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INTEGRATION OF ARTIFICIAL INTELLIGENCE, DIGITAL MULTIMEDIA, AND INDIGENOUS KNOWLEDGE IN SCIENCE EDUCATION: A SYSTEMATIC REVIEW

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ABSTRACT

Science education in the 21st century requires transformative approaches through the integration of Artificial Intelligence (AI), digital multimedia, and indigenous knowledge to enhance scientific literacy and sustainability awareness. However, comprehensive syntheses integrating these three elements remain limited. This study aims to (1) map research trends on the integration of AI, digital multimedia, and indigenous knowledge in science education from 2015 to 2025, (2) examine their effectiveness in improving scientific literacy, (3) analyze their contribution to sustainability awareness, and (4) identify research gaps. This study employed a systematic literature review (SLR) using the PRISMA 2020 protocol across Scopus, ScienceDirect, and Google Scholar databases. From 487 identified articles, 32 empirical and research-and-development studies met the inclusion criteria. The results indicate three major developmental phases: multimedia-augmented reality (2015-2019), pedagogy-technology integration (2020-2022), and AI-indigenous knowledge-sustainability convergence (2023-2025). The synergistic integration of these elements demonstrates greater effectiveness than conventional approaches in improving scientific literacy. Furthermore, AI and multimedia grounded in indigenous knowledge contribute to sustainability awareness through contextualization, interactive visualization, and value internalization. Five major research gaps were identified, particularly the absence of integrated learning development combining AI, digital multimedia, and Suku Anak Dalam ethnobotany within an Understanding by Design framework at the junior high school level. These findings highlight the potential for developing EthnoRimba Interactive multimedia as a comprehensive and innovative learning solution.

Keywords: *Artificial Intelligence, Digital Multimedia, Indigenous Knowledge, Scientific Literacy, Sustainability Awareness.*

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INTRODUCTION

Science education in the 21st century faces multidimensional challenges that require fundamental transformations in pedagogical approaches, instructional strategies, and learning media. The rapid advancement of Artificial Intelligence (AI), the evolution of digital multimedia, and the growing recognition of indigenous knowledge in formal education have created a landscape rich in opportunities yet marked by considerable complexity (Holmes et al., 2022; Mayer, 2021). Amid the accelerating forces of globalization, a paradox emerges: education systems are expected to "look forward" through the adoption of cutting-edge technologies while also "looking backward" by revitalizing endangered indigenous knowledge. Integrating these elements into a cohesive instructional framework therefore represents both a significant challenge and a strategic opportunity to enhance educational quality.

Scientific literacy, as a fundamental 21st-century competency, is no longer merely the ability to understand scientific concepts and principles, but encompasses the capacity to apply scientific thinking in real-life contexts, including addressing environmental crises and sustainability challenges (OECD, 2023). Data from the Programme for International Student Assessment (PISA) 2022 indicate that Indonesia's scientific literacy score (383) remains significantly below the OECD average (485), highlighting the urgent need for fundamental reforms in science learning approaches (OECD, 2023). Concurrently, sustainability awareness has become an increasingly crucial competency in response to the growing complexity of global environmental issues and climate change, which directly impact the sustainability of human life (Abdullah et al., 2024; Cao et al., 2025; Setiyaningsih et al., 2024).

As a megabiodiverse country, Indonesia possesses a wealth of indigenous knowledge that is highly valuable in supporting environmental sustainability. The Suku Anak Dalam (SAD) in Jambi Province, for example, possesses ethnobotanical knowledge passed down through generations, which is reflected in sustainable natural resource utilization practices (Ginting et al., 2025). However, this knowledge is currently threatened by modernization and has not been optimally integrated into formal education, thus creating a gap between scientific knowledge and indigenous knowledge. On the other hand, advancements in AI technology and digital multimedia offer revolutionary solutions to overcome various conventional learning barriers. Recent studies demonstrate that AI-based interactive multimedia can increase learning motivation, personalize the learning experience, and present abstract concepts visually and interactively (Hwang & Chen, 2023; Liu, 2022; Mayer, 2021).

A crucial question that warrants further investigation is how these three elements Artificial Intelligence (AI), digital multimedia, and indigenous knowledge can be synergistically integrated into a cohesive instructional design (Lestari et al., 2023; Sari et al., 2025). The Understanding by Design (UbD) framework developed by Wiggins and McTighe (2005) provides a backward-design approach that begins with desired learning outcomes, followed by assessment evidence and instructional activities. UbD is relevant to the future development of complex learning products because it can help align AI, multimedia, indigenous

knowledge, scientific literacy, and sustainability outcomes. However, UbD is not treated in this review as a search criterion, nor is its use claimed as an established empirical novelty of the reviewed literature. Instead, the review examines whether the existing evidence provides sufficient justification for proposing UbD as a design framework for subsequent instructional development.

This framework is considered highly compatible with efforts to integrate complex learning components, including AI, digital multimedia, and indigenous knowledge(Lestari et al., 2023; Hayat et al., 2025). Existing studies have provided important insights by examining these elements individually or by combining two of them. Nevertheless, the simultaneous integration of all three elements into a scientifically validated instructional product remains a promising area for further development and innovation in science education.Based on the elaboration above, this systematic review was conducted to: (1) map current research trends related to the integration of AI, digital multimedia, and indigenous knowledge in science education (2015-2025), (2) identify the extent to which this integration has proven effective in improving students' scientific literacy compared to conventional science learning methods, (3) identify how the use of digital multimedia and AI based on indigenous knowledge contributes to forming environmental sustainability awareness in students, and (4) identify research gaps as a foundation for developing further research.

RESEARCH METHOD

Research Design

This study employs a Systematic Literature Review (SLR) design adhering to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 version protocol (Page et al., 2021). The SLR approach was selected because it enables the systematic, transparent, and replicable identification, selection, and synthesis of relevant scientific evidence.

Literature Search Strategy

The literature search was conducted across three main databases: (1) Scopus, (2) ScienceDirect, and (3) Google Scholar. The search was also supplemented with hand-searching of relevant SINTA 1-2 accredited scientific journals. The search keywords were formulated using a combination of Boolean operators (AND, OR) with the combination: ("artificial intelligence" OR "AI" OR "machine learning") OR ("digital multimedia" OR "interactive multimedia")) AND ("science education") AND ("indigenous knowledge" OR "local wisdom" OR "ethnobotany") AND ("scientific literacy" OR "sustainability awareness" OR "environmental awareness").

Inclusion and Exclusion Criteria

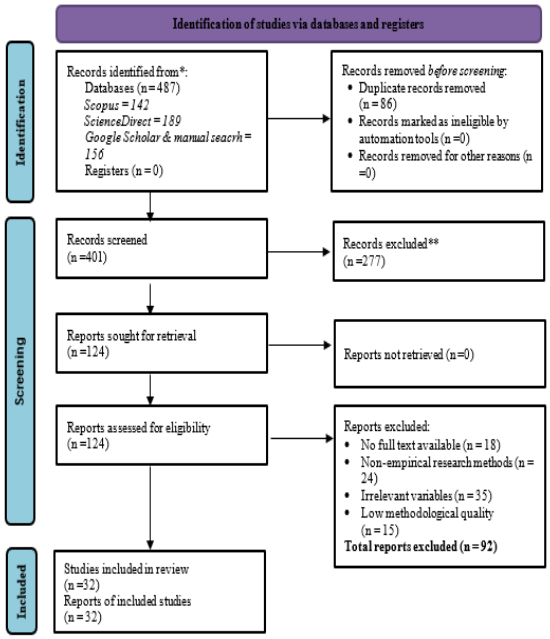
Article selection was based on predetermined inclusion and exclusion criteria established prior to the search process. Inclusion criteria encompassed: (1) articles published between 2015-2025, (2) national journals accredited SINTA 1-2 or international journals indexed by Scopus/Web of Science, (3) written in Indonesian or English, (4) discussing at least one main variable (AI, digital multimedia, indigenous knowledge, scientific literacy, or sustainability awareness) within the context of science education, (5) empirical research or research and development (R&D) articles, and (6) available in full-text. Exclusion criteria included articles outside the 2015-2025 timeframe, unaccredited journals,

review/meta-analysis articles, and duplicate articles. These criteria were adapted from the PRISMA 2020 protocol (Page et al., 2021).

Article Selection: PRISMA Diagram

The article selection process was carried out in four stages following the PRISMA 2020 flow (Page et al., 2021). From a total of 487 articles identified through searches of the three databases (Scopus, ScienceDirect, and Google Scholar), duplicates were removed, and gradual screening was conducted until 32 final articles that met all inclusion criteria were obtained (Figure 1).

Figure 1. PRISMA 2020 Flow Diagram of the Article Selection Process



Data Extraction and Analysis

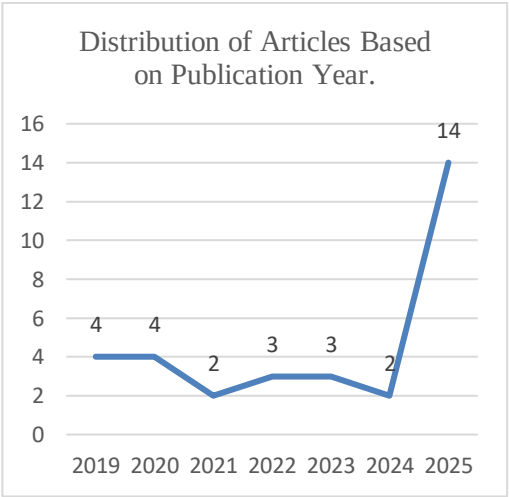
Data were extracted using a Synthesis Matrix that included: authors and year, country/research context, focus and objectives, research methods, variables, instruments, key findings, and limitations. Analysis was conducted thematically-narratively by identifying patterns, similarities, differences, and research gaps using a thematic synthesis approach (Thomas & Harden, 2008). The methodological quality of each article was assessed using a Quality Assessment Checklist adapted from CASP (Critical Appraisal Skills Programme).

RESULTS AND DISCUSSION

1. Characteristics of the Reviewed Articles

From the 32 articles meeting the inclusion criteria, several key characteristics can be identified. The distribution based on publication year indicates a highly significant upward trend, particularly in the last three years. During the 2015 - 2018 period, no articles meeting the criteria were found, publications began to emerge in 2019 with 4 articles, then 2020 with 4 articles, 2021 with 2 articles, 2022 with 3 articles, 2023 with 3 articles, 2024 with 2 articles, and peaked in 2025 with 14 articles (Figure 2).

Figure 2. Distribution of Articles Based on Publication Year.



Distribution by country of origin shows that Indonesia dominated the research (n = 23, 72%), followed by China (n = 3), while other countries such as Nigeria, Spain,

Romania, Saudi Arabia, South Korea, and Malawi contributed one study each (Figure 3). Distribution based on research methods reveals that quasi-experiments dominated with 19 articles (59%), followed by R&D, mixed-method, and SEM with 3 articles each, as well as qualitative and descriptive studies with 2 articles each (Figure 4).

Figure 3. Distribution of Articles Based on Country of Origin.

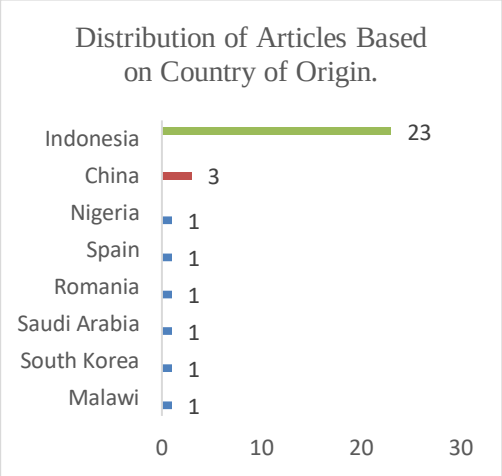
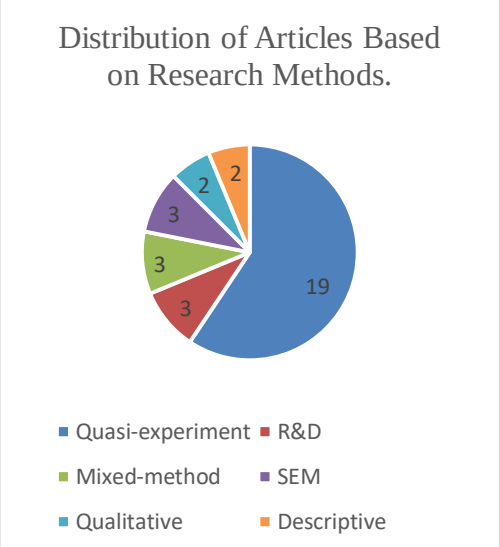


Figure 4. Distribution of Articles Based on Research Methods.



2. RQ1: Current Research Trends on the Integration of AI, Digital Multimedia, and Indigenous Knowledge in Science Education (2015–2025)

Based on the thematic analysis of the 32 articles, research development in this field can be grouped into three overlapping waves that nonetheless display clear shifts in focus.

First Wave (2015–2019): Multimedia and Augmented Reality

During this initial period, research was dominated by the development and testing of digital multimedia, especially augmented reality (AR), in science learning. The primary focus was on proving that digital technology particularly that which is visual and interactive is more effective than conventional methods in improving learning outcomes, scientific literacy, and science process skills. Notable studies in this wave include Cahyana et al. (2019) who used web-based learning to improve students' literacy and independent learning, Syawaludin et al. (2019) who developed AR-based interactive multimedia to enhance students' critical thinking skills, and Nugroho & Surjono (2019) who examined the effectiveness of mobile-based interactive learning multimedia on science process skills. A characteristic of the first wave is the limited integration with specific pedagogical approaches, and elements of indigenous knowledge had not yet widely emerged during this period.

Second Wave (2020–2022): Pedagogy-Technology Integration

The second wave was characterized by more complex integration between digital technology and active pedagogical approaches such as Problem-Based Learning (PBL), Inquiry Learning, and Discovery

Learning. Researchers began to realize that technology alone is insufficient appropriate pedagogical strategies are necessary to maximize technology's potential. Important studies in this wave include Widodo et al. (2020) who tested gadget-based interactive multimedia to improve Generation Z's scientific literacy, Ahied et al. (2020) who utilized AR in distance learning during the COVID-19 pandemic, and Heliawati et al. (2022) who developed ethnochemistry-based learning media integrating indigenous knowledge. The hallmark of the second wave is the emergence of ethnoscience and indigenous knowledge integration, particularly in studies from Indonesia.

Third Wave (2023–2025): Convergence of AI, Indigenous Knowledge, and Sustainability Awareness

The third wave marks an era of convergence between AI, digital multimedia, indigenous knowledge, and sustainability issues. Research during this period matured, featuring more advanced AI utilization (chatbots, virtual assistants, adaptive learning), more complex multi-element integration, and growing attention to sustainability awareness as a dependent variable. Significant studies include Simbolon et al. (2025) who developed an AI-driven interactive digital module integrating Papua's socio-cultural context, resulting in an up to 49% improvement in student understanding, Astawan et al. (2025) who tested PBL based on Balinese indigenous knowledge, resulting in increased scientific literacy alongside reduced misconceptions, and Ginting et al. (2025) who documented sustainability values in the indigenous knowledge of the SAD in Jambi.

3. RQ2: Effectiveness of AI, Digital Multimedia, and Indigenous Knowledge Integration on Students' Scientific Literacy

Synthesis of 22 articles that directly examined the effectiveness of interventions on scientific literacy yielded consistent findings. Overall, the integration of AI, digital multimedia, and indigenous knowledge has proven significantly more effective than conventional learning methods in improving students' scientific literacy across various educational levels.

Effectiveness of AI on Scientific Literacy

Several recent studies specifically employing AI as the core intervention demonstrate positive and significant effects. Simbolon et al. (2025) developed an AI-based interactive digital module with a Papuan socio-cultural context, in a mixed-method study of 200 students, this module enhanced student understanding by up to 49% compared to conventional learning. Ngandoh et al. (2025) confirmed that AI-based multimedia significantly improved conceptual understanding among junior high school students. However, Eteng-Uket (2025) provided an important nuance: AI chatbots do not always directly improve learning outcomes, but significantly increase student engagement indicating that AI functions more as an engagement facilitator that contributes to long-term improvements in scientific literacy.

Effectiveness of Digital Multimedia on Scientific Literacy

Studies based on digital multimedia, particularly augmented reality (AR), exhibit highly consistent and measurable effects.Ahied et al. (2020) reported that AR helped visualize abstract concepts, thereby improving conceptual understanding more

effectively than traditional methods. Yang et al. (2021) demonstrated that integrating AR with inquiry learning not only improved scientific literacy but also reduced cognitive load. Hadisaputra et al. (2025) showed that integrating AR with Sasambo ethnochemistry enhanced scientific literacy through conceptual visualization connected to local culture.

Effectiveness of Indigenous Knowledge Integration on Scientific Literacy

Studies integrating indigenous knowledge (or ethnoscience) into science learning show strong effectiveness. Astawan et al. (2025) conducted a quasi-experiment on 178 elementary students in Bali applying PBL based on indigenous knowledge, the results indicated a significant increase in scientific literacy alongside a significant decrease in misconception rates. Heliawati et al. (2022) proved that ethnochemistry-based learning media significantly increased scientific literacy by linking chemical concepts with local cultural practices.

Comparisons across studies reveal a critical pattern: the highest effectiveness is achieved when three elements technology (AI or multimedia), active pedagogical approaches, and indigenous cultural contexts are synergistically integrated.

4. RQ3: Contribution of Digital Multimedia and Indigenous Knowledge-Based AI to Environmental Sustainability Awareness

A total of 5 out of 32 studies explicitly examined the relationship between the use of digital multimedia and/or indigenous knowledge-based AI and the formation of sustainability awareness in students. These findings consistently indicate that the contextualization of learning based on local culture and environment significantly contributes to building students' ecological awareness. Hayat et al. (2025) used a STEAM approach integrated with local environmental contexts on 36 students and found a significant increase in sustainability awareness. Alsanie (2025), through an SEM study with 650 respondents, proved that structured digital technology integration has a significant positive effect on increasing sustainability awareness. Yıldız (2025) specifically examined AI-based multimodal learning in the context of sustainability, discovering that AI could contextually adapt learning content to align with local sustainability issues. Ginting et al. (2025) provided strong qualitative evidence that the SAD's indigenous knowledge about forest ecosystems contains profound sustainability values and has proven effective in maintaining ecosystem balance for centuries.

Synthesis of the five studies indicates that digital multimedia and indigenous knowledge-based AI contribute to sustainability awareness through three main mechanisms: (1) Contextualization mechanism presenting material based on the local environment and culture so that sustainability issues become more personally relevant and meaningful, (2) Visualization mechanism multimedia technology and AI interactively represent ecological phenomena, enhancing both students' understanding and empathy, and (3) Value integration mechanism reinforcing indigenous knowledge values regarding human-nature harmony, which is effective in shaping pro-environmental attitudes and behaviors.

5. RQ4: Research Gaps as a Foundation for Future Research Development

A comprehensive synthesis of the 32 articles identified five significant research

gaps that collectively open opportunities for highly original and impactful future research.

First, the simultaneous integration of Artificial Intelligence (AI), digital multimedia, and indigenous knowledge remains underexplored. Existing studies predominantly investigate these components in isolation or, at best, integrate only two of them (Hadisaputra et al., 2025; Simbolon et al., 2025). This indicates a lack of holistic instructional designs that combine all three elements into a single, validated learning product.

Second, the ethnobotanical knowledge of the Suku Anak Dalam (SAD) has not yet been optimally utilized as a foundation for digital learning content. Although Ginting et al. (2025) documented the richness of SAD indigenous knowledge, no studies have developed AI-based multimedia that incorporates standardized and empirically tested SAD ethnobotany content.

Third, the development of multimedia based on the Understanding by Design (UbD) framework that explicitly integrates indigenous knowledge at the junior high school level remains very limited. This gap is particularly significant considering that the topic of "Interactions of Living Things with Their Environment" in Grade VII offers strong potential for contextualization through indigenous knowledge.

Fourth, sustainability awareness has rarely been positioned as the primary dependent variable in studies on science learning multimedia in Indonesia. Furthermore, there is currently no validated instrument specifically designed to measure sustainability awareness among Indonesian junior high school students, highlighting a critical methodological limitation in existing research.

Fifth, there is a lack of longitudinal studies examining the long-term impact of integrating AI, multimedia, and indigenous knowledge. Most existing studies employ short-term intervention designs, typically ranging from 4 to 12 meetings, thereby limiting understanding of sustained effects on students' scientific literacy and sustainability awareness.

Taken together, these gaps underscore a significant research opportunity for the development of *EthnoRimba Interactive Multimedia*, an AI-driven science learning platform that integrates SAD ethnobotany within the UbD framework. This proposed innovation is expected to address the identified gaps comprehensively while contributing to the advancement of science education, particularly in enhancing scientific literacy and sustainability awareness among junior high school students.

6. Comparison of Research Methods and Quality

A review of the research methodologies from the 32 articles reveals that research designs were dominated by quasi-experiments (n = 16, ±59%), followed by R&D, mixed methods, and SEM (n = 3 each), as well as quantitative descriptive and qualitative studies (n = 2 each). This reflects a focus on testing intervention effectiveness, although the scarcity of randomized controlled trials (RCTs) limits causal inference strength. Most studies utilized small to medium sample sizes (N<100), restricting generalizability. Major limitations include short intervention durations (±4–8 meetings), weak control of confounding variables, potential Hawthorne effects, and minimal cross-contextual replication.

CONCLUSION

Based on the systematic synthesis of 32 scientific articles that met the inclusion/exclusion criteria, this study yields four main conclusions. First, research experienced a significant increase (2015-2025) moving through three waves: multimedia-AR, pedagogy-technology integration, and the convergence of AI-indigenous knowledge-sustainability, with Indonesia as the dominant contributor. Second, the integration of AI, multimedia, and indigenous knowledge has proven to be more effective than conventional methods, integrated approaches based on technology, active pedagogy, and cultural contexts produce significant improvements in conceptual understanding and data interpretation, alongside reductions in misconceptions. Third, integrating technology and indigenous knowledge enhances sustainability awareness through cultural contextualization, visualization of ecological phenomena, and the internalization of indigenous knowledge values, although evidence for long-term impacts remains limited. Fourth, there are five major research gaps that present an opportunity to develop *EthnoRimba Interactive* multimedia as a comprehensive learning innovation.

Based on these findings and conclusions, four strategic recommendations are formulated: (1) there is a need to develop AI-based *EthnoRimba Interactive* multimedia integrating SAD ethnobotany with the UbD framework to enhance scientific literacy and sustainability awareness among junior high school students using the ADDIE or 4D models, (2) future research should employ long-duration experimental designs coupled with the development of validated sustainability awareness instruments, (3) development must involve the SAD community as participatory partners, and (4) integration of indigenous knowledge into the science curriculum is necessary, along with the equitable distribution of technological infrastructure and teacher training in the utilization of indigenous knowledge-based AI and multimedia.

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