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SYNTHESIS OF EMPIRICAL EVIDENCE FOR THE DEVELOPMENT OF PjBL AND ETHNOSCIENCE-INTEGRATED INQUIRY LEARNING ON CRITICAL THINKING AND SCIENTIFIC LITERACY

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ABSTRACT

Science learning is often constrained by conceptual abstractions that limit the mastery of 21st-century skills. This study aims to synthesize empirical evidence related to the development of *the Project-Based Learning* (PjBL) model and *Ethnoscience integrated Inquiry Learning*. Using the *Systematic Literature Review* (SLR) method on 10 selected articles for the 2023-2025 period, this study analyzes the patterns and impacts of the integration of the model. The results of the analysis show a trend of shift from a manual approach to a hybrid model assisted by digital and virtual technologies. The integration of ethnoscience in PjBL and Inquisition has proven to be effective as a cognitive bridge that visualizes abstract concepts, as well as consistently improving critical thinking skills, cultural literacy, and entrepreneurship. It is concluded that the synergy between culture, constructivist pedagogy, and technology forms a strategic framework of "Eco-Technopedagogy". These findings recommend adapting a technology-supported local potential-based curriculum to produce a competent and characterful generation.

Keywords: ethnoscience; PjBL; inquiry learning

INTRODUCTION

Education in the 21st century faces the complex challenge of preparing adaptive human resources, where mastery of the 4C skills which is critical thinking, creativity, collaboration, and communication is fundamentally required. In this study, 21st-century skills are operationally defined as a set of high-order competencies that enable students to think critically, solve problems creatively, collaborate effectively, and communicate scientific ideas clearly. Meanwhile, Project-Based Learning (PjBL) is defined as a student-centered instructional model that engages learners in authentic, product-oriented tasks, whereas ethnoscience refers to the integration of indigenous knowledge systems into scientific learning to contextualize abstract concepts. Empirical evidence, however, shows a persistent gap between these demands and student achievement in Indonesia. Based on the 2018 PISA assessment, Indonesia ranked 71 out of 79 participating countries in science literacy, and the 2022 PISA results placed Indonesia 68 out of 80 countries in creative thinking (Mujriati *et al*., 2025; Noble *et al.*, 2025). These low scores highlight that conventional science instruction remains abstract, decontextualized, and distant from students' lived experiences, resulting in weak conceptual understanding and limited relevance to daily life (M. K. Sari *et al*., 2025).

To address this competency deficit, pedagogical transformation is required through student-centered learning models

such as PjBL and Inquiry Learning. Scientific Inquiry, defined as a systematic investigative process involving questioning, hypothesizing, observing, and explaining, has been proven to strengthen students' metacognitive abilities, scientific reasoning, and scientific attitudes (Mujriati *et al*., 2025).. Meanwhile, PjBL supports the development of collaborative problem-solving and sustained engagement, contributing significantly to motivation and mastery of 21st-century skills (Winaryati *et al*., 2025). However, challenges remain in ensuring cultural relevance. Science learning materials frequently lack alignment with students' cultural knowledge, causing a disconnect between scientific concepts and local wisdom. Ethnoscience integration seeks to bridge this divide by embedding indigenous knowledge into instructional activities, allowing abstract concepts to be contextualized through culturally meaningful practices.

Despite positive findings, existing research displays several measurable empirical gaps that justify the need for this study. First, there is limited cross-context evidence regarding how ethnoscience-integrated PjBL and Inquiry Learning perform across different educational levels and subject domains. Second, findings remain highly variable, with some studies showing strong effects on critical thinking while others report only modest gains, indicating inconsistencies that have not yet been systematically synthesized. Third, most existing research is short-term and lacks longitudinal evaluation, making it difficult to determine the sustainability of learning outcomes. Finally, few studies simultaneously examine the combined integration of PjBL, Inquiry Learning, and ethnoscience within technology-supported environments, leaving a gap in understanding multimodal pedagogical effectiveness. Therefore, a systematic synthesis is needed to map these variations and provide a comprehensive understanding of model development and its impacts on 21st-century skills.

Answering the challenge of relevance, the integration of ethnoscience into the PjBL and Inquiry learning models emerges as a strategic innovation. Ethnoscience plays a key role in bridging indigenous knowledge with modern scientific concepts, enabling culturally grounded learning experiences (Sudirman *et al*., 2025; Sumarni, 2023). Approaches such as Ethno-Inquiry provide opportunities for aspiring science teachers and students to strengthen their critical thinking performance through digital learning platforms (Prayogi *et al*., 2022). In addition, the integration of ethnoscience into science learning helps connect local and formal knowledge in a balanced and meaningful way, allowing students to preserve culture while simultaneously using it as a unique learning resource (Sumarni *et al.*, 2025). Importantly, these findings align with current educational policies in Indonesia that emphasize the development of higher-order thinking skills and the strengthening of cultural identity such as the Profil Pelajar Pancasila and the Merdeka Curriculum which encourage contextualized, student-centered learning. Therefore, ethnoscience-integrated PjBL and Inquiry Learning not only address conceptual abstraction but also support national curriculum priorities by promoting cultural literacy, scientific reasoning, and character-based education.

Recent research developments (2020–2025) show a positive trend in the application of ethnoscience-based learning

models. A meta-analysis study showed that the ethnoscience-based PjBL model had an effect measure (*effect size*) high (0.827) on students' critical thinking skills, which means that this model has a significant positive influence over conventional models (Rahman *et al.*, 2023). Other findings show that *Inquiry Learning* Ethnoscience-based effectively improves students' critical thinking and collaboration skills with a very strong correlation between the two variables (Sigh) *et al.*, 2024). In addition, the use of *E-worksheet* ethnoscience-based methods have also proven to be valid and practical in improving science literacy and critical thinking of junior high school students (Kotimah *et al.*, 2024).

Although empirical evidence supports the effectiveness of this model, the existing literature shows variations and gaps. Most research focuses on the development of specific teaching devices such as electronic modules or is conducted on a specific local scale (Kotimah *et al.*, 2024; C. K. Sari *et al*., 2025). There is also an urgent need for a comprehensive systematic review, given the lack of a synthesis that analyzes model research trends *Scientific Inquiry* and PjBL in relation to science literacy and critical thinking over the past decade (Mujriati *et al.*, 2025). In addition, the integration between ethnoscience, PjBL, and virtual technology to enhance critical thinking still needs to be further explored for its effectiveness and practicality in various educational contexts (Edit) *et al.*, 2025).

Therefore, research through the *Systematic Literature Review* (SLR) is indispensable for synthesizing this scattered empirical evidence. The SLR approach allows researchers to map the direction of research, identify gaps, and offer strategic recommendations for future science education innovations (Mujriati *et al*., 2025). This study will fill this gap by systematically analyzing how the PjBL and Inquiry models integrated with ethnoscience are applied, as well as the patterns of findings related to their impact on 21st century skills. This is important to validate the consistency of findings across different demographic and cultural contexts in Indonesia, as suggested in bibliometric studies related to ethnoscience-based PBL models (Damayanti) *et al*., 2025).

The main objective of this SLR is to synthesize empirical evidence regarding the effectiveness of model development *Project-Based Learning* (PjBL) and *Inquiry Learning* integrated ethnoscience with 21st century skills. The results of this study are expected to make a conceptual contribution to the development of culturally-based pedagogical theories and provide valuable insights for educators and policymakers in designing culturally inclusive and relevant curricula (Ali *et al*., 2025; São Paulo, Sã *et al.*, 2025). Thus, this research has high academic and practical relevance to strengthen the implementation of innovative science learning in Indonesia.

METHODS

Research Design

This study applies a Systematic Literature Review (SLR) design enriched with bibliometric analysis using VOSviewer to comprehensively map the knowledge landscape. This approach is guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol and the Kitchenham & Charters framework to ensure that the process of identifying, assessing, and synthesizing previous research is systematic, transparent, and accountable. In

addition to the search and screening stages, this study incorporates a structured quality assessment procedure for all primary studies. The quality appraisal was conducted using established checklists such as the Critical Appraisal Skills Programme (CASP) and the Joanna Briggs Institute (JBI) tools, focusing on methodological clarity, sample adequacy, data validity, and alignment between research questions, methods, and findings.

Studies that met the minimum threshold of methodological quality were included in the synthesis, whereas those with substantial methodological weaknesses were excluded or given lower interpretative weight. This quality assessment process ensured that the final synthesis is based on credible empirical evidence, allowing the review to identify reliable patterns, evaluate conceptual relationships, articulate research gaps, and build a strong theoretical basis for the development of Project-Based Learning (PjBL) and ethnoscience-based Inquiry Learning models. Through this qualitative-descriptive approach, the study aims to generate a rigorous and trustworthy synthesis of the existing literature.

Literature Search Strategy

The literature search strategy was carried out in a structured and gradual manner to capture relevant data from reputable academic databases, including Scopus, Sinta, Google Scholar, DOAJ, SpringerLink, ScienceDirect, and Wiley Online Library. The search focused on recent publications from 2020 to 2025 to ensure relevance to current curriculum and technological developments. The key terms used included “Project-Based Learning”, “Inquiry Learning”, “Ethnoscience”, “Indigenous Knowledge”, and “21st Century Skills”. Boolean operators (AND, OR, NOT) were applied to refine searches with formulations such as: (“Project-Based Learning” OR “Inquiry Learning”) AND (“Ethnoscience” OR “Local Wisdom”) AND “21st Century Skills”. All search steps were documented to ensure transparency and completeness.

In addition to the search process, this study implemented a detailed quantitative data extraction strategy to ensure consistency in evaluating the empirical strength of each primary study. Quantitative metrics extracted included effect size (ES), sample size (N), research design type, comparison groups, control variables, statistical tests used, and key outcome measures related to critical thinking, scientific literacy, collaboration, or other 21st-century skills. Studies were considered eligible for quantitative synthesis if they (a) reported sufficient statistical information to calculate or interpret effect sizes, (b) used clear operational definitions of measured variables, and (c) provided explicit descriptions of intervention characteristics such as duration, model integration, and technological components. Studies lacking essential quantitative data were excluded from numerical comparison but were still included in the qualitative synthesis when relevant. This structured extraction ensured methodological consistency and strengthened the interpretive reliability of the review findings.

Inclusion and Exclusion Criteria

To ensure that only valid, credible and relevant scientific sources are analyzed, inclusion and exclusion criteria are established as listed in the following Table 1:

Table 1. Inclusion and Exclusion Criteria

Criteria	Inclusions (Accepted)	Exclusion (Denied)
Types of Literature	Articles of scientific journals (empirical/conceptual) that have gone through *peer-review* and indexed international proceedings, as well as national journals.	Non-scientific works (blogs, opinions), *grey literature*, unpublished theses/theses, or *book chapters*.
Research Topics	Focus on PjBL or *Inquiry Learning* integrated with Ethnoscience and its impact on 21st century skills.	Discuss general learning models without ethnoscience integration or not measuring 21st century skills.
Language	Indonesian and English.	Languages other than Indonesian and English.
Year of Publication	Range of 2020 – 2025.	Published before 2020.
Accessibility	Full text is available.	Only abstract or locked access is available.
Originality	Original article (primary study).	Duplicate or re-review articles of the same article.

Literature Selection Procedure

The literature selection procedure is carried out through a series of systematic screening stages to ensure the accuracy of the data to be analyzed. This process starts with the initial identification of the literature based on the search results in a predefined database, followed by the removal of duplicates. The next stage is screening based on titles and keywords to eliminate irrelevant articles. The process continues with an eligibility test through an abstract review, and the last stage is inclusion through a full *review* of the full text of the article that meets all the inclusion criteria. This selection flow is visualized through the PRISMA Flowchart (Figure 1), which transparently displays the number of articles identified, screened, removed along with their reasons, and the final number of articles included in the analysis, thus ensuring replication and accuracy of the review process.

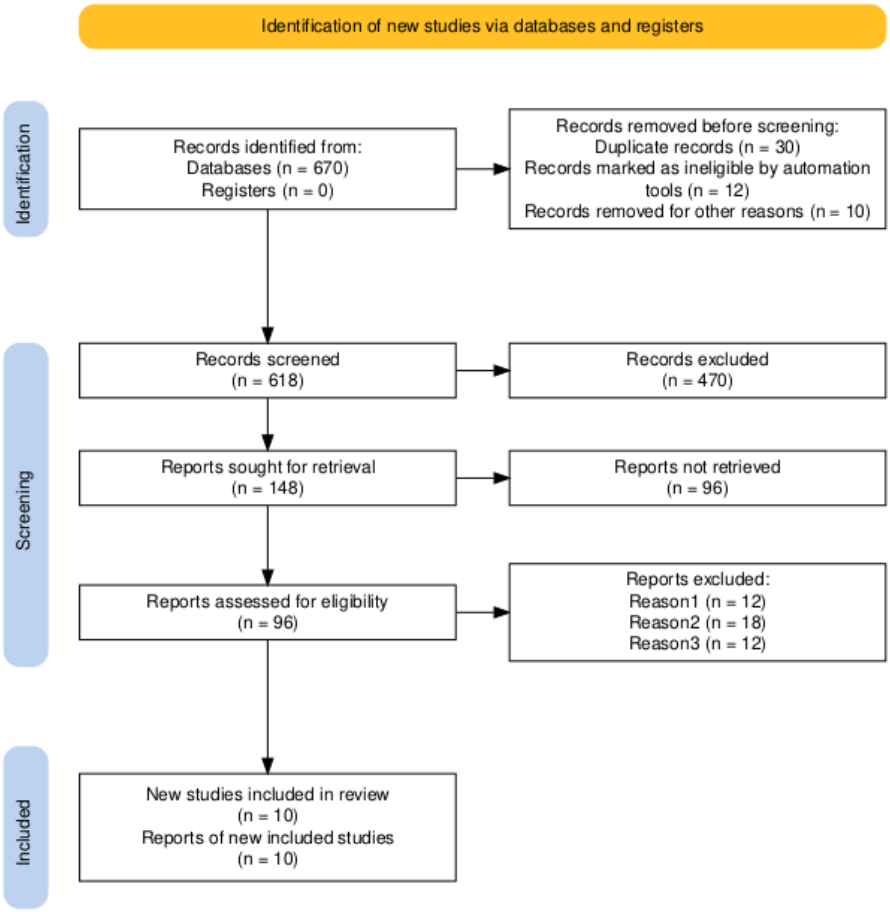


Table 2. Prisma Flow Diagram

Data Extraction and Analysis Process

Data from selected articles are systematically extracted using reference management software such as Mendeley, which facilitates standardization of metadata (researcher name, year, title, abstract) and conversion to RIS format. Furthermore, data analysis is carried out through two approaches: bibliometric analysis and qualitative synthesis. Bibliometric analysis, with the help of VOSviewer, is used to visualize a map of knowledge networks, identify dominant topic trends, and relationships between concepts. Meanwhile, qualitative synthesis focuses on extracting in-depth information about research objectives, theories, methods, contexts, and key outcomes related to the impact of learning models on 21st century skills. The results of these two analyses are then presented in summary tables and descriptive narratives to provide a comprehensive picture of research developments, patterns, and gaps.

Validity and Reliability

This study applies strict methodological measures to maintain objectivity and minimize bias. The validity of the review is ensured through the transparency of the search and selection process documented according to the PRISMA standard, as well as the use of VOSviewer which provides an objective visualization of bibliometric data, so that the interpretation of trends does not solely depend on the subjectivity of the researcher. Reliability is strengthened through the use of Mendeley's reference management software to organize articles and record selection decisions systematically. In addition, the data selection and extraction process involves repeated checks or the use

of two independent reviewers to ensure consistency of data interpretation. The synergy between the neat documentation at Mendeley and the objective analysis via VOSviewer aims to maintain the scientific integrity of the research and increase the credibility of the findings produced.

RESULTS AND DISCUSSION

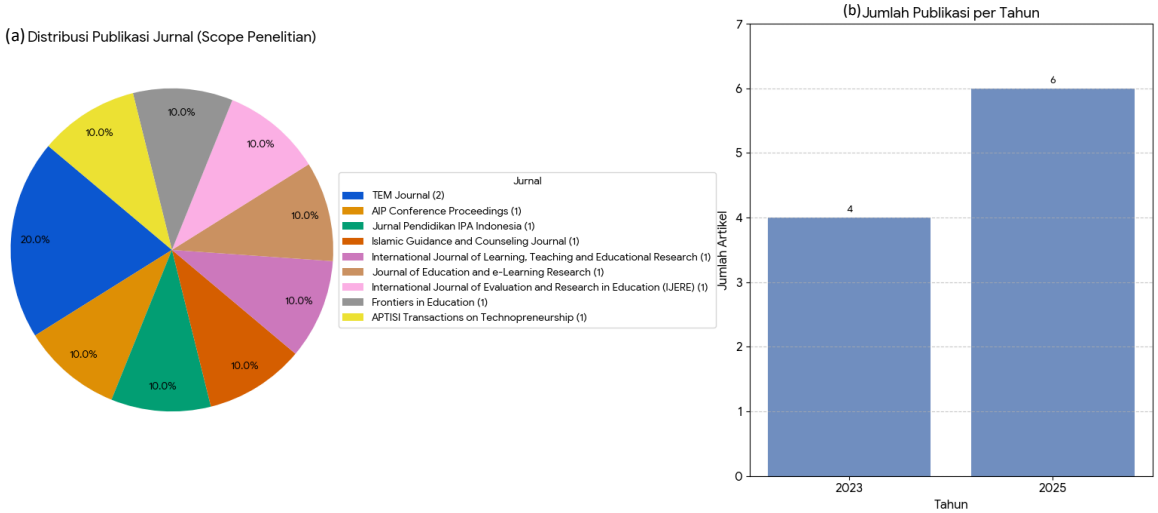


Figure 2. Distribution of journal publications (Research Scope) and Number of publications per year

Based on the pie chart illustrating the distribution of publications, it is evident that research on ethnoscience-integrated PjBL and Inquiry Learning appears across a wide range of internationally recognized journals, most of which focus on science and technology education. TEM Journal contributes the largest proportion of publications (20%, or 2 articles), while the remaining 80% is distributed evenly (10% each) across journals such as the Indonesian Journal of Science Education, IJERE, AIP Conference Proceedings, and others. This diversity of publication outlets such as spanning physics education, science education, counseling, and technopreneurship indicates that the integration of ethnoscience, STEM, and digital technology has strong multidisciplinary relevance.

In addition to distribution patterns, several quantitative indicators can be highlighted from the reviewed studies. Across the selected articles, the reported effect sizes for improvements in critical thinking and scientific literacy generally fall within the moderate-to-high range (e.g., ES = 0.50–0.82), with the strongest effects typically associated with technology-supported ethnoscience-based PjBL interventions. Furthermore, the most frequently measured outcomes include critical thinking (reported in 9 out of 10 studies), scientific literacy (6 out of 10 studies), and collaboration skills (4 out of 10 studies). However, a full meta-analysis could not be conducted due to substantial heterogeneity in research designs, measurement instruments, sample characteristics, and the operationalization of outcomes across studies. This variation makes it methodologically inappropriate to statistically pool effect sizes. Therefore, a narrative synthesis complemented with

bibliometric visualizations is used to provide a coherent interpretation of the patterns and trends observed in the literature.

Furthermore, the bar chart shows the trend of the year of publication which is very up-to-date, confirming the high *novelty* value of this reference collection. Data shows that the dominance of articles published (or scheduled to be published) in 2025 is 6 articles (60%), while the rest will be published in 2023 as many as 4 articles (40%). The high number of publications in 2025 shows that research issues regarding innovative learning models based on *Ethno-STEM*, *Digital Learning*, and *Critical Thinking* are hot topics (*emerging trends*) and very strategic to be used as the basis for the latest research.

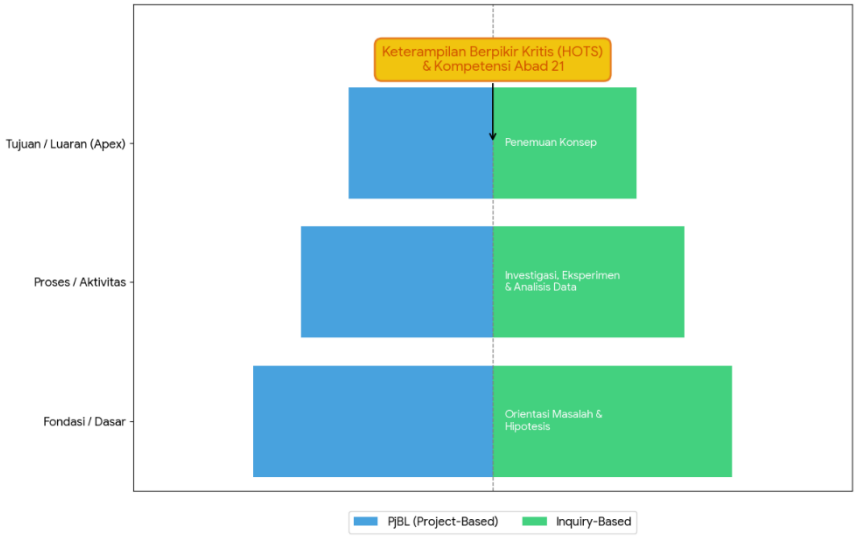


Figure 3. PjBL Integration and Inquiry Pyramid Diagram

This pyramid diagram illustrates that the Project-Based Learning (PjBL) and Inquiry Learning models, although starting from different foundational orientations, run in parallel to enrich students' learning experiences. On the left side, PjBL begins with product orientation and guiding questions that lead students into collaborative planning and creation phases. On the right side, the Inquiry model begins with problem orientation and hypothesis development, which then drive structured investigation, experimentation, and data analysis. The broader base of the pyramid represents the distinctive foundational processes of each model—PjBL emphasizes the creation of practical solutions, whereas Inquiry focuses on scientific proof and conceptual discovery.

Beyond structural differences, the convergence of both models at the apex can be theoretically explained through several mechanisms. First, the integration of ethnoscience provides strong contextual relevance, allowing abstract scientific concepts to be anchored in culturally meaningful practices. This contextual grounding enhances cognitive accessibility and facilitates deeper conceptual understanding. Second, both PjBL and Inquiry naturally promote intrinsic motivation by involving students in authentic, problem-based tasks that have clear relevance to their lived environment. Third, the combined structure of guided questioning in PjBL and systematic investigation in Inquiry functions as a form of cognitive scaffolding that supports students' progression from lower-order to

higher-order thinking processes. Through these mechanisms, the synergy of PjBL, Inquiry, and ethnoscience effectively strengthens students' higher-order thinking skills (HOTS) and overall 21st-century competence.

However, as it moves towards the top, these two approaches are converging, which indicates that the integration of the two results in much more comprehensive educational outcomes than if applied separately. The top of the pyramid that fuses symbolizes the ultimate goal of this synergy, which is the formation of Higher Level Thinking Skills (HOTS) and 21st century competencies. This interprets that when the ability to design real solutions (from PjBL) is based on a strong understanding of the concepts that are investigated (from the Inquiry), students will reach the highest cognitive level, namely the ability to evaluate and create critically.

Table 3. Separate Summary Table of Empirical Evidence & Qualitative Analysis

No.	Author & Year	Integration Models & Focus	Contribution of Research Direction Mapping	Filled Gap Analysis
1.	Squirt *et al*. (2025)	**Ethnoscience-PBL + Virtual Technology** (Literature Review & Model Design)	Mapping that the integration of three elements (Ethnoscience, PBL, Virtual Technology) is the most comprehensive framework compared to a separate implementation.	Fill in the theoretical gaps where a single model (only ethnoscience or only PBL) is considered insufficient to visualize abstract concepts and maximize analytical reasoning.
2.	Revelation *et al*. (2023)	Hybrid Ethno-PjBL + Virtual Assistive Technology (VAT)	Directing research trends from purely physical project learning towards **Hybrid** with the help of assistive technology for Basic Physics courses.	Addressing the gap of "visualization" in ethnoscience. So far, the cultural context has been difficult to explain scientifically (abstractly); VAT is here as a visual bridge to explain the concept.
3.	Sudarmin *et al*. (2023)	**Ethno-STEM Project-Based Learning** (Sudarmin Syntax)	Setting a new direction with the development of a specific syntax ("Sudarmin Syntax") that ties science to the external products of economics (batik & herbal tea).	Fill the gap in the Entrepreneurship aspect. Many PjBL models stop at learning products, but this research proves that these products can be life *skills* with selling value.

4.	Fitria & Asrizal (2025)	Blended Problem-Based Learning + Ethnoscience	Expanding the mapping of ethnoscience implementation into a *blended learning* environment at the junior high school (SMP) level.	Overcome the limitations of face-to-face interaction in cultural learning. It shows that ethnoscience is still effectively applied even though it uses mixed methods (online-offline).
5.	São Paulo *et al*. (2023)	**Dynamic blend of ethnoscience & inquiry** (Digital Platform)	Directing the research focus on empowering *Future Science Educators* through digital platforms, not just school students.	Fill in the gap in "teacher readiness". Offering a digital platform solution to train the critical thinking of prospective teachers who may not have been accommodated in the conventional model.
6.	Harjono *et al*. (2025)	Ethnoscience in Inquiry-Creative Learning	Added the "**Creative**" dimension to the standard Inquiry model, specifying that the inquiry must be creative in order to be a breakthrough.	Criticizing rigid inquiry models. This research fills the gap by proving that inquiry must be combined with creativity to truly improve critical thinking significantly.
7.	Atmosphere *et al.* (2025)	Ethnoscience (General Role)	Mapping the fundamental role of ethnoscience as a "bridge" (*bridging*) between STEM and Culture to build cultural literacy.	Fill the gap of "cultural identity" in STEM education that is often too technical, by emphasizing the importance of Cultural Literacy along with Critical Thinking.
8.	Juanta *et al*. (2025)	Digital Learning Tools in Science	Linking the use of digital tools with the formation of national character (**Pancasila Student Profile**) and entrepreneurial skills.	Bridging the gap between technological advancement and character building. Proving that digital science technology is not only cognitive, but also affective (Pancasila).
9.	Seedling *et al*. (2025)	Global Inquiry-Based Learning	Bring a global perspective into the inquiry model in primary education, balancing social and academic skills.	Balances the often biased research focus on academics, by highlighting the importance of social skills in global inquiry models.

10.	São Paulo *et al*. (2023)	Integrative Learning Model	Mapping the importance of integrative models to improve collaboration and motivation, in addition to problem-solving skills.	Fill the gap in the psychological aspect of students (motivation). Much research focuses on cognitive learning outcomes, this research emphasizes improved motivation and collaboration.

The synthesis of empirical evidence confirms that the development of learning models for 21st century skills can no longer stand alone, but rather requires a strong multidisciplinary integration between culture, pedagogy, and technology. The main relevance to the title of this research is shown by Verawati *et al*. (2025) which through its literature review validates that the most comprehensive framework today is the merger of Ethnoscience, PBL, and Virtual Technology, not partial implementation. This philosophical foundation of integration is strengthened by Atmosphere *et al*. (2025), which places ethnoscience as a vital bridge between culture and STEM to build critical literacy. Specifically in the development of the PjBL model, Sudarmin *et al.* (2023) make a real contribution through the new syntax (*Sudarmin Syntax*) in *Ethno-STEM Project-Based Learning*, which proves that cultural integration in a project can produce product outputs *Life skills* real. Furthermore, Revelation *et al.* (2023) Addressing the challenges of abstraction in this culture-based project model by developing an approach *Hybrid Ethno-PjBL* Help *Virtual Assistive Technology* (VAT), ensuring that the community's original science concepts can be scientifically visualized to support students' analytical skills.

In context *Inquiry Learning*, empirical evidence shows a significant transformation from conventional inquiry to inquiry that is adaptive to technology and creativity, in accordance with the demands of model development in the title of the study. Harjono *et al*. (2025) Offering novelty with models *Inquiry-Creative Learning*, which emphasizes that inquiry must be infused with elements of creativity to effectively boost critical thinking skills. The adaptation of this model into the digital ecosystem is validated by São Paulo *et al.* (2023), which develops *Dynamic Blend* between ethnoscience and inquiry on the platform *E-learning* for prospective science educators, as well as Fitria & Asrizal (2025) which proves the effectiveness of this integration in the *Blended Problem-Based Learning* in high school. The expansion of the scope of the inquiry model was also seen in the study Seedling *et al*. (2025), which balances the model *Global Inquiry* With social skills in primary education, it shows that the development of inquiry models is now moving flexibly across demographic boundaries and learning platforms.

The estuary of this synthesis proves that the integration of PjBL and ethnoscience-based inquiry has a consistent and holistic impact on 21st century skills, not only on cognitive but also affective and vocational aspects. Juanta *et al.* (2025)Reinforcing this relevance with the finding that digital learning tools in science

are able to simultaneously improve entrepreneurial skills (*entrepreneurial skills*) and strengthening the character of the Pancasila Student Profile. This is in line with São Paulo *et al.* (2023), who found that integrative learning models are highly effective in improving collaboration and learning motivation, which are soft components (*soft skills*) crucial in the 21st century. Thus, these ten articles collectively provide strong empirical evidence that the PjBL and Inquiiri model developed with ethnoscience and technology content is a strategic solution to produce a generation that has high-level thinking skills, has cultural character, and is ready to compete globally.

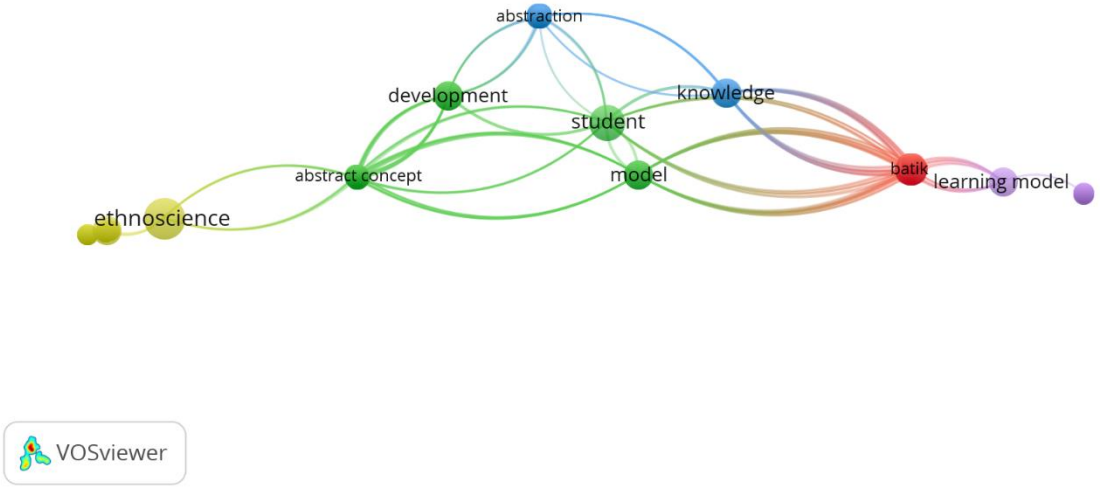


Figure 4. *Network Visualization*

This visualization of bibliometric data maps an interconnected research landscape, in which the Yellow and Green Clusters act as the main foundation of the development of modern pedagogy. The dominance of large circles on *Ethnoscience*, *Critical Thinking*, and *Digital Learning Platforms* in the Yellow cluster shows that the main trend today is to integrate ethnoscience not only as cultural content, but to use digital platforms to trigger critical thinking skills. This interacts closely with the Green cluster focusing on *Development*, *Student*, and *Abstract Concepts*, which indicates that the development of learning models is targeted at helping students understand abstract and difficult science concepts. The relevance to your research title is particularly strong here, as it proves that current model development (PjBL/Inquiry) must bridge such abstract concepts through the integration of digital technologies and ethnoscience to achieve desired 21st century skills.

Furthermore, the Red, Blue, and Purple Clusters show the concrete implementation and external orientation of the model. The Red Cluster with the keywords *Batik* and *Ethno* represents the tangible manifestation of the PjBL project based on local wisdom that has been applied, such as chemical analysis on batik. This side is deepened by the Blue cluster (*Abstraction*, *Knowledge*) which shows an in-depth inquiry process to build cognitive knowledge, and leads to the Purple cluster (*Learning Model*, *Academic Achievement*) as the final goal. This structure empirically validates the title of your research, confirming that the synthesis between real projects (Red/Batik), conceptual

understanding (Blue/Abstraction), and measurable learning models (Purple), effectively improves students' academic achievement and essential skills in the modern era.

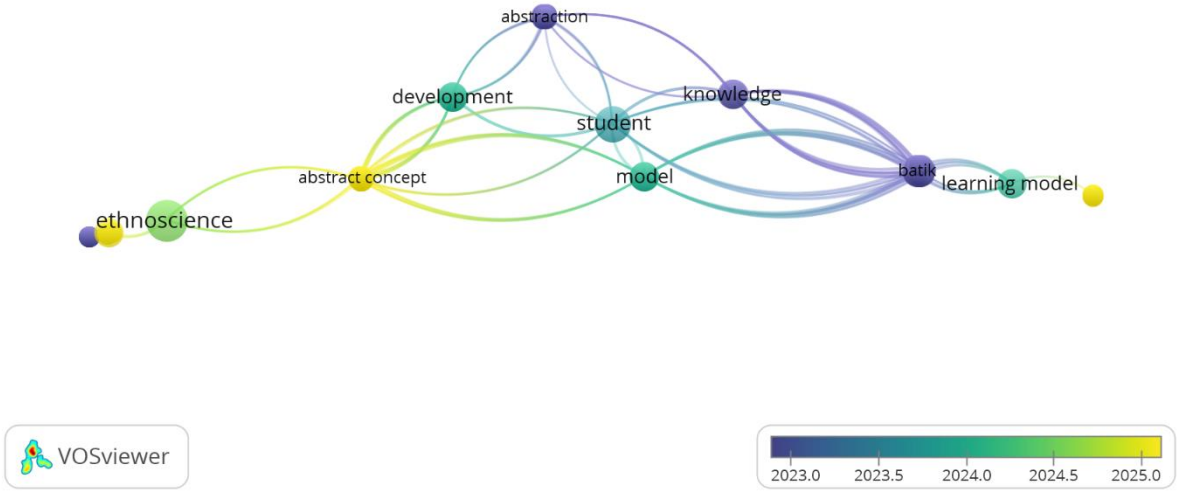


Figure 5. *Overlay Visualization*

Based on the visualization of *overlay data* in the 2023-2025 period, it is clear that the evolution of research trends that place technology as the main cognitive catalyst is clearly visible. The emergence of *the Digital Learning Platform* node (purple) that is closely connected to *Critical Thinking* (yellow, the latest trend 2024-2025) and *Ethnoscience* (green) indicates a paradigm shift in recent years: digital platforms are no longer just tools, but strategic instruments to process cultural content into critical thinking trainers. In addition, the central position of the *Abstract Concept* node (yellow) which is the dominant trend in 2025 and connects *Ethnoscience* with *Development* and *Model* (blue) confirms that the contemporary challenge of science education which is conquering abstract concepts is being answered through the development of cutting-edge models that use local culture as a cognitive bridge.

In terms of practical implementation recorded in the research trail until 2025, the dense network that connects *Students* (blue) with *Knowledge*, *Abstraction* (purple), as well as specific objects *Batik* and *Ethno* describes the mechanism of knowledge construction that is intact. The reciprocal connection between *the Learning Model* (blue) and *Batik* (purple) and *the Abstract Concept* (yellow) empirically validates the research direction of this period: that an effective learning model is one that is able to bind the real object of local wisdom (*Batik*) with scientific theory (*Abstract Concept*)). This proves that throughout 2023 to 2025, the integration of ethnoscience in the learning model has proven to be a fundamental solution to help students overcome science abstraction and build knowledge that leads to future competencies.

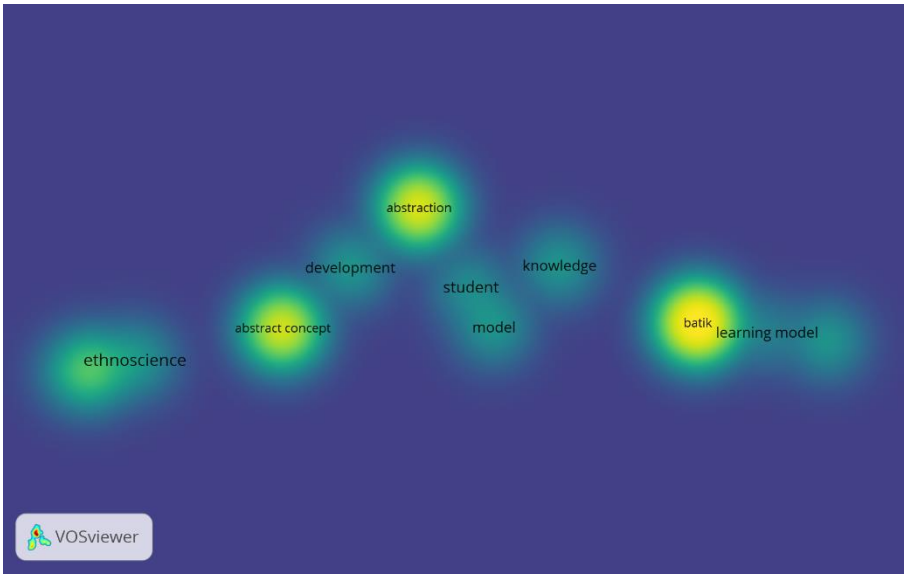


Figure 6. *Density Visualization*

The VOSviewer density visualization presents a strategic research focus map where the strong yellow saturation around the terms batik, abstraction, and abstract concept indicates that overcoming conceptual abstraction through culturally grounded learning objects remains a major challenge in science education. Surrounding this core area is a lighter yellow cluster associated with ethnoscience, which acts as a contextual bridge but gradually transitions into blue regions representing the development, model, and student clusters. These blue areas signify methodological gaps, particularly in the domain of model development, indicating that while cultural objects (such as batik) and conceptual challenges (abstraction) are widely examined, the systematic construction of learning models that transform these insights into instructional practice remains underexplored.

This condition provides strong justification for the urgency of the present study, which aims to fill this "blue space" by synthesizing a learning model (PjBL/Inquiry) that effectively integrates ethnoscience to support students' mastery of 21st-century competencies. Nevertheless, translating these theoretical insights into practical implementation requires careful consideration of field readiness. The success of ethnoscience-integrated models depends on teachers' pedagogical competence and their familiarity with culturally rooted science instruction, indicating a need for targeted professional development and continuous training programs. Additionally, the availability of school resources—such as digital tools, laboratory facilities, and culturally relevant materials—may vary widely across regions, influencing the extent to which such models can be adopted. Cultural barriers may also arise when local knowledge is interpreted differently across communities, requiring sensitivity and collaboration with local cultural practitioners. By acknowledging these practical considerations, this study bridges empirical evidence with real-world applicability, ensuring that the proposed model is not only theoretically robust but also feasible within diverse school contexts.

CONCLUSION

Based on a synthesis of empirical evidence from the recent literature (2023–2025), this study concludes that the integration of Project-Based Learning (PjBL) and Inquiry Learning with ethnoscience approaches represents one of the most effective pedagogical frameworks for strengthening 21st-century skills. The trend analysis highlights a significant paradigm shift from conventional learning toward digital and hybrid ecosystems, in which ethnoscience functions not merely as cultural enrichment but as a vital cognitive bridge that contextualizes abstract scientific concepts. Supported by technologies such as Virtual Assistive Technology (VAT) and digital learning platforms, this integrative model consistently demonstrates the ability to transform abstract concepts into concrete representations, thereby enhancing students' relevance, engagement, and understanding of science.

In terms of impact and contribution, the findings confirm that the model produces holistic outcomes not only improving critical thinking skills but also enhancing scientific literacy, cultural literacy, the character of the Pancasila Student Profile, and entrepreneurial skills derived from local potential. This synthesis addresses gaps identified in previous research by offering a systematic "Eco-Technopedagogy" framework, demonstrating that culturally grounded content supported by modern technology can serve as a new standard for science education that is globally competitive yet rooted in strong cultural identity.

Future research should prioritize controlled experimental studies to validate causal effects, long-term or longitudinal evaluations to measure sustainability of learning gains, and large-scale implementation trials to assess model feasibility across diverse regions and school types. Studies that examine cross-level consistency from elementary to higher education and comparative analyses between technology-assisted and non-assisted ethnoscience models are also urgently needed.

From a policy and practical perspective, this review recommends that educational stakeholders begin integrating ethnoscience-based PjBL and Inquiry Learning into curriculum planning, teacher training programs, and school-level innovations. Immediate steps may include developing teacher professional development modules on culturally contextualized science pedagogy, allocating resources for digital tools that support model integration, and fostering collaboration between schools and local cultural communities. Such efforts will help ensure that the proposed Eco-Technopedagogy framework not only remains theoretically robust but also practically adoptable within real classroom ecosystems.

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