

Deep Learning in Elementary Education: A Hybrid Systematic Literature Review and Bibliometric Analysis of Global Research Trends (2005-2025)

Rino Lengam¹, Marthen Luther Soplara², Susana Labuem³, Tri Wiyoko⁴, Nurfidianty Annafi⁵

¹Universitas Pattimura, Ambon, Indonesia; rino.lengam@lecturer.unpatti.ac.id

²Universitas Pattimura, Ambon, Indonesia; marthen.soplara@lecturer.unpatti.ac.id

³Universitas Pattimura, Ambon, Indonesia; susana.labuem@lecturer.ac.id

⁴Universitas Jambi, Universitas Muhammadiyah Muara Bungo, Jambi, Indonesia; yokostikipmb@gmail.com

⁵Universitas Nggusuwaru, Bima, Indonesia; nurfidianty89@gmail.com

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ABSTRACT

Deep learning has gained increasing attention in elementary education, yet the literature remains conceptually fragmented because the term refers both to artificial intelligence (AI)-based techniques and to pedagogical approaches that promote meaningful, student-centered learning. This study maps the development, conceptualization, dominant themes, and research gaps of deep learning in elementary education. A hybrid Systematic Literature Review (SLR) and bibliometric analysis was conducted using 44 Scopus-indexed journal articles published between 2005 and 2025. The review followed the PRISMA framework, while bibliometric mapping was performed using VOSviewer to examine publication trends, geographical distribution, collaboration patterns, subject areas, and keyword co-occurrence. Publications increased substantially after 2024, with Taiwan, the United States, and China among the leading contributors. Social Sciences represented the largest subject area, followed by Computer Science and Psychology. Keyword analysis identified deep learning, elementary education, students, interactive learning environments, teaching and learning strategies, and project-based learning as prominent themes. The literature reflects an intersection between AI-supported technologies and student-centered pedagogical practices, although international collaboration remains relatively fragmented. The findings indicate a growing convergence between technological and pedagogical perspectives on deep learning in elementary education. Future research should strengthen conceptual distinctions between these perspectives and expand multidisciplinary, longitudinal, ethical, and policy-oriented investigations to support developmentally appropriate and meaningful technology-enhanced learning.

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Corresponding Author:

Rino Lengam

Universitas Pattimura, Ambon, Indonesia; rino.lengam@lecturer.unpatti.ac.id

1. INTRODUCTION

The transformation of education in the twenty-first century has increasingly shifted learning practices from content transmission toward adaptive, participatory, and competency-oriented learning. This shift is driven by the growing importance of digital literacy, higher-order thinking skills, creativity, collaboration, and students' capacity to apply knowledge in complex real-life contexts (Ramamonjisoa, 2024). At the primary school level, this transformation is particularly important because early schooling provides the foundation for students' cognitive development, learning habits, social interaction, and affective growth (Nasri & Shanmuganathan, 2025). However, the integration of advanced technology and innovative pedagogical approaches in primary education remains uneven, especially when schools are expected to balance technological innovation with child-centered, ethical, and developmentally appropriate learning practices.

Within this broader transformation, the term deep learning has gained increasing attention in educational research. Nevertheless, its use remains conceptually ambiguous. In computer science, *deep learning* refers to a branch of artificial intelligence that uses multilayer neural networks to process large and complex data, recognize patterns, and support predictive or adaptive systems (Zepher, 2026). In education, however, deep learning may also refer to a pedagogical approach that encourages students to construct meaningful understanding, think critically, collaborate, communicate, create, and transfer knowledge to new situations (Taqiyya, et al, 2025). This second meaning is closely related to student agency, meaningful learning, and the development of global competencies. The distinction is important because studies that discuss deep learning in schools do not always refer to the same object: some examine algorithmic or AI-based systems, while others discuss instructional design and learning transformation.

Recent developments in artificial intelligence in education have intensified this conceptual overlap. AI-based systems, including adaptive learning platforms and learning analytics, can support personalization by processing student data and recommending learning pathways. Recent reviews show that AI in education is commonly associated with adaptive learning, personalized learning, automated assessment, and data-driven instructional support (Pareek, 2025). At the same time, international education frameworks emphasize that future learning should not be reduced to technological efficiency alone, but should strengthen student agency, well-being, competencies, and responsible participation in society (Yeo & Yeo, 2024). Therefore, in the context of this study, *deep learning* is positioned as a pedagogical approach supported by technology, rather than merely as an AI technique. This conceptual positioning allows the study to examine how technology-enhanced learning can contribute to deeper understanding, active student engagement, and meaningful learning experiences in primary education.

Primary education provides a crucial context for examining this issue. Unlike higher education or professional training, primary education involves younger learners whose cognitive, emotional, and social development requires careful pedagogical consideration (Sobirovich & Qizi, 2025). The use of technology at this level must therefore be evaluated not only in terms of innovation or efficiency, but also in terms of its alignment with students' developmental needs, teachers' pedagogical readiness, curriculum goals, and ethical safeguards. UNESCO's guidance on generative AI in education emphasizes the need for human-centered policies, teacher capacity building, and responsible governance when integrating AI-related technologies into educational settings (Chaure & Asad, 2024). This reinforces the need to understand whether existing studies on *deep learning* in primary education have adequately addressed pedagogical, technological, and policy dimensions in an integrated way.

Despite the growing number of studies on *deep learning* in primary education, the knowledge base remains fragmented. Many studies focus on specific applications, local interventions, or small-scale experiments, while fewer studies synthesize how the field has developed over time, which countries and disciplines dominate the discussion, what themes have emerged, and how the concept of *deep learning* is being framed (Zhang & Hu, 2025). Existing scholarship also often separates technological discussions from pedagogical ones, resulting in limited understanding of how AI-supported systems

and deep pedagogical learning may interact in primary school contexts. This fragmentation makes it difficult for researchers, teachers, and policymakers to identify the dominant trends, conceptual gaps, and future directions of the field.

The research gap addressed in this study is therefore not simply the lack of studies on *deep learning*, but the lack of an integrated mapping that distinguishes, connects, and critically examines two overlapping meanings of the term: deep learning as AI-based technology and deep learning as a pedagogical approach. Previous reviews in artificial intelligence in education have provided broad insights into AI applications, research topics, and methodological trends, including adaptive and personalized learning. However, studies that specifically map deep learning in primary education from both systematic and bibliometric perspectives remain limited. This gap is significant because primary education requires a more careful synthesis that considers not only technological advancement, but also pedagogical relevance, teacher practice, student-centered learning, and policy implications.

To address this gap, the present study combines a Systematic Literature Review and Bibliometric Analysis of 44 Scopus-indexed articles published up to September 9, 2025. The Systematic Literature Review is used to identify, evaluate, and synthesize the conceptual focus, methodological tendencies, and pedagogical implications of previous studies. Bibliometric analysis complements this process by mapping publication trends, country contributions, disciplinary distribution, author collaboration, and keyword co-occurrence. By integrating these two approaches, this study provides both interpretive depth and structural mapping of the research landscape. This combined design is important because a purely narrative review may not fully reveal the intellectual structure of the field, while a purely bibliometric analysis may not sufficiently explain the pedagogical meaning and implications of the findings.

The theoretical framework of this study is grounded in three complementary perspectives. First, the pedagogical perspective of deep learning emphasizes meaningful understanding, active inquiry, collaboration, creativity, critical thinking, and knowledge transfer. This perspective is consistent with the 6Cs framework, which conceptualizes deep learning as the development of character, citizenship, collaboration, communication, creativity, and critical thinking. Second, the student-agency perspective highlights learners as active participants who are able to make choices, reflect on learning, and contribute responsibly to their communities. This aligns with the OECD Learning Compass 2030, which places student agency, competencies, and well-being at the center of future-oriented education. Third, the technology-enhanced learning perspective views AI and data-driven systems as tools that may support personalization, adaptive feedback, and learning analytics, but whose value depends on ethical, pedagogical, and contextual alignment. These three perspectives provide the analytical lens for distinguishing technological deep learning from pedagogical deep learning, while also examining how both may contribute to educational transformation in primary schools.

This study contributes to the literature in three ways. First, it clarifies the conceptual boundary between deep learning as an AI technique and deep learning as a pedagogical approach in primary education. Second, it provides an integrated map of publication trends, disciplinary patterns, geographical contributions, and thematic developments based on Scopus-indexed literature. Third, it offers implications for educators and policymakers by identifying how deep learning-oriented practices may be supported through teacher professional development, digital infrastructure, curriculum design, ethical governance, and international collaboration. In doing so, this study seeks to move the discussion beyond descriptive mapping toward a more analytical understanding of how the field is structured, where its weaknesses lie, and what directions are needed for future research and practice.

To address these gaps, this study employs a hybrid Systematic Literature Review (SLR) and bibliometric analysis to provide an integrated understanding of deep learning research in elementary education. The SLR is used to examine how deep learning is conceptualized, particularly in distinguishing AI-based applications from pedagogical approaches, while bibliometric analysis is used to map the structural development of the field in terms of publication trends, disciplinary orientations, geographical distribution, collaboration patterns, and thematic relationships. Drawing on Scopus-

indexed literature published between 2005 and 2025, the study seeks to identify not only the current structure and dominant themes of the research landscape but also its methodological, theoretical, and practical gaps. Accordingly, the study addresses four research questions: (1) How has research on deep learning in elementary education evolved in terms of publication trends, disciplinary orientation, geographical distribution, and collaboration patterns? (2) How do existing studies conceptualize deep learning in elementary education, particularly in distinguishing between AI-based deep learning and pedagogical deep learning? (3) What dominant themes, methodological tendencies, and theoretical orientations characterize the current literature? and (4) What research gaps and future directions can be identified to support the pedagogically meaningful, ethical, and policy-relevant implementation of deep learning in elementary education?

2. METHODS

This study employed a hybrid review design integrating a Systematic Literature Review (SLR) and bibliometric analysis to systematically examine the development and characteristics of deep learning research in elementary education. The SLR was used to identify, screen, evaluate, and synthesize relevant studies, particularly to examine how deep learning has been conceptualized and applied across technological and pedagogical perspectives. Bibliometric analysis complemented this process by quantitatively mapping publication trends, geographical and institutional contributions, collaboration patterns, disciplinary orientations, and thematic relationships within the literature. The review process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to enhance transparency and reproducibility, while bibliometric mapping was conducted using VOSviewer. The overall methodological procedure comprised database selection, search strategy development, application of inclusion and exclusion criteria, systematic screening, quality assessment, data extraction, and bibliometric and thematic analysis, as described in the following subsections.

This study began by establishing an operational understanding of deep learning in educational contexts to guide the literature identification, screening, and analysis processes. This step was necessary because the term deep learning is used in the literature to represent different but potentially interconnected perspectives, ranging from artificial intelligence-based techniques for prediction, classification, and adaptive systems to learning approaches that emphasize personalization, student-centered environments, cognitive engagement, and skill development. Rather than treating these perspectives as conceptually identical, the present study used their defining characteristics to determine the educational relevance of the retrieved studies and to support their subsequent interpretation. The defining elements synthesized from the literature are presented in Figure 1 and served as the conceptual basis for distinguishing technological applications from pedagogically oriented uses of deep learning throughout the systematic review and bibliometric analysis.

Table 1. Defining Elements of Deep Learning

No.	Defining factors of Deep Learning	Reference
1	The application of deep learning in the context of education aims to develop a recommendation system capable of adapting learning materials to the individual characteristics of students based on predicted learning styles.	(Araujo, et al., 2020)
2	Deep learning is a rapidly developing problem-solving paradigm that has emerged in the last decade and has been widely applied across various disciplines.	(Yuan, Wang, Kushniruk, & Peng, 2017)
3	Deep learning is utilized to extract features from both text and images in question-based learning scenarios, with a model design that is adaptable and continuously improves as data increases.	(Pardamean, Suparyanto, Cenggoro, Sudigyo,

		& Anugrahana, 2022)
4	The concept of deep learning is recognized as an important strategy that seeks to address fundamental questions about its purpose, nature, and implementation in the context of education, while also highlighting its compatibility with the principles of inclusion and personalized learning.	(Kovac, Nome, & Jesen, 2023)
5	In the context of education, deep learning techniques have the potential to create student-centered learning ecosystems with strategies tailored to individual needs and preferences.	(Ahad, Tripathi, & Agarwal, 2018)
6	Deep learning is recognized as having enormous potential for improving educational research, particularly in understanding and predicting student performance and satisfaction.	(Tzeng, Lee, Huang, Huang, & Lai, 2022)
7	Deep learning approaches are those that categorize the cognitive presence phase in online discussions and have been proven to produce performance comparable to traditional classifiers.	(Hu, Donald, & Giacaman, 2023)
8	Deep learning models are able to achieve high accuracy in recognizing self-regulatory behavior while also predicting the interaction experiences felt by students.	(Lee et al., 2022)
9	The deep learning approach is understood as a model-based learning strategy that integrates in-depth analytical capabilities to support skill development, particularly in visualization-based learning environments.	(Yuan et al., 2017)
10	The deep learning approach is an artificial intelligence-based learning strategy used to automate the classification of cognitive presence in student interactions, specifically through online discussion posts.	(Lee et al., 2022)

The study selection process was conducted systematically using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to ensure transparency and consistency in identifying relevant literature. The review proceeded through the main stages of identification, screening, eligibility assessment, and final inclusion, with studies progressively evaluated according to the predefined search strategy and inclusion and exclusion criteria. This procedure was designed to ensure that the final dataset consisted of studies that were methodologically appropriate and relevant to the investigation of deep learning within elementary education contexts. The complete literature selection process and the number of records retained or excluded at each stage are summarized in Figure 1.

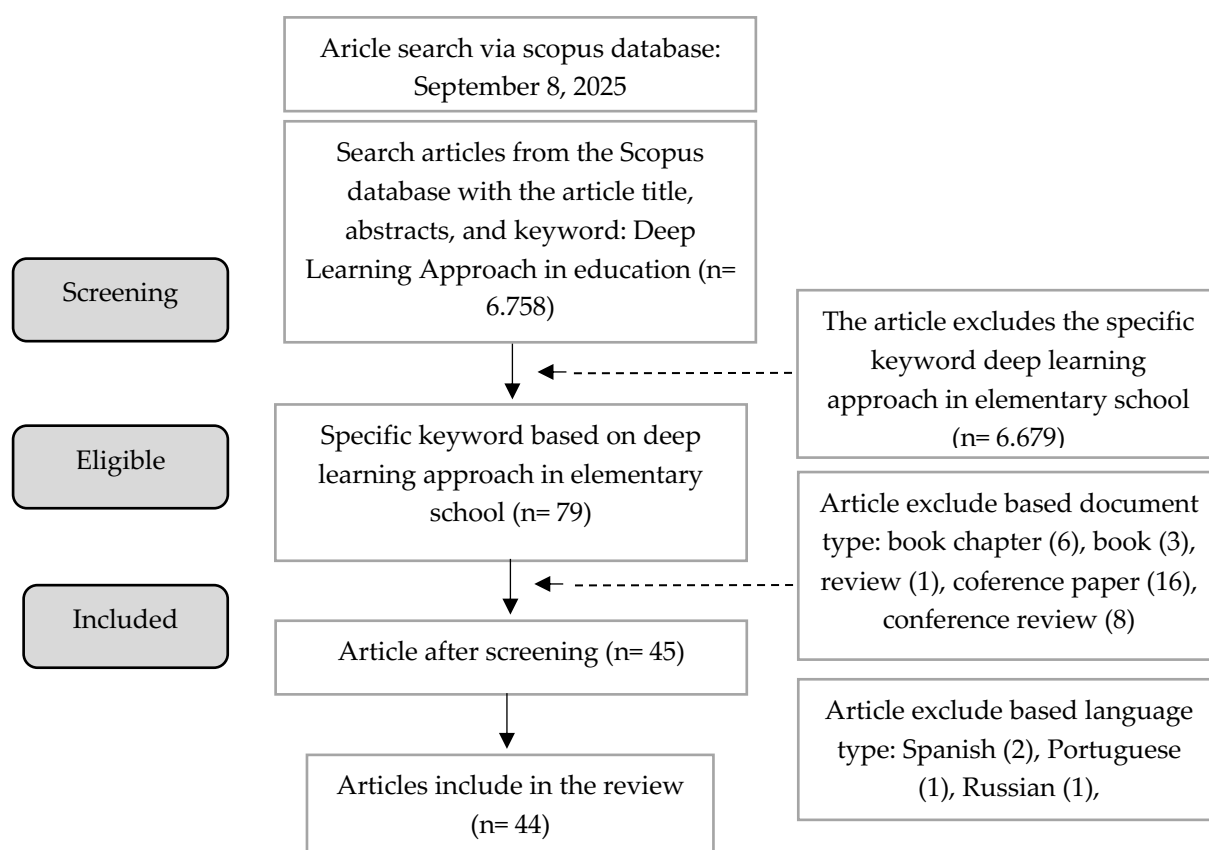


Figure 1. Systematic Literature Review information flow using PRISMA

2.1. Database Selection and Justification

This study exclusively used the Scopus database as the primary source of literature retrieval. Scopus was selected because it is recognized as one of the largest multidisciplinary abstract and citation databases covering high-quality peer-reviewed journals in education, social sciences, and computer science. Compared with other indexing services, Scopus provides broader international coverage, standardized bibliographic metadata, citation tracking features, and compatibility with bibliometric software such as VOSviewer. The use of a single database was intended to maintain consistency in indexing standards, avoid duplication across databases, and ensure homogeneity in metadata extraction for bibliometric mapping.

2.2. Search Strategy

The literature search was conducted on September 9, 2025, using the Scopus advanced search feature. The search process focused on publications related to deep learning approaches in elementary education published between 2005 and 2025. The search query was formulated to capture studies discussing both pedagogical deep learning and technology-assisted learning approaches within primary education contexts. The exact search used in scopus was:

TITLE-ABS-KEY ("deep learning" AND ("elementary education" OR "elementary school" OR "primary education" OR "primary school") AND PUBYEAR > 2004 AND PUBYEAR < 2026.

The search was restricted to article titles, abstracts, and keywords to ensure relevance to the research objectives. The time span of 2005–2025 was selected because the term “deep learning” began to emerge more consistently in educational and technological literature during this period, particularly

following the expansion of digital learning environments and artificial intelligence applications in education.

2.3. Inclusion and Exclusion Criteria

To ensure consistency and relevance, this study established explicit inclusion and exclusion criteria prior to the screening process.

Inclusion Criteria

Articles were included if they met the following criteria:

1. Published between 2005 and 2025.
2. Indexed in the Scopus database.
3. Published in peer-reviewed academic journals.
4. Written in English.
5. Focused on deep learning approaches, technology-enhanced learning, AI-supported learning, or pedagogical deep learning in elementary or primary education contexts.
6. Provided empirical, conceptual, or evaluative discussions relevant to learning processes in primary education.

Exclusion Criteria

Articles were excluded if they:

1. Were conference papers, conference reviews, book chapters, books, editorials, or notes.
2. Discussed deep learning solely from a technical computer science perspective without educational relevance.
3. Focused on secondary education, higher education, or non-formal education without discussing elementary education.
4. Were not written in English.
5. Had incomplete bibliographic metadata or inaccessible full texts.

2.4. PRISMA Screening Process

The article screening process followed the PRISMA protocol and consisted of four stages: identification, screening, eligibility, and inclusion.

At the identification stage, the initial Scopus search produced 6,758 documents related to “deep learning in education.” After refining the search using elementary education-related keywords, 79 documents remained.

During the screening stage, documents were filtered according to publication type. A total of 34 documents were excluded, consisting of conference papers (16), conference reviews (8), book chapters (6), books (3), and review articles (1). This process resulted in 45 journal articles.

At the eligibility stage, language screening was conducted. One article was excluded because it was published in non-English languages (Spanish, Portuguese, and Russian versions), resulting in a final dataset of 44 articles eligible for analysis.

The final sample of 44 articles was considered adequate because bibliometric studies emphasize relevance and thematic consistency rather than large sample size alone. The selected articles represented the core literature specifically discussing deep learning approaches within elementary education contexts. Moreover, the dataset demonstrated sufficient diversity in publication years, countries, journals, subject areas, and research themes to support meaningful bibliometric mapping and systematic synthesis.

2.5. Quality Assessment (Critical Appraisal)

To strengthen the credibility of the review, all included articles underwent a critical appraisal process. The assessment focused on four dimensions:

1. Clarity of research objectives;

2. Methodological transparency;
3. Relevance to elementary education contexts;
4. Contribution to pedagogical or technological understanding of deep learning.

Each article was independently evaluated using a qualitative scoring approach adapted from systematic review standards in educational research. Articles with weak methodological descriptions, unclear contexts, or insufficient relevance to elementary education were carefully reconsidered during the screening stage. This quality assessment process ensured that only studies with adequate academic rigor contributed to the final synthesis.

2.6. Data Analysis Procedure

The bibliometric analysis was conducted using VOSviewer version 1.6.20. Bibliographic metadata were exported directly from Scopus in CSV format, including authors, affiliations, abstracts, keywords, citations, and source titles.

The analysis focused on:

- publication trends,
- country contributions,
- institutional affiliations,
- source journals,
- author productivity,
- subject areas,
- and keyword co-occurrence networks.

The VOSviewer settings used in this study were as follows:

- Analysis type: Co-occurrence analysis;
- Unit of analysis: Author keywords;
- Counting method: Full counting;
- Minimum keyword occurrence threshold: 2 occurrences;
- Network visualization mode enabled;
- Normalization method: Association strength.

For country collaboration analysis, a minimum threshold of one document per country was applied. The visualization maps were interpreted based on node size, link strength, and cluster relationships to identify dominant research themes and international collaboration patterns.

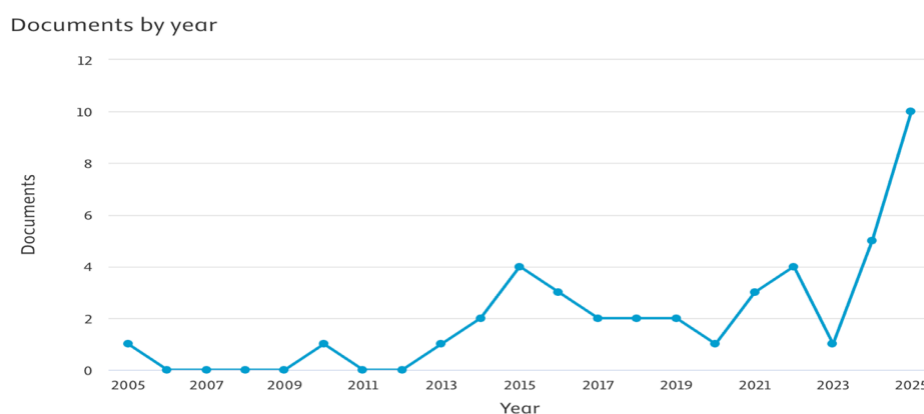
2.7. Research Transparency and Replicability

To improve transparency and reproducibility, this study explicitly reports the database source, search date, search query, inclusion and exclusion criteria, PRISMA screening stages, and bibliometric software configuration. These procedures allow future researchers to replicate, validate, or extend the present study using equivalent search strategies and analytical settings. The combination of systematic review procedures and bibliometric mapping also enhances methodological robustness by integrating qualitative synthesis with quantitative scientific mapping.

3. FINDINGS AND DISCUSSION

3.1. Publication Trends

This study identified 44 Scopus-indexed articles discussing deep learning within the context of elementary education published between 2005 and 2025. The publication analysis demonstrates a fluctuating yet progressively increasing trend throughout the observed period.



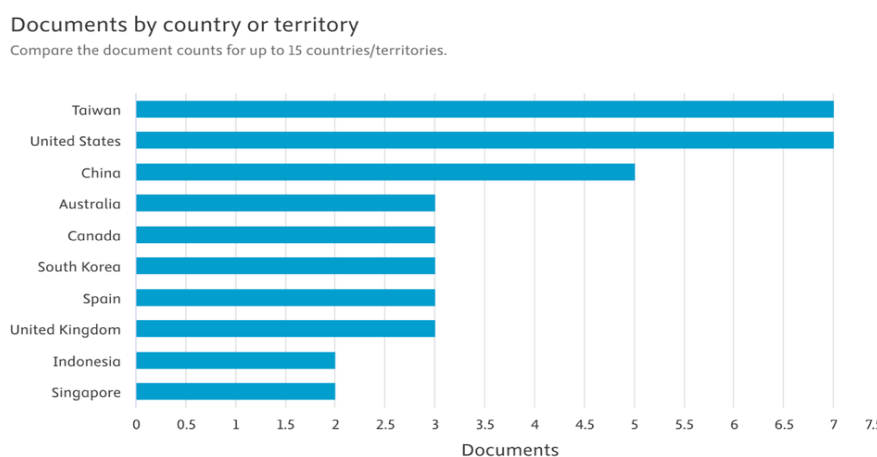
Source: Scopus database

Figure 2. Annual Publication Trends on Deep Learning in Elementary Education (2005-2025)

Figure 2 illustrates the annual distribution of publications related to deep learning in elementary education over the last two decades. During the early period between 2005 and 2020, the number of publications remained relatively low and inconsistent. A gradual increase became visible after 2021, followed by a substantial surge during 2024–2025.

These findings indicate that research on deep learning in elementary education is still categorized as an emerging research field, although it has begun to attract broader attention within the global educational research agenda. The rapid increase in publications after 2024 reflects the growing integration of artificial intelligence technologies, learning analytics, and adaptive learning systems into elementary education settings.

3.2. Geographical Distribution and Collaboration



Source: Scopus database

Figure 3. Distribution of Publications by Country/Territory

Figure 3 presents the distribution of publications based on countries or territories contributing to research on deep learning in elementary education. Taiwan and the United States emerged as the most dominant contributors, each producing seven publications. Other countries, including China, Australia, Canada, South Korea, Spain, and the United Kingdom, also demonstrated significant contributions, while developing countries such as Indonesia and Singapore began to participate despite their relatively smaller number of publications.

This distribution suggests that research on deep learning in elementary education continues to be dominated by countries with strong technological capacity and advanced digital educational infrastructure.

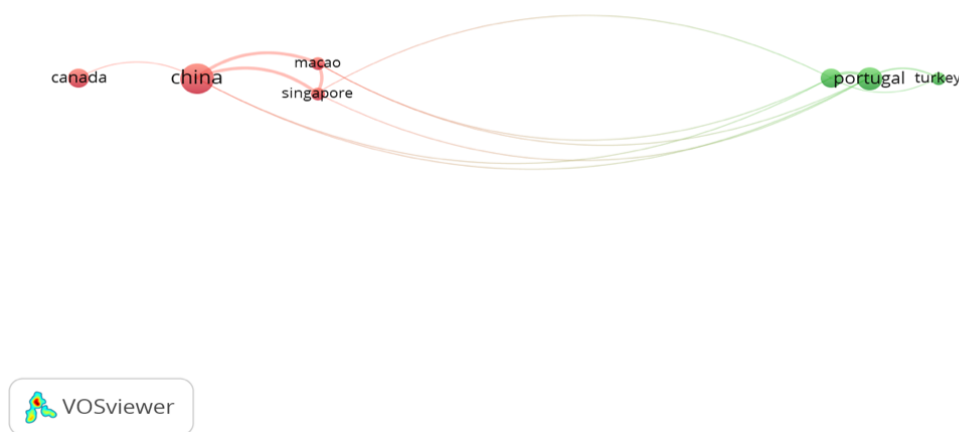
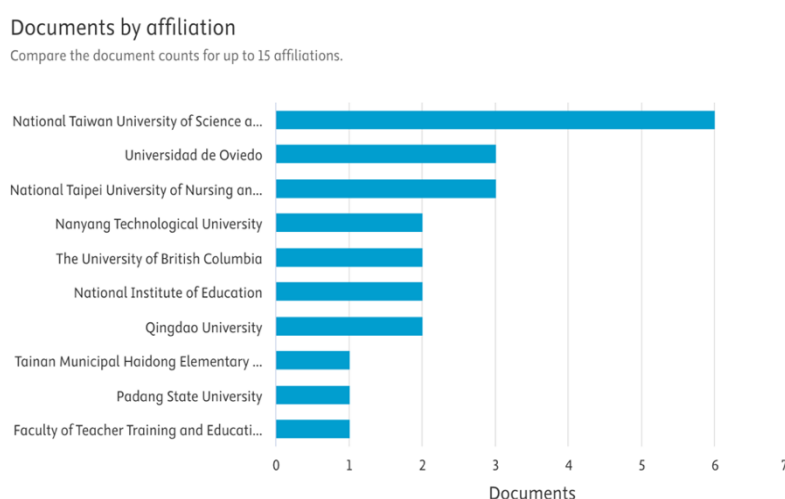


Figure 4. Network country visualization

Figure 4 illustrates the international collaboration network among countries based on VOSviewer visualization analysis. The findings reveal that scientific collaboration patterns remain relatively limited and tend to form regional clusters. China appears to function as a major collaboration hub with relatively strong research connections to Canada, Singapore, and Macao.

Meanwhile, several European countries form smaller and relatively isolated collaboration networks. These findings indicate that research on deep learning in elementary education is still developing regionally and has not yet fully evolved into a globally integrated research network.

3.3. Institutional and Author Productivity

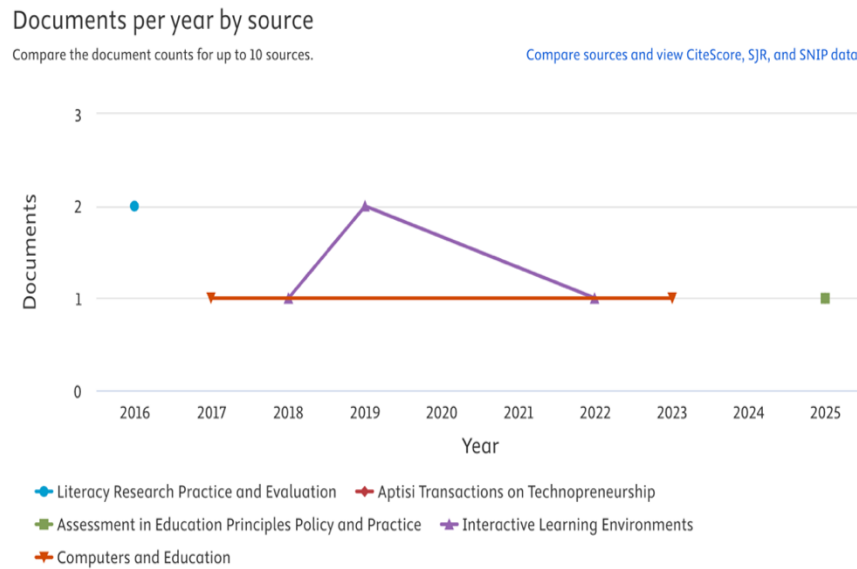


Source: Scopus database

Figure 5. Institutional Contribution to Deep Learning Research in Elementary Education

At Figure 5 demonstrates the contribution of institutions to publications on deep learning research in elementary education. The National Taiwan University of Science and Technology recorded the highest contribution, followed by Universidad de Oviedo, National Taipei University of Nursing and Health Sciences, and Nanyang Technological University.

The concentration of publications within a limited number of institutions indicates that research development in this field continues to be dominated by universities and research centers possessing strong technological resources and research support systems.

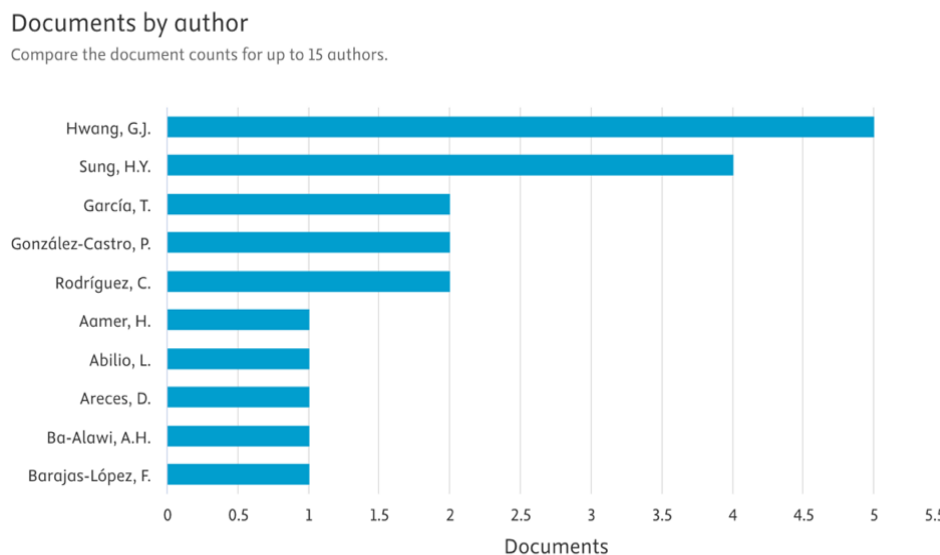


Source: Scopus database

Figure 6. Distribution of Publications by Journal Sources

Figure 6 presents the distribution of publications based on journal sources. Most articles were published in journals focusing on educational technology, digital learning, and pedagogical innovation, including *Interactive Learning Environments* and *Computers and Education*.

This distribution demonstrates that research on deep learning in elementary education continues to evolve at the intersection of educational studies and learning technology research.



Source: Scopus database

Figure 7. Author Productivity in Deep Learning Research

Figure 7 illustrates the distribution of author productivity in deep learning research within elementary education. Hwang and colleagues appear as the most dominant contributors compared with other researchers.

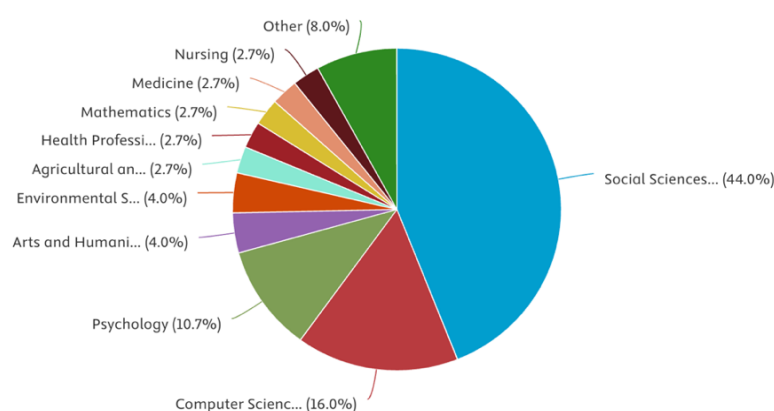
The dominance of a limited number of authors indicates that this research area is still developing within specific academic communities specializing in educational technology and AI-supported learning environments.

3.4. Subject Areas and Research Focus

The subject-area analysis indicated that most publications originated from Social Sciences (44%), followed by Computer Science (16%) and Psychology (10.7%). Smaller contributions emerged from Arts and Humanities, Environmental Science, Health Professions, and Mathematics.

Keyword co-occurrence analysis revealed that the dominant research themes included “deep learning,” “elementary education,” “students,” “interactive learning environments,” “learning strategies,” and “project-based learning.” These findings indicate that the current research landscape primarily emphasizes student-centered pedagogies supported by digital and adaptive technologies.

Documents by subject area

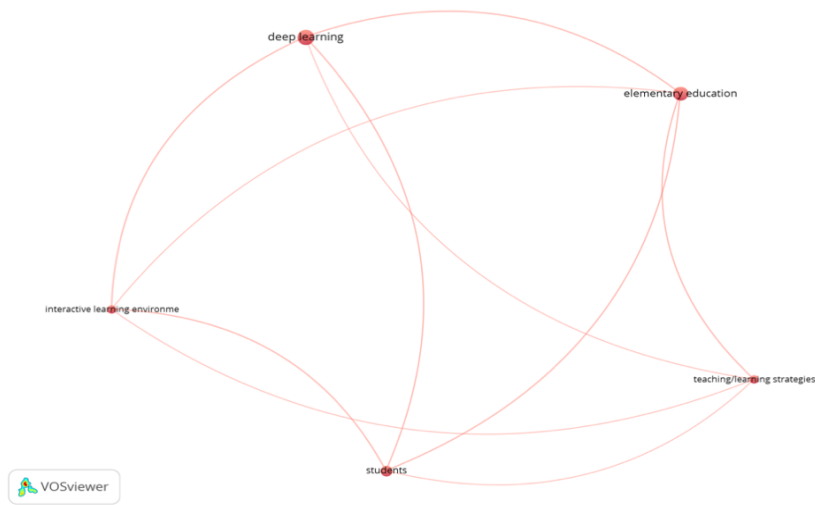


Source: Scopus database

Figure 8. Distribution of publication by subject area

Figure 8 presents the distribution of subject areas related to deep learning research in elementary education. Social Sciences accounted for the largest proportion of publications, followed by Computer Science and Psychology.

The dominance of Social Sciences indicates that existing research primarily emphasizes pedagogical dimensions, instructional strategies, and students' learning experiences rather than focusing solely on the technical aspects of artificial intelligence.



Source: Output VOSviewer software

Figure 9. Keyword Co-occurrence Network of Deep Learning Research

Figure 9 illustrates the keyword co-occurrence network based on VOSviewer analysis. Keywords such as “deep learning,” “elementary education,” “students,” “interactive learning environments,” and “project-based learning” demonstrate the strongest interconnections within the research network. These findings suggest that current research on deep learning in elementary education is largely directed toward the development of interactive, collaborative, and student-centered learning environments.

Table 2. Keyword Occurrence and Total Link Strength		
Rank	Keyword	Total link stength
1	Deep learning	6
2	Elementary education	5
3	Students	3
4	Interactive learning environments	2
5	Teaching/learning strategies	2
6	Education	3
7	Approachs to learning	2
8	Learning	3
9	Learning context	2
10	Project-based learning	2

Source: Output VOSviewer software

Table 2 presents the occurrence frequency and total link strength of the primary keywords identified in deep learning research within elementary education. The keywords “deep learning” and “elementary education” demonstrate the highest level of interconnectedness, indicating that these concepts function as the central themes within the evolving research network.

Discussion

The findings indicate that research on deep learning in elementary education has developed from a relatively limited field into an emerging area of educational research, with a particularly noticeable increase in publications after 2024. This growth should be interpreted in relation to the broader expansion of artificial intelligence, adaptive learning, learning analytics, and digitally supported

pedagogies in education. Previous research has demonstrated that deep learning technologies can process educational data to support prediction, classification, and personalization, thereby extending the potential role of artificial intelligence beyond administrative or automated functions (Ahad et al., 2018; Hernández-Blanco et al., 2019). In primary education specifically, AI-based approaches have also been employed to predict students' learning characteristics and facilitate more individualized learning experiences (Pardamean et al., 2022). The recent publication growth identified in this study therefore suggests increasing scholarly attention to the intersection between technological innovation and the pedagogical needs of younger learners.

An important finding concerns the conceptual diversity surrounding the term *deep learning*. The reviewed literature suggests that deep learning cannot be treated as a single, homogeneous concept in educational research. One strand conceptualizes it primarily as an artificial intelligence technique involving computational models for prediction, classification, feature extraction, and adaptive decision making. For example, deep learning has been applied to educational text mining (Araujo et al., 2020), prediction of learning styles in primary education (Pardamean et al., 2022), and classification of cognitive presence in digital learning environments (Hu et al., 2023). A second strand places greater emphasis on deeper forms of learning involving meaningful understanding, student engagement, learning strategies, and the development of higher-order competencies. Kovac et al. (2023), for instance, highlight the need to critically examine the purpose and implementation of deep learning within educational settings. These perspectives are related but should not be considered interchangeable. The present findings therefore reinforce the importance of maintaining a clear conceptual distinction between *deep learning as an AI technique* and *deep learning as a pedagogical orientation*, while examining the circumstances under which technological applications may support deeper and more meaningful learning.

The geographical distribution of publications provides another important insight into the structure of this research field. Taiwan, the United States, and China emerged as major contributors, while the collaboration network indicates that international research connections remain relatively fragmented. This pattern suggests that knowledge production is concentrated within particular national and institutional research ecosystems rather than distributed evenly across educational contexts. Such concentration is significant because the implementation and educational value of technology are influenced by infrastructure, curriculum, teacher capacity, and local learning environments. Consequently, findings generated in technologically advanced contexts should not automatically be generalized to primary education systems with different levels of digital access and institutional support. The limited participation of developing contexts identified in the dataset also indicates a need for broader geographical representation in future research.

The disciplinary distribution further demonstrates the hybrid character of this research domain. Social Sciences constituted the largest subject area, followed by Computer Science and Psychology. This pattern is important because it indicates that deep learning in elementary education is not exclusively a computational issue. Rather, the field lies at the intersection of technological development, pedagogy, learning processes, and student development. The prominence of Social Sciences is consistent with the keyword network, in which concepts such as *students*, *interactive learning environments*, *teaching/learning strategies*, and *project-based learning* appear alongside *deep learning*. Previous studies similarly demonstrate that technology-supported environments can facilitate interactive learning and higher-order thinking when technological tools are integrated with appropriate instructional strategies (Sung et al., 2019, 2022). Thus, the educational contribution of deep learning technologies depends not merely on algorithmic sophistication but on how these technologies are embedded within pedagogically meaningful learning designs.

The prominence of student-centered and interactive themes also has implications for the role of teachers. Technology should not be interpreted as a substitute for pedagogical decision making; instead, its educational value depends substantially on teachers' ability to select, interpret, and integrate digital resources according to learners' needs. Research on elementary educators during

technology-mediated instruction has demonstrated the importance of combining technological, pedagogical, and content knowledge when designing digital learning experiences (Gonzalez & Mohamad, 2022). Similarly, the development of digital literacy in elementary classrooms requires purposeful teacher strategies rather than simply increasing access to technological tools (Kumari, 2024). Accordingly, the expansion of AI-supported deep learning environments should be accompanied by professional development that strengthens teachers' digital pedagogical competencies, their capacity to interpret technology-generated information, and their awareness of the developmental characteristics of elementary learners.

The findings also reveal several areas that remain insufficiently represented in the current literature. Although technological applications, adaptive learning, and student-centered strategies are increasingly visible, issues concerning ethics, equity, long-term developmental consequences, and governance remain comparatively limited. This gap is particularly important in elementary education because younger students require greater protection regarding data privacy, algorithmic decision making, equitable access, and developmentally appropriate technology use. Future research should therefore move beyond questions of technological effectiveness and examine how AI-supported environments influence students' cognitive, social, and emotional development over time. Longitudinal studies, cross-country comparisons, and interdisciplinary research involving education, developmental psychology, learning sciences, and digital ethics would provide a stronger evidence base for responsible implementation.

Overall, this study suggests that deep learning research in elementary education is evolving toward a multidisciplinary domain in which technological and pedagogical perspectives increasingly intersect. However, conceptual ambiguity remains a fundamental challenge. Future scholarship should explicitly identify whether *deep learning* refers to an AI methodology, a pedagogical approach, or an intentional integration of both. Greater conceptual precision, broader international collaboration, and stronger attention to ethical and developmental considerations would enable the field to progress beyond technology-driven innovation toward evidence-based, equitable, and pedagogically meaningful applications in elementary education.

4. CONCLUSION

This study provides an integrated systematic and bibliometric overview of deep learning research in elementary education based on 44 Scopus-indexed articles published between 2005 and 2025. The main findings reveal a substantial increase in publications after 2024, with Taiwan, the United States, and China emerging as major contributors, while Social Sciences, Computer Science, and Psychology represent the dominant disciplinary areas. The thematic analysis further demonstrates that deep learning in elementary education encompasses two related but conceptually distinct perspectives: deep learning as an artificial intelligence-based technique for prediction, classification, personalization, and adaptive learning, and deep learning as a pedagogical orientation associated with meaningful, interactive, and student-centered learning. The growing intersection of these perspectives indicates the potential of technology to support deeper learning experiences; however, international collaboration remains fragmented, and ethical, developmental, and equity-related issues are still underrepresented in the literature. These findings should be interpreted in light of several limitations, particularly the exclusive use of the Scopus database, the restriction to English-language journal articles, and the relatively small dataset of 44 studies, which may limit the representation and generalizability of the global research landscape. Furthermore, bibliometric analysis primarily captures publication patterns and thematic relationships and therefore cannot establish the pedagogical effectiveness or long-term developmental effects of deep learning implementation in elementary education. Future research should incorporate multiple databases and multilingual publications, conduct longitudinal and cross-country comparative studies, and adopt interdisciplinary perspectives that integrate education, developmental psychology, learning sciences, and digital ethics. Greater conceptual precision is also

needed to distinguish AI-based deep learning from pedagogical deep learning and to examine how these perspectives can be responsibly integrated to support developmentally appropriate, equitable, and meaningful learning in elementary education.

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