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# Bibliometric analysis of deep learning research trends as a pedagogical approach to science learning in elementary schools (2021–2025)

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**Abstract**
The dynamics of education in the 21st century demand a pedagogical transformation towards holistic competency development. This study aims to analyze the research trend of Deep Learning as a pedagogical approach to social studies learning in elementary schools. Using bibliometric methods, this study mapped the intellectual structure of 574 scientific articles (2021–2025) sourced from Google Scholar through the Publish or Perish software and VOSviewer. The results of the network visualization analysis identified five main clusters that showed a shift in focus from the technical aspects of computing towards the integration of intelligent technologies in classroom practice. The publication trend jumped significantly after 2023, with the latest topics focusing on critical thinking, creativity, and artificial intelligence (AI) literacy. Density analysis reveals research gaps: the literature is dominated by science and STEM content, with little exploration of the social dimension (social studies) or local wisdom. This research concludes that Deep Learning has developed into a technological entity that supports the achievement of the 8 Dimensions of the Graduate Profile through the principles of mindful, meaningful, and joyful learning. The practical implications provide guidance for educators to integrate technology scaffolding with in-depth inquiry, shaping adaptive lifelong learners in the era of disruption.
**Keywords:** Deep Learning; bibliometrics; science learning; elementary school; digital pedagogy

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## INTRODUCTION

The dynamics of global education in the 21st century demand a fundamental transformation from a mere content-mastery paradigm to deep and holistic competency development. The Organisation for Economic Co-operation and Development (OECD), through the Learning Compass 2030 framework, emphasizes the urgency of providing "transformative competencies" for students, which include critical thinking, complex problem-solving, and adaptability (OECD, 2023). In response to this challenge, the concept of Deep Learning has become a major focus for researchers and practitioners worldwide. In contrast to the definition of deep learning in computer science (artificial intelligence), Deep Learning in education is defined as a learning design process that enables students to master essential competencies for solving real-world problems.

Theoretically, the Deep Learning framework developed by Fullan et al. (2018) is rooted in social constructivism, where learning is seen as the process of knowledge creation through social interaction and deep reflection. Fullan formulated six core competencies (6Cs) that form the pillars of this approach: Character (resilience and empathy), Citizenship (global citizenship), Collaboration (teamwork), Communication (effective communication), Creativity (economic and social innovation), and Critical Thinking (evaluation of information). In practice, these six elements operate in an integrated manner, helping students understand relationships between concepts in meaningful ways. This approach challenges traditional linear models, offering a more dynamic pedagogical structure in which teachers act as learning activators rather than mere transmitters of content.

At the national level, the relevance of this approach has grown stronger in line with Indonesia's new education policy direction projected for 2025. The Ministry of Primary and Secondary Education has begun discussing a transition to a Deep Learning-based curriculum to overcome stagnant education quality and create a meaningful, joyful, and mindful learning atmosphere (Huda et al., 2025). The urgency of implementing this approach is strongly felt at the elementary school level, especially in Natural and Social Sciences. As the foundation of science and social literacy, elementary science learning often faces classic obstacles: the dominance of lecture-based and memorization methods leading to superficial understanding (McPhail, 2021). The application of Deep Learning is expected to catalyze the transformation of IPAS learning from mere knowledge transfer to an in-depth inquiry process (Wijaya et al., 2025). Although discourse on Deep Learning as a curriculum strategy is evolving, comprehensive mapping of research trends on this topic in basic education remains scarce. One academic challenge is term ambiguity, since the literature is currently dominated by thousands of articles on technology-based "deep learning" (AI/neural networks), which often obscures the visibility of Deep Learning research in a purely pedagogical context (Crompton et al., 2020; Zhai et al., 2021). In addition, there have been few bibliometric studies specifically examining the evolution of themes, collaboration networks, and research gaps related to the implementation of Deep Learning in elementary science education between 2021 and 2025. This period encompassing post-pandemic recovery and preparation for a new curriculum is a crucial phase; thus, an in-depth analysis of the literature during this time is very important.

Based on these gaps, this study aims to analyze the development of research trends regarding the use of Deep Learning as a pedagogical approach in elementary science learning. Specifically, this bibliometric analysis outlines a comprehensive topic map of the Deep Learning theme through network visualization, examines fluctuations in research trends on Deep Learning in learning management during 2021–2025, and visualizes the level of novelty to develop a relevant research roadmap for future curriculum development. The results of this study are expected to contribute theoretically by clarifying the distinction between Deep Learning in technological research and Deep Learning as a pedagogical approach, and to provide practical guidance for educators in designing effective learning strategies.

## METHODS

This study used a bibliometric analysis approach to quantitatively map scientific trends and to identify intellectual structures in the field of Deep Learning curriculum studies. This approach was chosen because it can analyze large volumes of bibliographic data to uncover patterns of topic evolution, collaboration networks, and research gaps not apparent in conventional literature reviews. The research procedure followed the science mapping workflow developed by Donthu et al. (2021), which consists of three main stages: (1) data collection, (2) data screening, and (3) data visualization analysis.

### Data Collection

At the data collection stage, the metadata of relevant scientific articles was collected using the Publish or Perish (PoP) software version 8.0, querying the Google Scholar database. This database was chosen to capture a wide range of open literature, with a focus on articles from reputable international journals. To ensure the relevance of the data, a search strategy using English keywords with specific Boolean operators was applied. The search strings used were: ("Deep Learning" OR "Deep Learning Approach" OR "Deep Learning Curriculum") AND ("Elementary School" OR "Primary School") AND ("Science" OR "Social Studies" OR "Learning").

### Data Filtering

The raw results were then manually filtered by screening titles and abstracts to ensure content suitability. Strict inclusion and exclusion criteria were applied. Included articles had to be published in 2021–2025, written in English, and substantively address Deep Learning as a pedagogical approach in primary education. Articles identified as duplicates, editorials, or those primarily discussing technical programming aspects were excluded to maintain the validity of the dataset.

### Data Visualization Analysis

The last stage is the analysis of bibliographic data that has passed the selection. The data was exported in Research Information Systems (RIS) format to be analyzed using the VOSViewer software version 1.6.19 (Van Eck & Waltman, 2010). The analysis focused on keyword co-occurrence mapping to reveal the conceptual structure of this field of study. The results were then described through three types of visualization: Network Visualization to identify dominant clusters of research topics, Overlay Visualization to track trends in topic novelty by publication year, and Density Visualization to detect densely researched topics versus sparse areas as a basis for future research recommendations.

## RESULTS AND DISCUSSION

### Results

Based on the stages of data collection carried out through the Google Scholar database using the Publish or Perish software, the following findings regarding publication trends and bibliometric visualization maps were obtained.

#### Publication Trend Selection and Development Data

Data search was carried out through the Publish or Perish application by accessing the Google Scholar database. Based on the search parameters that have been directly restricted in the system for the 2021–2025 range, a total of 582 documents were found that contained the target keywords. Since age restrictions have been implemented by the system since its inception, the focus of the advanced selection is on the quality and relevance of the content.

From the total documents, a manual check is carried out to separate valid international journal articles from other documents such as blank citations, theses, or irrelevant proceedings. After eliminating articles that did not meet the criteria, a final dataset of 574 articles was obtained. The data shows that in the last five years, the trend of publication has fluctuated that tends to increase, with the highest number of publications recorded in 2025. This indicates that the discourse on Deep Learning in science and social learning is highly relevant and attracts international interest. The lowest number of publications was recorded in 2021, but this figure continues to increase significantly in 2023 and peaks in 2025. This improvement in the graph reflects the high interest of the global academic community in examining the application of deep learning in response to the demands of 21st century competencies, as illustrated in Figure 1.

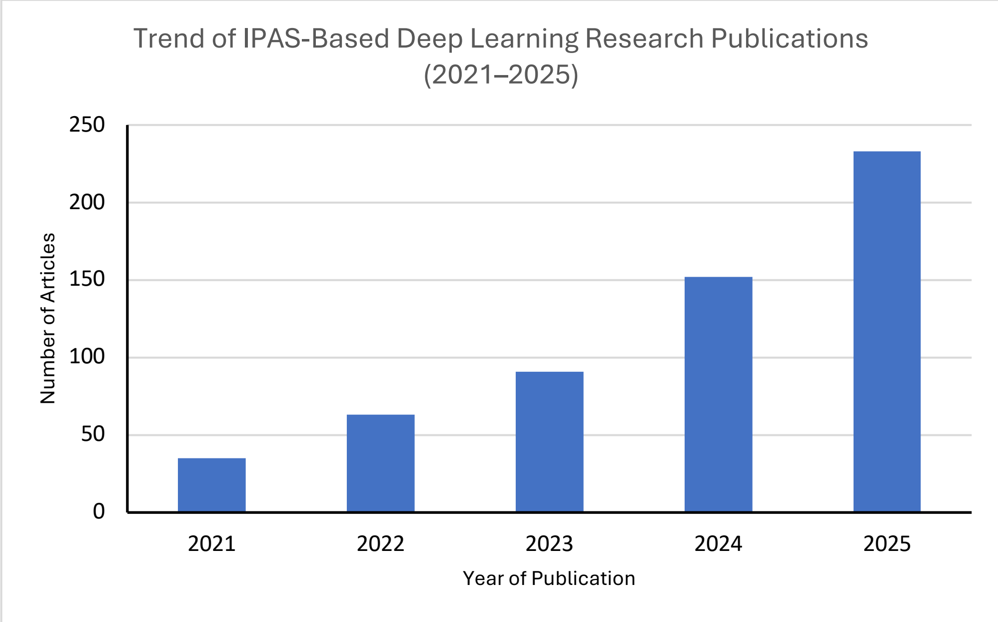


Figure 1. Trend of increasing number of publications (2021–2025)

**Bibliometric Network Visualization**

The network visualization analysis of Deep Learning research in IPAS (science learning in elementary education) using VOSviewer revealed five main clusters or thematic groups in the bibliometric map. Together, these five clusters constitute the key themes of research progress in this field, as shown in Figure 2.

Cluster 1 is displayed in red consisting of 9 items, including challenges, computer science, deep learning algorithms, deep learning models, elementary school children, machines, machine learning, systems, and techniques. In this cluster, it was found that the topics of Machine Learning and Deep Learning Models were the most dominant items. In the context of pedagogy, the dominance of this technical term indicates that the current research trend is still in the adaptation stage, where the concept of Deep Learning is often analyzed intersecting with computing technology (computer science) before being translated into practical learning strategies for elementary school students.

Cluster 2 is displayed in green consisting of 9 items, including challenge, covid, field, implementation, opportunity, practice, problem, project, and scoping review. In this cluster, the topics of Challenge and Implementation are the main nodes that are closely connected. This shows the reality in the field that the application of the Deep Learning approach in learning faces various practical challenges, especially those that arise due to the impact of the Covid pandemic. This cluster reflects the dynamics of the learning transition in elementary schools, where teachers must balance the demands of a project-based curriculum with implementation constraints in the field.

Cluster 3 is displayed in blue consisting of 8 items, namely bibliometric analysis, context, learning process, literature, role, science, teacher, and web. In cluster 3, it was found that the topic of Teacher plays a central role in the network, which is directly connected to the Learning Process and Science. These findings are particularly relevant to the pedagogical aspect, which confirms that the success of Deep Learning is highly dependent on the role of teachers in designing the learning process. The appearance of the keyword Science in this cluster also provides preliminary evidence that science content (IPAS) is the main context in which the role of teachers is widely researched.

Cluster 4 is displayed in yellow consisting of 7 items, including critical thinking skills, effects, effectiveness, meta-analysis, outcomes, primary school students, and strategy. In cluster 4, the topics of Primary School Students and Critical Thinking Skill emerged as the most prominent items. The strong relationship between these two items confirms the main goal of the application of Deep Learning as a pedagogical approach in elementary school, which is to improve high-level thinking skills. This cluster is proof that the focus of research outcomes has shifted from just mastering the material to strengthening students' critical thinking competencies.

The fifth cluster is displayed in purple and consists of five items, namely classroom, creativity, engagement, literature review, and science education. This cluster most explicitly represents IPAS content, as science education nodes are closely connected to creativity and student engagement. These relationships indicate that science subjects provide a particularly supportive context for applying Deep Learning to foster active participation and creative learning experiences. Collectively, these findings demonstrate that Deep Learning is predominantly implemented within science learning contexts to promote active and in-depth learning, as illustrated in Figure 2.

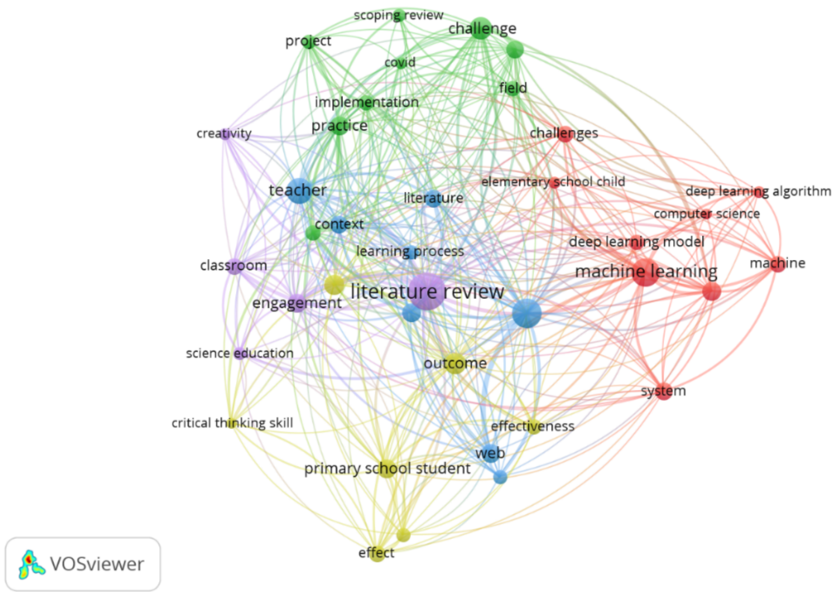


Figure 2. Network visualization research keywords

**Novelty Trend Visualization (Overlay Visualization)**

An overlay visualization was used to examine patterns and shifts in research on Deep Learning as a pedagogical approach in IPAS learning during the 2021–2025 period. This analysis was conducted to identify changes in research focus based on publication year within international journal articles indexed in Google Scholar.

The overlay visualization indicates that more recent studies are represented by lighter colors, particularly yellow, which highlight emerging research themes. These recent topics include critical thinking skills, creativity, student engagement, science education, primary school students, and learning processes. This pattern suggests that current research trends increasingly emphasize student learning outcomes rather than focusing solely on technical or computational aspects of Deep Learning.

This thematic evolution occurred alongside a substantial increase in research output over time, which provides important contextual grounding for interpreting novelty patterns. The convergence between publication growth and thematic shifts indicates that changes in research focus developed in parallel with the expansion of scholarly interest, as reflected in Figure 1 and further detailed through overlay visualization in Figure 3.

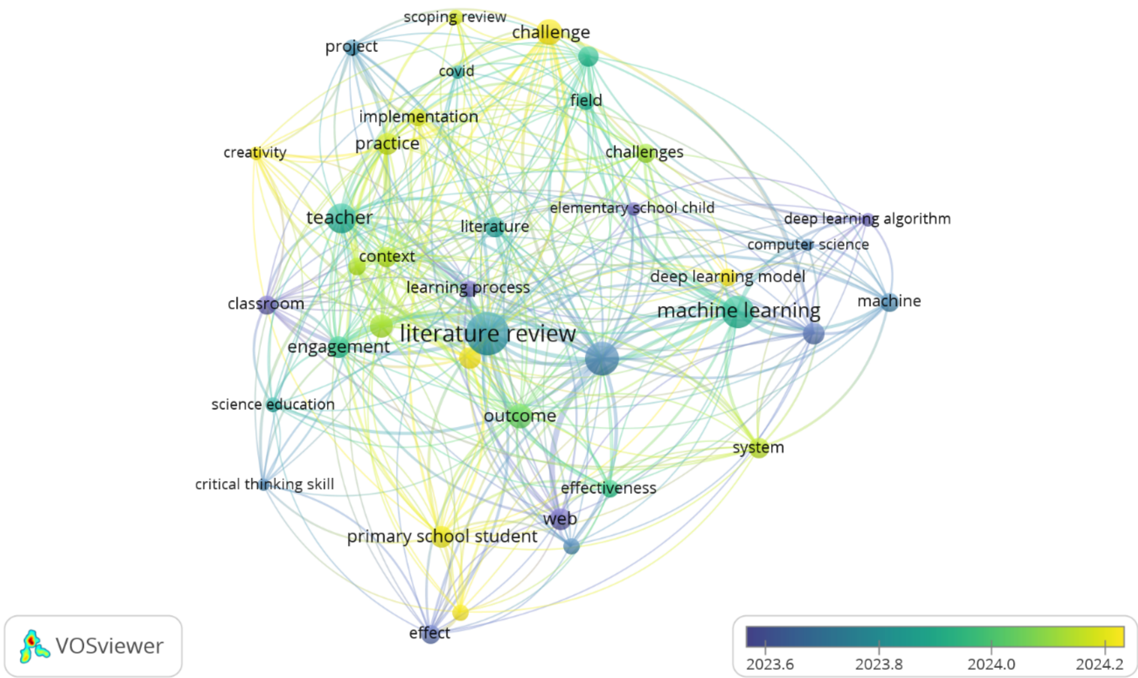


Figure 3. Overlay visualization novelty of research topics

**Density Visualization**

Density visualization examines the concentration of keywords related to deep learning, pedagogical approaches, and elementary education. Color intensity in the density map represents the frequency with which particular research topics are investigated. Bright yellow areas indicate topics that are most frequently examined, including machine learning, literature reviews, teacher roles, science education, and critical thinking skills. In contrast, areas represented by increasingly faded yellow colors indicate topics that are less frequently explored, such as creativity, student engagement, project-based learning, scoping reviews, field-based studies, challenges, and web-related contexts, as illustrated in Figure 4.

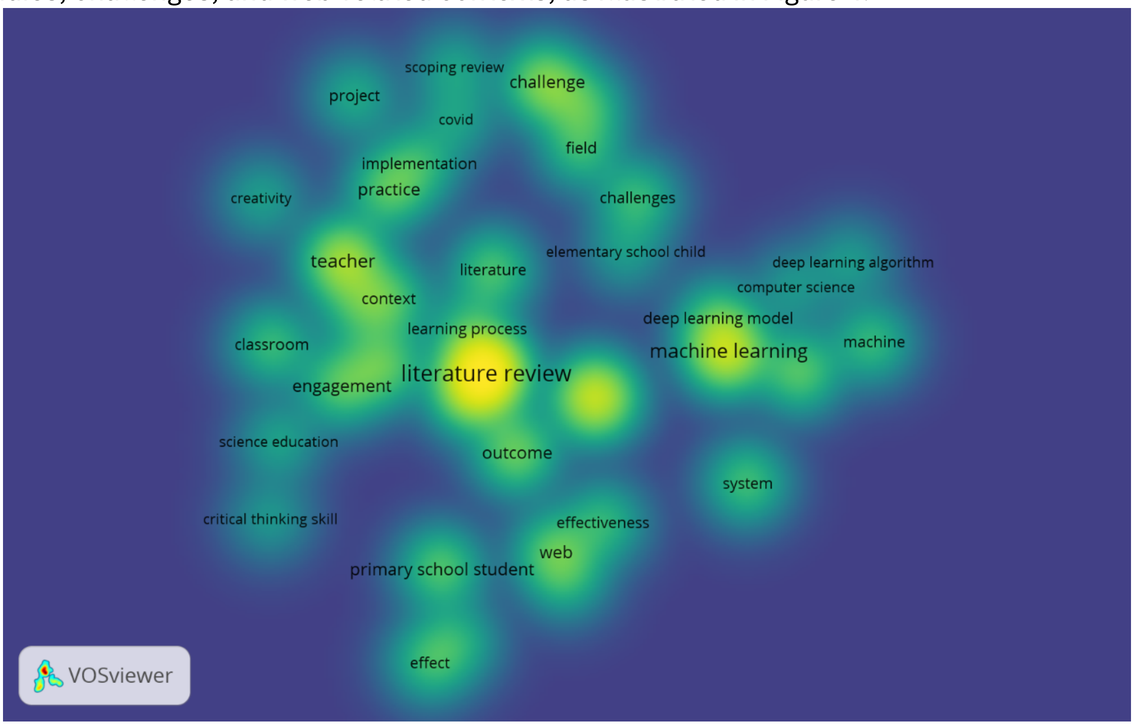


Figure 4. Density visualization and topic saturation

**Top Cited Papers**

This bibliometric analysis also maps articles with the greatest academic impact based on citation frequency. The dataset shows that the most highly cited studies are closely associated with technological trends and pedagogical innovation in education. The article with the highest citation count was authored by (Casal-Otero et al., 2023), entitled “AI literacy in K-12: a systematic literature review,” which has received 738 citations. The prominence of this publication indicates that artificial intelligence literacy represents a central issue in contemporary primary and secondary education. The second most cited study was conducted by (Xu & Ouyang, 2022) with 608 citations, focusing on the application of AI technologies in STEM education, followed (Wu & Yu, 2024) which ranked third with 599 citations and examined the impact of AI chatbots on student learning outcomes. Collectively, these citation patterns indicate that current global research discourse is strongly dominated by the integration of intelligent technologies into science education and learning curricula, as summarized in Table 1.

Table 1. Ten articles with the highest citations
(Data Source: Processed from google scholar via publish or perish)

| Ratings | Author | Title | Year | Journal Source | Citation |
|---|---|---|---|---|---|
| 1 | (Casal-Otero et al., 2023) | AI literacy in K-12: a systematic literature review | 2023 | International Journal of STEM Education (Springer) | 738 |
| 2 | (Xu & Ouyang, 2022) | The application of AI technologies in STEM education: a systematic review from 2011 to 2021 | 2022 | International Journal of STEM Education | 608 |
| 3 | (Wu & Yu, 2024) | Do AI chatbots improve student learning outcomes? Evidence from a meta-analysis | 2024 | British Journal of Educational Technology | 599 |
| 4 | (Marín-Marín et al., 2021) | STEAM in education: a bibliometric analysis of performance and co-words in Web of Science | 2021 | International Journal of STEM Education (Springer) | 329 |
| 5 | (Barua et al., 2022) | Artificial Intelligence Enabled Personalised Assistive Tools to Enhance Education of Children with Neurodevelopmental Disorders—A Review | 2022 | International Journal of Environmental Research and Public Health (MDPI) | 311 |
| 6 | (Yim & Su, 2025) | Artificial intelligence (AI) learning tools in K-12 education: A scoping review | 2025 | Journal of Computers in Education | 303 |
| 7 | (Zhang & Tur, 2024) | A systematic review of ChatGPT use in K-12 education | 2024 | European Journal of Education | 293 |
| 8 | (Alfaisal et al., 2024) | Metaverse system adoption in education: a systematic literature review | 2024 | Journal of Computers in Education | 282 |
| 9 | (Taj & Zaman, 2022) | Towards industrial revolution 5.0 and explainable artificial intelligence: Challenges and opportunities | 2022 | International Journal of Computing and Digital System | 247 |
| 10 | (Yu et al., 2021) | Analysis of collaboration evolution in AHP research: 1982–2018 | 2021 | International Journal of Information Technology & Decision Making | 229 |

## Discussion

### Trend Evolution: From Theoretical Concepts to Technological (Technological-Pedagogical) Integration

Based on the analysis of the articles with the highest citation impact, it can be seen that there is a fundamental shift in the trend of Deep Learning research at the primary education level, which is now transforming into the integration of intelligent technology in pedagogy. The high number of references in the literature on AI literacy at the K-12 level confirms that the current definition of "deep learning" is no longer inseparable from the mastery of adaptive technology from an early age (Casal-Otero et al., 2023; Taj & Zaman, 2022; Yim & Su, 2025). The demarcation between technical and pedagogical research is getting thinner, where the most influential research shows that the application of AI technology in STEM (Science, Technology, Engineering, Mathematics) education is the most dominant strategy to achieve a deep understanding of concepts (Marín-Marín et al., 2021; Xu & Ouyang, 2022; Yu et al., 2021). This provides theoretical implications that Deep Learning in the modern context should be understood as a hybrid learning ecosystem that combines human inquiry with machine intelligence, rather than just conventional teaching methods (Barua et al., 2022; Fullan et al., 2018).

Furthermore, the emergence of the *Industry 5.0* era demands a reorientation of science learning objectives. Students are now expected not only to understand natural phenomena, but also to collaborate with explainable intelligent systems (*explainable AI*). Bibliometric evidence shows that global research collaborations are focusing on developing ethical and transparent decision-making frameworks for the use of technology (Taj & Zaman, 2022; Yu et al., 2021). This indicates that Deep Learning is no longer just a classroom strategy, but an existential need to prepare digital natives who are technologically literate. The active involvement of students in manipulating science variables through digital simulations is a key indicator of the success of this pedagogy, replacing the passive demonstration model that has dominated conventional science classes (Marín-Marín et al., 2021).

**The Effectiveness of Deep Learning in Personalization and Learning Outcomes**

The bibliometric findings confirm that the implementation of Deep Learning supported by technology has proven to be effective in improving learning outcomes and student personalization. Meta-analysis of the use of intelligent chatbots and assistive systems shows a significant impact in helping students understand complex material according to their respective learning speeds (Barua et al., 2022; Wu & Yu, 2024). In the context of pedagogy, this answers the challenge of inclusive education, where generative technologies such as ChatGPT if managed with the right pedagogical framework are able to provide the scaffolding (gradual assistance) that students need to reach a higher level of thinking (Yim & Su, 2025; Zhang & Tur, 2024). Empirical evidence from these reputable articles reinforces the argument that the success of Deep Learning relies heavily on teachers' readiness to adopt digital tools to create relevant and immersive learning experiences (Alfaisal et al., 2024; Casal-Otero et al., 2023; McPhail, 2021).

The practical implications of these findings are crucial for inclusive education, where AI-based assistive technology becomes a bridge for students with special needs or neurodevelopmental disorders to access the same curriculum. In-depth research shows that personalized tools are able to detect patterns of student learning difficulties in real-time and provide precise early intervention, a capability that is difficult for teachers to manually perform in large classrooms (Barua et al., 2022; Yim & Su, 2025). Additionally, the use of chatbots in the science inquiry process provides a safe space for students to ask questions without fear of being judged, which psychologically enhances their confidence and intrinsic motivation in problem-solving (Wu & Yu, 2024; Zhang & Tur, 2024). Thus, technology-based Deep Learning not only deepens the material, but also expands educational accessibility for all students.

**Relevance to the Independent Curriculum**

The global trend that leads to inquiry-based learning and technology has substantial alignment with the Independent Curriculum policy in Indonesia, especially in the content of IPAS (Natural and Social Sciences). The implementation of the STEAM approach and the use of immersive technology (Metaverse) that dominates international research trends have proven to be very relevant to facilitate the achievement of the 8 Dimensions of the Graduate Profile, especially in the aspects of critical reasoning, creativity, and independence (Alfaisal et al., 2024; Kemendikbudristek, 2022; Marín-Marín et al., 2021). The principle of differentiated instruction that is at the heart of the Independent Curriculum has received strong support from the global literature that emphasizes that Deep Learning must accommodate the unique needs of each learner through flexible learning paths (Barua et al., 2022; Rahayu et al., 2022; Tomlinson, 2017). The integration of Deep Learning in IPAS not only aims at cognitive mastery of science content, but also the formation of lifelong learner characteristics who are adaptive and resilient to the changing times (Indarta et al., 2022; Nasution, 2022; Xu & Ouyang, 2022).

At the classroom level, integrating the STEAM model is the most concrete manifestation of Deep Learning in science education and is in line with the principles of mindful, meaningful, and joyful learnin (Kemendikbudristek, 2022). This approach breaks down the traditional barriers between subjects, allowing students to see the connections between scientific principles and engineering solutions through meaningful projects. As a result, knowledge is no longer taught in a fragmented manner (Marín-Marín et al., 2021; McPhail, 2021; Xu & Ouyang, 2022). Achieving this vision of curricular coherence requires transforming the role of IPAS teachers in Indonesia from being primarily information providers to becoming inquiry facilitators who design quality learning experiences for all students (Fullan et al., 2018; Rahayu et al., 2022). By adopting a Deep Learning mindset, elementary education can give students the space to explore content consciously and meaningfully, helping them meet the expected graduate competency standards (Nasution, 2022).

**Research Gap: Social Dimension Inequality**

Although publication trends have spiked, the density visualization and citation analysis reveal a marked imbalance in the focus of IPAS research. Most "top-tier" studies concentrate on technical content (STEM/AI) and natural sciences, whereas social aspects (social studies), culture, and local wisdom are largely neglected in the influential literature (Greenhalgh et al., 2020; Mandiudza, 2013; Taj & Zaman, 2022; Xu & Ouyang, 2022).Topics related to civic education or cultural values appear with very low density, indicating that the global discourse tends to ignore humanistic contexts in favor of technical advances (Bozkurt et al., 2020; Greenhalgh et al., 2020). This gap presents strategic opportunities for further research to develop a more holistic Deep Learning model. Such a model would not only be technologically advanced (AI-based) but also culturally grounded, balancing students' scientific reasoning skills with social sensitivity (Fullan et al., 2018; Kleven et al., 2019; Zhang & Tur, 2024).

The lack of research connecting Deep Learning to local wisdom and social ethics is a critical gap that must be addressed. The dominance of technocentric perspectives in global literature risks creating a generation that is technologically savvy but socially and culturally uninformed (Mandiudza, 2013; Taj & Zaman, 2022). Future studies should explore how Deep Learning can be applied in social studies instruction to instill values of empathy, tolerance, and historical awareness relevant to the nation's identity. Developing an "Ethno-Deep Learning" model combining technological sophistication with local cultural richness could be an innovative solution to balance students' hard skills and soft skills in this era of disruption (Fullan et al., 2018; Indarta et al., 2022).

## CONCLUSION

This study provides a comprehensive bibliometric overview of Deep Learning research as a pedagogical approach in elementary science education from 2021 to 2025. First, the network visualization mapped out the landscape of this research, revealing that Deep Learning themes in IPAS are grouped into key clusters that integrate technological dimensions with pedagogical dimensions. This mapping clarifies the distinction between Deep Learning as a technological endeavor and Deep Learning as a pedagogical strategy focused on meaningful, deep understanding of content.

Second, the trend analysis showed a sharp increase in research interest over the five-year period, especially after 2023. There has been a discernible shift in focus from conventional teaching and learning strategies towards hybrid strategies that utilize intelligent tools and assistants. Deep Learning has thus become a crucial approach for addressing the complexity of the IPAS curriculum and improving classroom engagement and management in elementary schools.

Third, the overlay visualization highlighted where the research novelty lies and pointed to a future research roadmap. Current innovations center on integrating generative AI and immersive technologies to support the diverse competencies outlined in the Pancasila Student Profile. However, the analysis also exposed a persistent gap: the socio-cultural dimension of Deep Learning remains underrepresented. Addressing this gap should be a priority for future curriculum development and research so that Deep Learning implementations can truly align with the vision of holistic, mindful, and joyful education.

In practical terms, these findings suggest that effective IPAS learning strategies in elementary schools should blend technological scaffolding with in-depth inquiry. Educators are encouraged to integrate digital tools in a way that enriches inquiry-based learning and caters to individual student needs. Theoretically, this study confirms that Deep Learning in elementary education has evolved into a technology-integrated paradigm aimed at cultivating lifelong learners who are critical, creative, and adaptive to change. By embracing both advanced technologies and local pedagogical values, stakeholders in education can ensure that Deep Learning not only elevates academic outcomes but also nurtures well-rounded individuals ready to thrive in the era of disruption.

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