposed. Future research should focus on developing and empirically testing integrative learning models that combine artificial intelligence, STEM approaches, and local wisdom to ensure their effectiveness in real classroom settings. It is also important to explore the prior knowledge and readiness of prospective physics teachers in implementing such approaches, as this aspect plays a crucial role in successful learning outcomes. Additionally, researchers are encouraged to conduct interdisciplinary studies that bridge technological innovation with cultural and contextual dimensions of education, particularly within the Indonesian context. Educational institutions and policymakers should support training programs that enhance teachers' competencies in integrating advanced technologies with ethnoscience-based learning. Finally, expanding data sources and employing mixed-method approaches are recommended to provide more comprehensive and in-depth insights into the development of contextual and technology-enhanced science education.

CONCLUSION

Based on the results of the integrative review, it can be concluded that the research trend on the integration of Artificial Intelligence (AI), ethnoscience, and STEM learning in the education of prospective physics teachers in Indonesia has shown a significant increase in recent years. However, this development is still dominated by studies focusing on the use of AI and technology-based STEM development separately, while integration with ethnoscience or local wisdom has not yet become a primary focus. In terms of research focus, existing studies largely emphasize the development of technology-based learning models, the implementation of STEM in science education, and the integration of local values to enrich learning. Nevertheless, studies that specifically connect these three aspects within a comprehensive framework, particularly in the context of prospective physics teacher education, remain very limited. In addition, the aspect of prospective teachers' prior knowledge as a crucial factor in learning success has not been extensively explored.

Furthermore, the characteristics of existing studies are generally dominated by qualitative approaches and development research, with limited contributions from quantitative and mixed methods. Most publications originate from national journals and conference proceedings and are primarily conducted by domestic institutions, with international collaboration still not optimal. This review also identifies several important research gaps, including the lack of comprehensive integration of AI, ethnoscience, and STEM, the limited focus on the prior knowledge of prospective physics teachers, and the scarcity of empirical studies testing the effectiveness of such integration in practice. Therefore, future research should be directed toward developing more holistic and integrative learning models, accompanied by stronger empirical investigations and increased international collaboration, in order to provide broader contributions and greater impact on the advancement of science education in Indonesia.

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AUTHOR CONTRIBUTION STATEMENT

YY: conceptualized the study, designed the research framework, conducted data analysis, and prepared the original manuscript draft. BH: Contributed to the research methodology, supervised the study, and reviewed and revised the manuscript critically. MN was responsible for data curation, validation of results, and contributed to the interpretation of findings. PM: Assisted in data collection, literature review, and manuscript editing. IAP: Contributed to formal analysis, provided additional resources, and participated in reviewing and refining the final manuscript. All authors have read and approved the final version of the manuscript.

REFERENCES

Aguayo, C., Videla, R., & Ibacache, C. (2023). Ethical enactivism for smart and inclusive STEAM learning design. *Heliyon*, *9*, 1–15. https://doi.org/10.1016/j.heliyon.2023.e19205

Ainur, I., Raditya, F. N., Ahla, D. A. R., & Riski Muhammad, H. (2025). Ethnoscience-enhanced physics virtual simulation and augmented reality with inquiry learning: Impact on students' creativity and motivation. *Thinking Skills and Creativity*, *57*, 101846. https://doi.org/10.1016/j.tsc.2025.101846

Amalu, E. H., Short, M., Lin, P., Hughes, D. J., Adebayo, D. S., Kukka, M., Polyzou, O., & Ekere, N. N. (2023). Critical skills needs and challenges for STEM / STEAM graduates increased employability and entrepreneurship in the solar energy sector. *Renewable and Sustainable Energy Reviews*, *187*, 113776. https://doi.org/10.1016/j.rser.2023.113776

Ammar, M., Al-thani, N. J., & Ahmad, Z. (2024). Role of pedagogical approaches in fostering innovation among K-12 students in STEM education. *Social Sciences & Humanities Open*, *9*, 100839. https://doi.org/10.1016/j.ssaho.2024.100839

Anggita, S., Endraswara, S., & Rohman, A. (2024). Revitalizing local wisdom within character education through ethnopedagogy approach: A case study on a preschool in Yogyakarta. *Heliyon*, *10*(10), e31370. https://doi.org/10.1016/j.heliyon.2024.e31370

Bardoe, D., Hayford, D., Bagngmen, R., & Gyabeng, J. (2023). Challenges to the implementation of STEM education in the Bono East Region of Ghana. *Heliyon*, *9*, e20416. https://doi.org/10.1016/j.heliyon.2023.e20416

Beege, M., Hug, C., & Nerb, J. (2024). AI in STEM education: The relationship between teacher perceptions and ChatGPT use. *Computers in Human Behavior Reports*, *16*, 100494. https://doi.org/10.1016/j.chbr.2024.100494

Blackwell, W. (2019). *Cochrane Handbook for Systematic Reviews of Interventions*. John Wiley & Sons Ltd. http://www.wiley.com/go/permissions

Boneva, Y., & Dimitrov, S. (2024). Criteria and Approaches for Optimization of Criteria Criteria and and Approaches Approaches for for Optimization Optimization of for Optimization of Education Criteria and Approaches for Optimization of Innovative Methods for STEM. *Science Direct IFAC Papers OnLine*, *58*(3), 123–128. https://doi.org/10.1016/j.ifacol.2024.07.137

Bui, T., Tran, T., & Nguyen, T. (2023). Dataset of Vietnamese preschool teachers' readiness towards implementing STEAM activities and projects. *Data in Brief*, *46*, 108821. https://doi.org/10.1016/j.dib.2022.108821

Campbell. (2021). *Campbell systematic reviews : Policies and guidelines* (Welch, Viv, Issue February). The Campbell Collaboration.org. https://doi.org/10.4073/cpg.2016.1

Dhany, K. R., & Yulianti, D. (2025). The Prospects and Challenges of STEM-PjBL with Design Thinking Strategies in Enhancing Students ' Creativity and Entrepreneurial Thinking in the Context of Plastic Waste Recycling : Teachers ' Perspectives. *Jurnal Penelitian Pendidikan IPA*, *11*(1), 28–37. https://doi.org/10.29303/jppipa.v11i1.9357

Evans, C. (2024). Care experienced students ' transitions to university : learning identities , prior educational experiences and socio-cultural contexts. *British Journal of Sociology of Education*, *45*(7–8), 1059–1073. https://doi.org/10.1080/01425692.2024.2392148

Govender, N., Moheeput, K., & Singh, A. (2025). Cultural decolonization and implications for pedagogy in integrating STEM - IKS education in the Global South. *Cultural Studies of Science Education*, *October*, 1–25. https://doi.org/10.1007/s11422-025-10270-6

Gusman, T. A., & Yulina, I. K. (2023). The Effect of STEM Integrated Problem-Based Learning Model on Students ' Critical Thinking Skills on Electrolyte and Non- Electrolyte Solution Materials. *Jurnal Penelitian Pendidikan IPA*, *9*(10), 8911–8917. https://doi.org/10.29303/jppipa.v9i10.5163

Hakim, A., Efwinda, S., Damayanti, P., Syam, M., Mutmainah, O., & Norsaputra, A. (2023). Improving Climate Literacy of High School Students Through Physics Teaching Materials Based on STEM. *Jurnal Pendidikan IPA Indonesia*, *12*(4), 526–537. https://doi.org/10.15294/jpii.v12i4.43188

Hambali, I. M., Prasetya, A., Marzuki, W., & Jaafar, W. (2026). Revitalizing indigenous wisdom to prevent bullying : A qualitative ethnographic study of Bugis-Makassar cultural values in education. *Social Sciences & Humanities Open*, *13*(November 2025), 102342. https://doi.org/10.1016/j.ssaho.2025.102342

Holtbrügge, D., Wicht, L., & Bernhard, T. (2025). The use and usefulness of artificial intelligence in international business education. Evidence from a field study. *International Journal of Management Education*, *23*(3). https://doi.org/10.1016/j.ijme.2025.101258

Iqbal, M. Z., & Campbell, A. G. (2023). AGILEST approach : Using machine learning agents to facilitate kinesthetic learning in STEM education through real-time touchless hand interaction. *Telematics and Informatics Reports*, *9*(100034), 1–11. https://doi.org/10.1016/j.teler.2022.100034

Kunioshi, N., Noguchi, J., & Tojo, K. (2019). Evidence of cultural differences between American and Japanese mainstream science and engineering contexts from analysis of classroom discourse. *European Journal of Engineering Education ISSN:*, *3797*. https://doi.org/10.1080/03043797.2018.1428531

Lohakan, M., & Seetao, C. (2024). Large-scale experiment in STEM education for high school students using artificial intelligence kit based on computer vision and Python. *Heliyon*, *10*(e31366), 1–16. https://doi.org/10.1016/j.heliyon.2024.e31366

Malele, V., & Ramaboka, M. E. (2023). The Design Thinking Approach to students STEAM projects.

Science Direct, *91*(March), 230–236. https://doi.org/10.1016/j.procir.2020.03.100

Mansour, N., Cevik, M., & Uzun, Y. (2025). Exploring the Impact of STEAM and Connected Learning on Skills of digital age in Primary Schools. *Thinking Skills and Creativity*, 1–42. https://doi.org/10.1016/j.tsc.2025.102024

Maryna, N., Hanna, M., Kristina, P., Olena, K., Serhii, K., & Yana, S. (2025a). STEM education through the eyes of teachers from various specialties in Ukrainian Pedagogical University. *International Journal of Educational Research Open*, *9*, 100464. https://doi.org/10.1016/j.ijedro.2025.100464

Mezinska, S., Abolina, A., & Lubkina, V. (2024). Design-driven innovation in STEM disciplines in higher education : The role and impact of transversal competences. *Journal of Open Innovation: Technology, Market, and Complexity*, *10*(100429), 1–15. https://doi.org/10.1016/j.joitmc.2024.100429

Nehru, Purwaningsih, S., Riantoni, C., Ropawandi, D., & Novallyan, D. (2024). Mapping Students ' Thinking Systems In Critical Thinking Based On Stem Project-Based Learning Experiences. *Jurnal Ilmiah Ilmu Terapan Universitas Jamb*, *8*(1), 136–144. https://onlinejournal.unja.ac.id/JIITUJ/article/view/32027

Nirmala, S. A., Rokhmat, J., Ramdhani, A., & Sukarso, A. A. (2025). The Implementation of Project Based Learning integrated Ethno- STEM in Indonesia. *Jurnal Penelitian Dan Pengkajian Ilmu Pendidikan: E-Saintika*, *9*(2), 316–332. https://doi.org/https://doi.org/10.36312/e-saintika.v9i2.2856

Nkopodi, N., Jakovljevic, M., & Photo, P. (2024). Criteria for enhancing student wellbeing in STEM classrooms : ICT and indigenous knowledge in South African higher education. *Discover Education*, *3*(152), 1–15. https://doi.org/10.1007/s44217-024-00251-2

Nowak, P. M. (2026). Artificial Intelligence in Analytical Chemistry: Towards Yet Undiscovered Opportunities. *Analytical Chemistry*, *98*(8), 5843–5853. https://doi.org/10.1021/acs.analchem.5c06840

Otto, S., Lavi, R., & Brogaard, L. (2025). Human-GenAI interaction for active learning in STEM education : State-of-the-art and future directions. *Computers & Education*, *239*(105444), 1–16. https://doi.org/10.1016/j.compedu.2025.105444

Pardosi, J., Putra, I. M., & Napitupulu, B. P. (2026). Integration of local wisdom in tourism : a cultural studies perspective for sustainable development in Samosir. *Cogent Social Sciences*, *12*(1). https://doi.org/10.1080/23311886.2026.2624136

Parviz, M. (2024). AI in education : Comparative perspectives from STEM and Non-STEM instructors. *Computers and Education Open*, *6*(100190), 1–12. https://doi.org/10.1016/j.caeo.2024.100190

Permanasari, A., Rubini, B., Pursitasari, I. D., Nurramadhani, A., Hadiana, D., Suwarma, I. R., & Kumano, Y. (2024). Fun Classroom: How Seven Graders and Science Teachers Respond to STEM Learning as the First Experience in Suburban Area? *Jurnal Pendidikan IPA Indonesia*, *13*(1), 55–63. https://doi.org/10.15294/jpii.v13i1.47386

Prihatiningtyas, S., Yunus, S. R., & Putra, I. A. (2025). Enhancing science literacy through flipbook-based STEM Qur'an e-modules: a case study in Islamic boarding schools. *Humanities & Social Sciences Communications*, *12*(2025), 1–12. https://doi.org/10.1057/s41599-025-05054-w

Rahardjanto, A., Hudha, A. M., & Permana, T. I. (2025). Ecocultural practices in East Java , Indonesia : A hermeneutic phenomenological study on " Reresik Kali " as local wisdom for river conservation. *Social Sciences & Humanities Open*, *12*(November), 102176. https://doi.org/10.1016/j.ssaho.2025.102176

Santos, J. M. D. S., Silveira, A. R. P., & Breda, A. M. R. D. A. (2025). Empowering Mozambican educators : Overcoming technological challenges to implement STEAM education. *International Journal of Educational Research Open*, *9*(100481), 1–9. https://doi.org/10.1016/j.ijedro.2025.100481

Shahat, M. A., Emam, M. M., Alhinai, M., Omara, E. M., Alhabsi, N., Alhosni, K., Al-yahmedi, A., Al-amri, M., & Ismail, S. S. (2025). Enhancing middle school science education : Evaluating a competency-based STEM training program for teachers. *Social Sciences & Humanities Open*, *11*(101457), 1–13. https://doi.org/10.1016/j.ssaho.2025.101457

Shofiyah, N., Mauliana, M. I., & Wulandari, R. (2021). STEM Approach : The Development of Optical Instruments Module to Foster Scientific Literacy Skill. *Jurnal Penelitian Dan Pengkajian Ilmu*

Pendidikan: E-Saintika, *5*(2), 92–103. https://doi.org/https://doi.org/10.36312/esaintika.v5i2.388

Simpson, A., Mccann, J., Miroff, L. E., & Mcgee, T. (2025). The Complex STEM Identity Development of Middle School Girls in a Culturally Infused Afterschool Program. In *Journal for STEM Education Research* (Issue 0123456789). Springer International Publishing. https://doi.org/10.1007/s41979-025-00162-3

Skowronek, M., Gilberti, M., Petro, M., Sancomb, C., Maddern, S., & Jankovic, J. (2022). Inclusive STEAM education in diverse disciplines of sustainable energy and AI. *Energy and AI Journal*, *7*(October 2021), 1–5. https://doi.org/10.1016/j.egyai.2021.100124

Sutaphan, S., & Yuenyong, C. (2023). Enhancing grade eight students ' creative thinking in the water STEM education learning unit. *Cakrawala Pendidikan Jurnal Ilmiah Pendidikan*, *42*(1), 120–135. https://doi.org/https://doi.org/10.21831/cp.v42i1.36621

Suyono, S., & Azizah, U. (2020). Development of STEM-Based Chemistry Textbooks to Improve Students ' Problem Solving Skills. *Jurnal Penelitian Dan Pengkajian Ilmu Pendidikan: E-Saintika*, *4*(3), 308–318. https://journal-center.litpam.com/index.php/e-Saintika/article/view/306

Thinnakorn, W., Noonsuk, W., & Srimuang, K. (2026a). Cultural identity, local wisdom and sustainability of bamboo in forming vernacular architecture: a case study of Bang Chak and Khlong Noi communities, Mueang District, Nakhon Si Thammarat Province. *Cogent Arts & Humanities*, *13*(1). https://doi.org/10.1080/23311983.2025.2603722

Thinnakorn, W., Noonsuk, W., & Srimuang, K. (2026b). Cultural identity , local wisdom and sustainability of bamboo in forming vernacular architecture : a case study of Bang Chak and Khlong Noi communities , Mueang District , Nakhon Si Thammarat Province forming vernacular architecture : a case study of Bang. *Cogent Arts & Humanities*, *13*(1). https://doi.org/10.1080/23311983.2025.2603722

Tripp, J. N., & Waight, N. (2024). Paradoxical perceptions : minoritized high school students ' stereotypical and expansive views of science and scientists at an urban , inclusive STEM-focused high school (ISHS). *Disciplinary and Interdisciplinary Science Education Research*, *6*(21), 1–28. https://doi.org/https://doi.org/10.1186/s43031-024-00110-y

Valeri, F., Nilsson, P., & Cederqvist, A. (2025). Exploring students' experience of ChatGPT in STEM education. *Computers and Education: Artificial Intelligence*, *8*(100360), 1–12. https://doi.org/10.1016/j.caeai.2024.100360

Weldeana, H. N., Sbhatu, D. B., & Berhe, G. T. (2023). Freshman STEM students' misconceptions in a basic limit theorem of lim x→0(sinx/x). *Heliyon*, *9*(12), 1–16. https://doi.org/10.1016/j.heliyon.2023.e22359

Yang, W., Liang, L., Xiang, S., & Yeter, I. H. (2025). Making a Makerspace in early childhood education : Effects on children ' s STEM thinking skills and emotional development. *Thinking Skills and Creativity*, *56*(101754), 1–16. https://doi.org/10.1016/j.tsc.2025.101754

Yanti, Y. E., Safitri, R., Perucha, R., Afidh, F., Azmi, N., Zainuddin, A. A., Aatieff, A., Hussain, A., & Azmi, M. K. (2025). Implementing R-STEM and the ISLE Model to Enhance Students ' Conceptual Understanding of Magnetic Induction at Unsyiah Laboratory School. *Jurnal Penelitian Pendidikan IPA*, *11*(3), 760–768. https://doi.org/10.29303/jppipa.v11i3.8665

Yolanda, Y., Arini, W., Fauziah, A., Effendi, E., & Pribadi, I. A. (2025). Artificial Intelligence assisted Renewable Energy Case Based Learning Integrated with Science Process Skills and Digital Literacy. *Jurnal Penelitian Dan Pengkajian Ilmu Pendidikan: E-Saintika*, *9*(2), 405–428. https://doi.org/10.36312/e-saintika.v9i2.3050

Yolanda, Y., Arini, W., Pribadi, I. A., & Setiawan, T. (2025). High Efficiency , Low Emissions And High Power : Iot Based Biomass Stove Fueled By Corn Cob And Coconut Shell For Sustainable Renewable Energy. *International Journal of Environmental Sciences 23s*, *11*(23s), 5329–5343. https://doi.org/https://doi.org/10.64252/apvsya80

Yolanda, Y., & Pribadi, I. A. (2026). Transformation Science Classes with Artificial Intelligence and the Tradition of "Sedekah Bumi": Learning About Renewable Energy in Context. *Jurnal Ilmiah Ilmu Terapan Universitas Jambi*, *10*(1), 221–237. https://doi.org/10.22437/jiituj.v10i1.45003