

Global Trends and Outcomes of the Deep Learning Approach in Biology Education: A Systematic Literature Review (2021–2026)

Tren Global dan Capaian Pendekatan Deep Learning dalam Pembelajaran Biologi: Systematic Literature Review (2021-2026)

Marzukah¹⁾, Nurul Intan Cahyani¹⁾, Sri Herawati Ali¹⁾, Arifah Novia Arifin²⁾

¹⁾ Study Program of Biology Education Postgraduate, State University of Makassar, Mallengkeri Raya Street Number 44 , Makassar, South Sulawesi, Indonesia, 90224

²⁾ Biology Departement, Faculty of Mathematics and Natural Science, State University of Makassar, Mallengkeri Raya Street Number 44 , Makassar, South Sulawesi, Indonesia, 90224

*Corresponding author: arifahnoviaarifin@unm.ac.id

Corresponding author: arifhamkoviaa@unm.ac.id		Article Information	
Abstract		Keywords:	Kata kunci:
<p>This study aims to analyze global trends, implementation across educational levels, and learning outcomes of the Deep Learning approach in Biology education from 2021 to 2026. A Systematic Literature Review (SLR) was conducted following PRISMA guidelines, supported by bibliometric analysis using VOSviewer. The final Google Scholar search in September 2026 identified 1,000 records, of which only 10 articles met the inclusion criteria due to limited relevance to Biology education. Results showed that 70% of articles were published in 2026. Quantitative methods predominated (50%), followed by Research and Development (30%) and qualitative approaches (20%). Bibliometric analysis identified deep learning as a central keyword associated with digital technology, instructional models, and laboratory activities. Regarding author affiliations, 70% of articles involved Indonesian researchers, while others represented Indonesia–Thailand collaborations and affiliations in Norway and the United States. Studies primarily focused on senior high schools (50%), followed by elementary (20%), junior high schools (10%), and multiple educational levels. Ecology and environmental topics were most frequently examined. Reported outcomes included cognitive abilities, higher-order thinking skills, science process skills, scientific and digital literacy, and sustainability-oriented attitudes and character development. These findings highlight the need for broader research across educational contexts to strengthen evidence and assess outcome consistency.</p>		Deep Learning; Biology Education; Systematic Literature Review; PRISMA; Bibliometric Analysis; Learning Outcomes.	Deep Learning; Pembelajaran Biologi; Tinjauan Pustaka; PRISMA; Analisis Bibliometrik;
<p>Penelitian ini bertujuan menganalisis tren global, penerapan lintas jenjang pendidikan, dan capaian pendekatan Deep Learning dalam pembelajaran Biologi selama 2021–2026. Penelitian menggunakan Systematic Literature Review (SLR) berpedoman PRISMA, dilengkapi analisis bibliometrik menggunakan VOSviewer. Penelusuran terakhir melalui Google Scholar pada September 2026 menghasilkan 1.000 rekaman, tetapi hanya 10 artikel memenuhi kriteria inklusi karena sebagian besar tidak relevan dengan pembelajaran Biologi. Hasil menunjukkan 70% artikel terbit pada 2026. Metode penelitian didominasi pendekatan kuantitatif (50%), diikuti Research and Development (30%) dan kualitatif (20%). Analisis bibliometrik menempatkan deep learning sebagai kata kunci sentral yang berkaitan dengan teknologi digital, model pembelajaran, dan praktikum laboratorium. Berdasarkan afiliasi, 70% artikel melibatkan penulis dari Indonesia, sedangkan lainnya mencakup kolaborasi Indonesia–Thailand serta afiliasi Norwegia dan Amerika Serikat. Penelitian paling banyak dilakukan pada jenjang SMA (50%), disusul SD (20%), SMP (10%), dan studi lintas jenjang. Penerapannya mencakup beragam materi Biologi, terutama ekologi dan lingkungan. Capaian yang dilaporkan meliputi peningkatan kemampuan kognitif, berpikir tingkat tinggi, keterampilan proses sains, literasi sains dan digital, serta sikap dan karakter berorientasi keberlanjutan. Temuan ini menggambarkan kecenderungan penelitian yang masih terkonsentrasi pada konteks tertentu, sehingga diperlukan kajian lebih luas untuk memperkuat bukti penerapan pada berbagai jenjang pendidikan, sekaligus menguji konsistensi hasil pada konteks pembelajaran yang berbeda.</p>		History	
		Manuscript received	: 19/10/2026
		Revised	: 26/10/2026
		Accepted	: 31/10/2026
		Published	

Penelitian ini bertujuan menganalisis tren global, penerapan lintas jenjang pendidikan, dan capaian pendekatan Deep Learning dalam pembelajaran Biologi selama 2021–2026. Penelitian menggunakan Systematic Literature Review (SLR) berpedoman PRISMA, dilengkapi analisis bibliometrik menggunakan VOSviewer. Penelusuran terakhir melalui Google Scholar pada September 2026 menghasilkan 1.000 rekaman, tetapi hanya 10 artikel memenuhi kriteria inklusi karena sebagian besar tidak relevan dengan pembelajaran Biologi. Hasil menunjukkan 70% artikel terbit pada 2026. Metode penelitian didominasi pendekatan kuantitatif (50%), diikuti Research and Development (30%) dan kualitatif (20%). Analisis bibliometrik menempatkan deep learning sebagai kata kunci sentral yang berkaitan dengan teknologi digital, model pembelajaran, dan praktikum laboratorium. Berdasarkan afiliasi, 70% artikel melibatkan penulis dari Indonesia, sedangkan lainnya mencakup kolaborasi Indonesia–Thailand serta afiliasi Norwegia dan Amerika Serikat. Penelitian paling banyak dilakukan pada jenjang SMA (50%), disusul SD (20%), SMP (10%), dan studi lintas jenjang. Penerapannya mencakup beragam materi Biologi, terutama ekologi dan lingkungan. Capaian yang dilaporkan meliputi peningkatan kemampuan kognitif, berpikir tingkat tinggi, keterampilan proses sains, literasi sains dan digital, serta sikap dan karakter berorientasi keberlanjutan. Temuan ini menggambarkan kecenderungan penelitian yang masih terkonsentrasi pada konteks tertentu, sehingga diperlukan kajian lebih luas untuk memperkuat bukti penerapan pada berbagai jenjang pendidikan, sekaligus menguji konsistensi hasil pada konteks pembelajaran yang berbeda.

A. INTRODUCTION

Biology education faces challenges during the transition from conventional teaching approaches to a process of deep understanding (Deep Learning). This is because learning that is solely one-way and based on repetition tends to produce short-term memories that are easily forgotten and difficult to apply in new contexts (Muhammad et al., 2026). Conversely, the deep learning approach encourages students to integrate newly acquired information into their existing cognitive schemas and strengthens their ability to connect scientific principles with real-world problems (Cebrero, 2025).

The concept of deep learning in contemporary biology education encompasses two interrelated dimensions. The first dimension is deep learning pedagogy, which is learner-centered and aims to support the development of 21st-century competencies (Fitrah et al., 2025). The second dimension is deep learning within the domain of artificial intelligence (AI), focusing on the use of intelligent computational models to help visualize biological phenomena that are abstract or microscopic in nature (Rakhmawati et al., 2026). This review focuses on deep learning as a pedagogical approach in Biology education. Articles that used deep learning only as an AI technique were not treated as part of the Deep Learning approach analyzed here.

The application of deep learning approaches reveals varying patterns depending on the level of education. At the secondary school level, implementation is dominated by the integration of problem-based learning, project-based learning, inquiry-based learning, and STEM/STEAM approaches that combine AI and augmented reality (A. A. Wibowo et al., 2024). Meanwhile, at the higher education level, the implementation of deep learning focuses more on computational science, the use of virtual laboratory simulations, and the development of independent research skills (Zunifa et al., 2025).

Integrating deep learning approaches supported by technology has been shown to have a positive impact on various student learning outcomes. Several studies have reported significant improvements in critical thinking, complex problem-solving, digital literacy, and understanding of biological concepts (Ajibike, 2025). In addition, data-based inquiry and collaborative activities can strengthen students' scientific argumentation, metacognition, and independent learning skills (Papanephytous & Nicolaou, 2025).

Deep learning offers transformative potential for implementing Biology education, but its adoption faces numerous systemic challenges. Fundamental barriers include disparities in digital infrastructure, teachers' lack of preparedness and limited pedagogical training, and evaluation gaps caused by school examination systems that prioritize assessing the recall of theoretical knowledge over authentic competencies (Aziz et al., 2026). In addition, integrating deep learning with AI introduces ethical risks, such as the potential misuse of information and the erosion of students' critical-thinking skills (Mnguni et al., 2026).

Based on previous research, scientific publications on the integration of deep learning and AI in Biology education have increased rapidly during the 2021–2026 period, while existing studies have largely remained focused on specific materials or local contexts (Garzon et al., 2025). Therefore, a structured Systematic Literature Review (SLR) based on the PRISMA protocol is needed to comprehensively synthesize global trends, patterns of implementation across educational levels, and their impact on learning outcomes. Given this urgency, this study formulates three main research questions:

RQ 1: How have research developments and trends regarding the Deep Learning approach in Biology education evolved during the 2021–2026 period?

RQ 2: How is the Deep Learning approach applied in Biology education based on educational level and learning content?

RQ 3: What are the outcomes of applying the Deep Learning approach in Biology education based on the learning achievements or changes in students' abilities reported in the studies?

B. METHOD

Research Design

This study uses the Systematic Literature Review (SLR) method to identify, select, evaluate, and synthesize research findings on Deep Learning approaches in Biology education. The SLR process is structured according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines so that the identification, screening, eligibility assessment, and article selection processes can be reported systematically and transparently (A. Wibowo & Putri, 2021). In addition to the SLR, this study also employs bibliometric analysis to describe global trends and developments in research on Deep Learning in Biology education. Bibliometric analysis is conducted with the assistance of VOSviewer software to visualize keyword co-occurrence and the bibliometric networks formed from the identified publications (Utari et al., 2025).

Formulation of The Research Questions (RQs)

The Research Questions (RQs) were formulated as the basis for determining the focus of the literature search, selection, extraction, and analysis (Rahmawati & Turista, 2026). The RQs were designed to provide an overview of the global development of Deep Learning while also identifying how this approach has been applied and what outcomes it has produced in the context of Biology education. Based on these objectives, this study formulated the following three RQs:

RQ1: What have been the developments and research trends related to the Deep Learning approach in Biology education globally during the 2021–2026 period?

RQ2: How has the Deep Learning approach been applied in Biology education based on educational level and learning content?

RQ3: What have been the outcomes of applying the Deep Learning approach in Biology education based on the learning achievements or changes in students' abilities reported in the studies?

Data Sources and Search Strategy

The data sources in this study consisted of scholarly articles discussing Deep Learning approaches in Biology learning and education. The literature was retrieved through Google Scholar with the assistance of Publish or Perish (PoP) software, which was used to search for and collect bibliographic data. Google Scholar was selected because it provides broad coverage of academic literature from various journals and scholarly publications, including national and regional journals that may not be indexed in commercial databases (Yusra & Asmara, 2026). Its free accessibility and broad coverage made it suitable for identifying studies from diverse educational contexts, particularly those relevant to Biology education in Indonesia. The search was limited to articles published between 2021 and 2026 to capture recent developments in the application of Deep Learning in Biology learning and education. The keyword used in the literature search was "Deep Learning Approach in Biology Learning."

However, relying solely on Google Scholar may have resulted in the omission of relevant studies indexed in other academic databases. Therefore, the findings of this review should be interpreted within the scope of the articles retrieved through the selected search strategy rather than as a comprehensive representation of all research on the topic. Future reviews are encouraged to expand the search to additional databases, such as Scopus, ERIC, and Web of Science, where accessible, and to incorporate alternative keywords and related terms to improve the comprehensiveness of the literature search.

It is also freely accessible and indexes national and regional journals that are not always covered by commercial databases, which suits the aim of capturing studies from diverse contexts, including Indonesia. The search was limited to articles published during the 2021–2026 period so that the review could describe developments in Deep Learning research within the specified timeframe. The keyword used to conduct the literature search was “Deep Learning Approach in Biology Learning.” This is acknowledged as a limitation: the findings represent the articles retrieved from Google Scholar, not all research on the topic. Future reviews are recommended to complement the search with these databases and additional keywords.

Inclusion and Exclusion Criteria

Inclusion and exclusion criteria were established to ensure that the analyzed articles aligned with the research objectives and questions (Saputro et al., 2025). These criteria were applied during the screening and eligibility assessment stages so that the literature used had sufficient relevance to the focus of the review. The inclusion and exclusion criteria are presented in Table 1.

Table 1. Inclusion and Exclusion Criteria for the Study

Aspect	Inclusion Criteria	Exclusion Criteria
Topic	Discusses deep learning approaches	Does not discuss deep learning approaches
Context	Relates to biology learning	Does not relate to biology learning
Publication type	Original research article	Review article, editorial, book, undergraduate thesis, master's thesis, doctoral dissertation, or non-research publication
Availability	Full paper is accessible (directly or through additional retrieval efforts).	Full paper is inaccessible after additional retrieval efforts
Research focus	Discussess the application of deep learning and/or learning outcomes relevant to effectiveness	Does not provide information relevant to the RQs

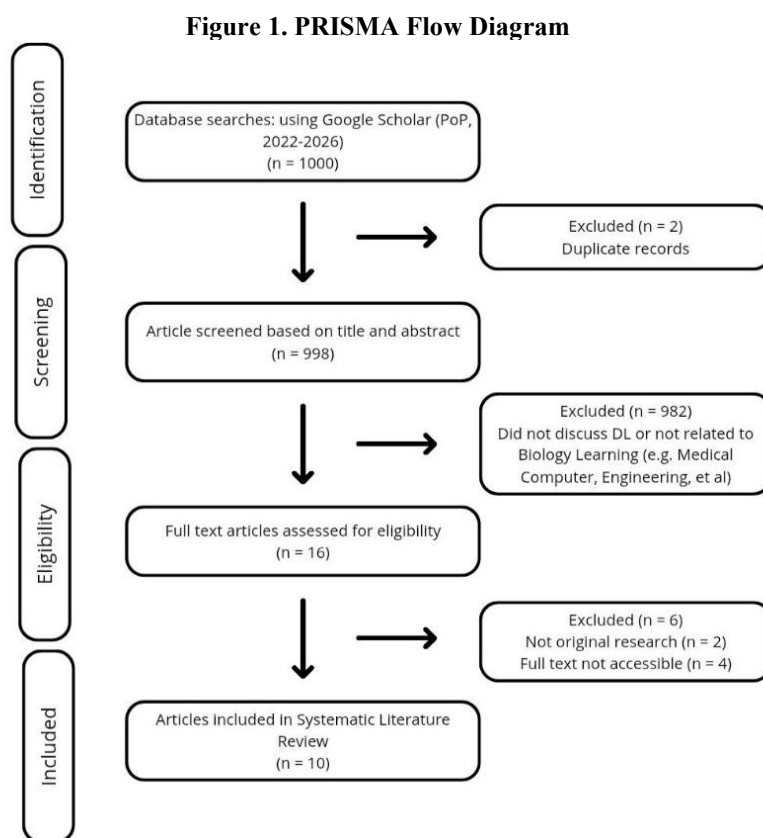
Selection Process

The article selection process followed the PRISMA (*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*) guidelines, consisting of four stages: identification, screening, eligibility assessment, and inclusion. The literature search was conducted on September 12, 2026, using Google Scholar and Publish or Perish (PoP), covering publications from 2021 to 2026. Four reviewers screened the articles based on their titles, abstracts, and full texts. Duplicate articles, studies unrelated to Deep Learning in Biology education, articles outside the specified period, and those with inaccessible full texts were excluded. Disagreements among reviewers were resolved through discussion or, if necessary, consultation with a third reviewer. Articles meeting all inclusion criteria were selected for final analysis. The search was conducted in September 2026. The articles were reviewed by the authors, first based on their titles and

abstracts, and subsequently based on their full text. Any disagreements regarding whether an article met the criteria were resolved through discussion until a consensus was reached.

Moving on to the screening stage, each article was rigorously selected based on the alignment of its title and abstract with the research topic's scope. Studies that did not focus on Deep Learning approaches or fell outside the field of biology education were immediately excluded from the research results. Next, articles that successfully pass this stage will be evaluated during the eligibility assessment phase through a full-text-review to cross-check them against the evaluation criteria. A publication will be automatically disqualified if it is not original research manuscript, if the full text inaccessible, or if it fails to present empirical findings that answer the RQ.

In the final stage, inclusion, the set of articles proven to have met all eligibility criteria was officially designated as the primary literature forming the basis of the study SLR study. A detailed summary of the fluctuations in the number of articles eliminated or retained at each stage was recorded to ensure methodological transparency. The entire track record of the screening stages for these research articles was then mapped onto the standard PRISMA flowchart structure. A complete visualization of the literature selection process from start to finish is comprehensively presented in Figure 1.



Data Extraction

The data extraction process was conducted comprehensively on all articles that met the inclusion criteria. At this stage, the researcher collected various essential pieces of information from each study, including the authors' names, year of publication, and country of origin. Technical and pedagogical aspects, such as the target educational level, learning materials, research methods, forms of Deep Learning implementation, and final findings, were also recorded in detail. All of this information was systematically organized to facilitate comparisons across publications, while ensuring that all RQ could be answered comprehensively and in a structured manner (Rahmeisi et al., 2025).

Specifically, the research findings were analyzed in greater depth and re-mapped to address the RQ 3. In this section the various findings from these articles were grouped based on the types of achievements or changes in abilities experienced by students following the intervention. These categories are highly diverse, ranging from improvements in overall learning outcomes and enhanced critical and creative thinking skills to mastery of science literacy and problem solving skills. In addition to cognitive achievements, other supporting aspects, are also summarized to ensure that the results of this literature review are more comprehensive.

Data Analysis

The extracted data were analyzed using descriptive and bibliometric approaches. Descriptive analysis was used to identify the characteristics of the studies, patterns in the application of Deep Learning, educational levels, Biology topics, and the student outcomes or abilities reported in the studies. Meanwhile, bibliometric analysis was conducted using VOSviewer to visualize the development of research findings based on keyword co-occurrence (Utami & Karlina, 2022). The results of the analysis were then used to examine global research trends in Deep Learning and synthesize findings on its application and effectiveness in Biology education.

C. RESULTS AND DISCUSSION

Results

Publication Year Distribution

The analysis of the publication-year distribution conducted on the 10 primary studies that passed the selection process resulted in a mapping of diverse publication trends over time. This summary maps the number of articles published each year from 2021 to 2026 that focus on the implementation of Deep Learning in Biology education. The results of the analysis are presented in Table 2.

Table 2. Distribution of Articles by Publication Year

No.	Authors	Year	Number	Percentage
1	Nurwidodo, N., Hindun, I., Wahyuni, S., Lambensa, H.	2026	7	70%
2	Hanum, E., Hasanah, Z., Roswita, C.			
3	Husain, I. H., Mardin, H.			
4	Salsabilla, O. P., Hamidah, A., Putri, H. M.			

5	Nurfarida, D., Sumarno, H., Kamaludin, K., Al Adawiyah, R., Wahyudin, W., Suryana, A.			
6	Fariha, A. M. A., Anantyarta, P., Setiawan, H.			
7	Wungubelen, A., Nurhayati, B., Ismail, I., Daud, F., Ali, A.			
8	Mutiarani, A., Amprasto, Kusnadi	2025	1	10%
9	Winje, O., Londal, K.	2023	1	10%
10	Green, N. H., Walter, M., Anderton, B. N.	2022	1	10%

Based on Table 2, 7 of the 10 selected articles (70%) were published in 2026. The number of publications remained constant in 2022, 2023, and 2025, with 1 article each year. This describes only the 10 selected articles.

Research Approach and Design (Research Types/Methods)

The trends in research types and approaches related to the application of the deep learning approach in Biology education show comprehensive methodological variation. This classification was conducted to identify the research designs most commonly used by researchers. The grouping focuses on the specific approaches and designs applied to measure the outcomes of implementing or developing deep learning approach interventions. The classification results are presented in Table 3.

Table 3. Classification of Research Approaches and Design

No.	Author & Years	Approach	Design	Number	Percentage
1	Nurwidodo, N., Hindun, I., Wahyuni, S., Lambensa, H. (2026)	Quantitative	Quasi Experiment	4	40%
2	Green, N. H., Walter, M., Anderton, B. N4. (2022)				
3	Salsabilla, O. P., Hamidah, A., Putri, H. M. (2026)				
4	Nurfarida, D., Sumarno, H., Kamaludin, K., Al Adawiyah, R., Wahyudin, W., Suryana, A. (2026)				
5	Wungubelen, A., Nurhayati, B., Ismail, I., Daud, F., Ali, A. (2026)	Quantitative	Survey	1	10%
6	Hanum, E., Hasanah, Z., Roswita, C. (2026)	Research & Development	ADDIE	2	20%
7	Husain, I. H., Mardin, H. (2026)				
8	Fariha, A. M. A., Anantyarta, P., Setiawan, H. (2026)	Research & Development	4D	1	10%
9	Mutiarani, A., Amprasto, Kusnadi. (2025)	Qualitative	Exploratori	2	20%
10	Winje, O., Londal, K. (2023)				

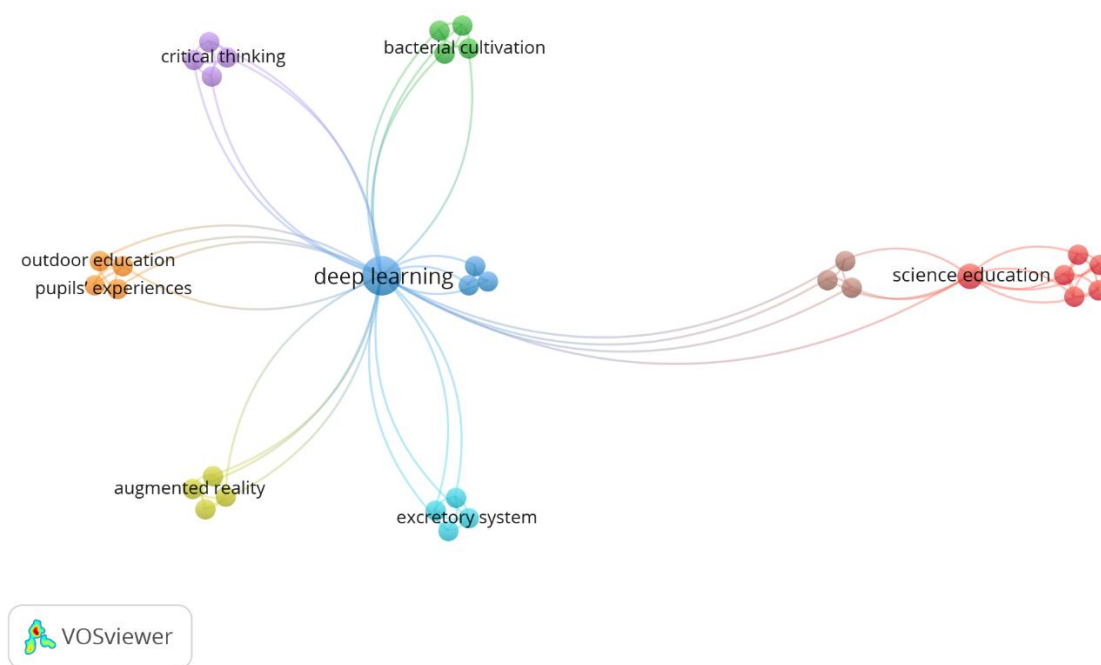
Based on the classification results shown in Table 3, research on Deep Learning in Biology education is predominantly conducted using a quantitative approach, accounting for 50% of the studies, with most employing a quasi-experimental design examine the variables. However, a quasi-experiment does not by itself prove that the method caused higher learning outcomes,

because participants are not randomly assigned and the groups may differ at the start. In addition, the Research and Development (R&D) approach accounts for 30% of the studies, showing that several studies focused on creating instructional products, such as e-modules and other learning tools, that can support the Deep Learning approach.

Keyword Analysis

The bibliometric network map was generated through VOSviewer visualization using keywords obtained from the selected articles. This mapping provides an overview of the thematic focus of global research. Bibliometric mapping was also conducted to extract and visualize the thematic relationships among the main variables. Based on this mapping, the keywords in the reviewed literature are strongly centered on “deep learning.” The bibliometric visualization is presented in Figure 2.

Figure 2. Bibliometric Data Visualization Results



The visualization obtained from the bibliometric analysis presented in Figure 2 shows Deep Learning as the primary central node, strongly connected to various variables, both instructional and cognitive. This suggests that Deep Learning cannot be operationalized in isolation but must be combined with digital technology, simple laboratory experiments, and even integrated with other learning models to achieve the objectives of a learning process.

Author Country Distribution (Author Affiliations)

A demographic analysis of the researchers was also conducted to obtain a comprehensive overview of the global distribution of this study. This mapping is a crucial for assessing the extent to which research trends related to Deep Learning approaches are of interest to the academic community in various parts of the world. Through this analysis, we can identify which regions or countries are currently most actively engaged in and leading the way on this issue.

Technically, the detailed data on this country-level distribution was extracted directly from the institutional affiliations listed by each author in their published manuscripts. The country shown is the location of the authors' institution, which is not always the country where the study was conducted, so Table 4 describes author affiliations and not the distribution of research sites. The complete summary of the distribution of authors by country has been compiled and presented in greater detail in Table 4.

Table 4. Distribution of Author's Country Affiliations

Affiliation Country	Type	Number	Percentage
Indonesia	Independent	7	70%
Indonesia-Thailand	Collaboration	1	10%
Norway	Independent	1	10%
United States America (USA)	Independent	1	10%

Based on the affiliation data presented in Table 4, the distribution of authors' countries of origin reveals a relatively concentrated geographic pattern while still indicating the presence of collaboration. The majority of publications and studies related to the implementation of the deep learning approach in biology education were initiated by researchers from higher education institutions in Indonesia, accounting for 70% and representing independent research. In addition, one article originated from Norway and another from the United States. The collaborative research was affiliated with institutions in Indonesia and Thailand and consisted of one article. This indicates that educational institutions in Southeast Asia, particularly in Indonesia, have a strong interest in implementing deep learning in biology education and the national curriculum.

Distribution by Education Level

An in-depth analysis of the selected literature reveals variations in the range of educational levels and grade levels involved in the implementation and study of deep learning in Biology education. This classification was conducted to identify the educational level at which the Deep Learning approach is implemented most intensively. The results of this classification are presented in Table 5.

Table 5. Classification of Educational Levels in the Studies

Educational Level	Number	Percentage
Senior High School (SMA)	5	50%
Junior High School (SMP)	1	10%
Elementary School (SD)	2	20%
Across Educational Levels (SD, SMP, SMA)	1	10%
Across Educational Levels (SMA & Higher Education)	1	10%

Based on the classification results in Table 5, the implementation of the Deep Learning approach is predominantly concentrated at the senior high school level, as evidenced by the fact that 5 of the 10 studies focus on senior high school. In addition, studies covering multiple educational levels also include senior high school as one of the levels for Deep Learning interventions. Deep Learning can also be used at the elementary, junior high, and higher education levels. Therefore, the Deep Learning approach is not limited to senior high school but can also be implemented or focused on other educational levels.

Distribution of Biology Learning Materials

An analysis of the distribution of learning materials was conducted to identify the biology topics or content addressed in the literature. This was done to reveal which areas of knowledge are considered relevant to the characteristics of the Deep Learning approach. Each article was assigned to one main scope based on the topic it primarily studied, so no article was counted more than once and the Number column in Table 6 adds up to 10 (for example, Ecology and Environment: $2 + 2 = 4$ articles). The distribution of the materials is presented in Table 6.

Table 6. Distribution of Biology Learning Materials

Main Topic	Scope	Number
Ecology and Environment	Environment	2
	Ecosystem	2
Human Physiology and Anatomy System	Excretory System	2
	Physiological Systems	1
Biodiversity	Botany	1
Cellular and Molecular Biology	Genetics	1
Applied Microbiology	Microbiology	1

Based on Table 6, the distribution of the materials indicates that integrating Deep Learning with Biology education can accommodate a comprehensive range of topics, from macroscopic and interactive concepts to microscopic and systemic understanding. The areas most frequently discussed are ecology and the excretory system, indicating that contextual topics closely related to students' everyday lives can serve as the primary foundation for implementing Deep Learning.

Distribution of Student Achievement and Improvement

Based on the results of an in-depth analysis of the selected literature, the studies reviewed report positive results of deep learning on student learning achievement. Because effect sizes and the quality of evidence were not systematically extracted, this review describes the direction of

the reported results and does not estimate the size of the impact. The outcome dimensions were categorized by extracting dependent-variable data from articles focusing on changes associated with the Deep Learning intervention. The resulting categories varied, ranging from cognitive dimensions to student character. A summary of student achievement is presented in Table 7.

Table 7. Summary of Student Achievement

Achievement/Skill Dimension	Specific Indicators Based on the Literature
Cognitive and Thinking Skills	Understanding of contextual science concepts, problem-solving skills, improved critical-thinking skills, creative-thinking skills, and improved cognitive learning outcomes.
Practical and Science Process Skills	Improved Science Process Skills (SPS), as well as improved performance and evaluation of laboratory practicums.
Digital and Scientific Literacy Proficiency	Strengthened scientific literacy and mastery of digital literacy skills.
Attitudes, Affective Development, and Sustainable Character	Development of environmental awareness, interstudent collaboration competencies, and the achievement of balanced educational experiences.

Based on the summary in Table 7, it can be interpreted that the empirical outcomes of interventions using the Deep Learning approach have a very broad impact. These instructional interventions produce measurable 21st-century skills, including problem-solving abilities and scientific literacy, operational skills such as digital literacy and SPS, and the development of positive moral attitudes toward the environment.

Discussion

Publication Year Distribution

The distribution by publication year shows the number of articles published by year from 2021-2026. Table 1 indicates that the highest number of publications occurred in 2026, with 7 articles, 70% of all articles analyzed. Furthermore, 1 article (10%) was published in each other of the years 2025, 2023, and 2022. Meanwhile, no articles were recorded for the year 2024.

Based on this distribution, it is evident that publications on the studied topic experienced a significant increase in 2026. The dominance of publications in 2026 indicates that research on Deep Learning approaches in biology education remains a focus in recent studies. However, it should be noted that this distribution only reflects are the articles that were successfully identified and met the study's criteria, therefore, the number of publications in each year does not directly represent the total research conducted on Deep Learning approaches in education.

Research Approach and Design (Research Types/Methods)

Based on Table 2, the articles analyzed employed three research approaches, quantitative, RnD, and qualitative. The quantitative approach accounted for the largest number of articles, namely 5 articles (50%). This approach includes quasi-experimental designs and surveys, which are used to collect and analyze measurable data. The quasi-experimental approach is widely used in educational research because it allows researchers to assess the impact of an intervention in real-world learning conditions without having to fully randomize the subjects. This method is considered effective for generating findings that are contextual and relevant to learning practices (Zajić & Maksimović, 2022).

Furthermore, the Research and Development (R&D) approach was used in 3 articles (30%). Based on the table, the development models used included ADDIE and 4D. The Research and Development (R&D) approach is widely used in educational research because it is oriented toward the development of educational products that can be used in practice and undergo a validation process. R&D is suitable for research that produces learning media, instructional materials, learning tools, assessment instruments, and learning models (Rahayu, 2025).

Meanwhile, the qualitative approach was found in 2 articles (20%) with an exploratory design. According to (Hasan Bora, M. A., Afriani, D., Artiani, L. E., Puspitasari, R., Susilawati, A., ... & Hakim, A. R, 2025), the qualitative approach is used to gain an in-depth understanding of a phenomenon by considering the context and experiences of research participants. Thus, based on this distribution, the studies reviewed were predominantly quantitative (50%), followed by R&D (30%), and qualitative (20%). This composition indicates that research on this topic does not focus solely on quantitative measurement but also encompasses product development and in-depth exploration of phenomena.

Keyword Analysis

Based on the results of a bibliometric analysis using VOSviewer, keyword mapping was conducted to identify the thematic focus and relationships between themes in the selected literature. The mapping results show that the keyword “deep learning” serves as the central node, exhibiting strong connections to various variables—both those related to instructional and cognitive aspects. Deep learning’s position as the central node indicates that research on this topic does not stand as an isolated field of study. Based on the mapping results in the file, deep learning is linked to digital technology, simple laboratory experiments, and various learning models. In educational literature, deep learning refers to a learning process that emphasizes deep understanding, the ability to connect knowledge, the application of knowledge in new situations, and higher-order thinking skills (Akmal et al., 2025).

(Wu, 2024) explains that deep learning is related to active understanding and the critical use of knowledge, including the ability to transfer and apply knowledge to solve real-world problems. This concept is also linked to the development of higher-order thinking skills and 21st-century skills. For several years now, some experts have associated the environment-based deep learning approach proposed by (Erlina, 2025). Her research reveals that the implementation of an environment-based deep learning approach in biotechnology education at MTsN 3 Pangandaran demonstrates that the learning process not only results in improved conceptual understanding but also fosters a transformative learning experience. This approach integrates elements of inquiry-based learning, authentic student engagement with the surrounding environment, and scientific reflection on the results of experimental activities.

The mapping reveals a significant relationship between deep learning and digital technology. This relationship aligns with advances in educational research, which increasingly utilizes technology to create learning environments that foster deeper understanding. The application of deep learning is closely tied to instructional media, which play a vital role in connecting abstract concepts to students’ real-world experiences. In biology, digital media help illustrate complex processes such as photosynthesis or bodily structures, thereby deepening students’ understanding and grounding it in context (Primahesa et al., 2023).

The implementation of deep learning-based instructional media at the high school level, particularly in biology classes, has shown positive results in enhancing students’ motivation and

conceptual understanding. A study by (Pasaribu et al., 2025) found that the use of digital interactive media in biology instruction helps students understand complex concepts such as ecosystems and organ systems through 3D visualizations and virtual simulations. Teachers generally implement Project-Based Learning (PjBL), Problem-Based Learning (PBL), and inquiry-based learning strategies to foster critical and collaborative thinking skills.

The keyword “deep learning” in the mapping results is also linked to other learning models. These findings indicate that deep learning is not always positioned as a standalone learning model. Rather, the concept can be integrated into various learning models or strategies.

This is consistent with research conducted by (Ardhana et al., 2025), in which they applied a Problem-Based Learning model combined with a Deep Learning approach to improve students’ critical thinking skills. Based on the results of the study and analysis conducted, it can be concluded that the implementation of the Problem-Based Learning (PBL) model combined with Deep Learning principles is effective in enhancing students’ critical thinking skills in biology. This model encourages students to be more active in their learning by engaging in activities that involve searching for, analyzing, evaluating, and solving problems relevant to daily life. Combining PBL with the Deep Learning approach enables a learning process that is more adaptive, interactive, and capable of accommodating the needs of each student (Domu et al., 2023).

Distribution of Authors’ Countries (Author Affiliations)

A demographic analysis of researchers based on their country of affiliation shows that research on the implementation of deep learning in biology education still exhibits a relatively concentrated geographic distribution. According to Table 3, 7 articles (70%) were authored by researchers affiliated solely with institutions in Indonesia. Furthermore, there was 1 article (10%) resulting from a collaboration between Indonesia and Thailand, while Norway and the United States each contributed 1 article (10%) independently. Thus, among the 10 selected articles, most had authors affiliated with Indonesia. This reflects only the composition of the selected articles and does not show that Indonesia dominates deep learning research worldwide.

Indonesia’s dominance indicates that studies on deep learning in biology education within the analyzed collection of articles are strongly linked to the Indonesian educational context. Indonesia’s dominance indicates that research on deep learning in biology education within the analyzed dataset is closely tied to the national educational context. Educational reforms in various countries, including Indonesia, are increasingly moving toward the implementation of deep learning as one strategy to improve the quality of learning outcomes. The growing interest among Indonesian researchers in deep learning approaches also reflects progress in efforts to modernize the learning process.

From the perspective of student engagement, (Puspita et al., 2025) found that the application of deep learning in science education at the elementary school level can increase student participation while fostering the development of higher-order thinking skills. These findings align with the indicators listed in Table 6, particularly regarding the cultivation of environmental awareness, the development of collaborative competencies, and the creation of a balanced learning experience.

In addition to independently conducted studies, one article—representing 10% of the total—involved collaboration between Indonesian and Thai researchers. This finding indicates that research on deep learning in education is beginning to expand through international

collaborative networks. Cross-national collaboration can serve as a platform for exchanging knowledge, experiences, and perspectives in designing and developing educational research. UNESCO also emphasizes that international collaboration plays a crucial role in strengthening knowledge exchange and promoting the development of educational practices supported by research findings.

The contributions from Norway and the United States—each accounting for 10%—indicate that the topic of deep learning in biology education is also garnering attention from countries outside the Southeast Asian region. However, based on the analyzed articles, the contributions from these two countries remain isolated, as each is represented by only one article. Therefore, this geographic distribution is more accurately interpreted as a form of diversity in the origin of the research, even though the studies are generally still dominated by researchers from Indonesia.

Educational transformations in various countries, including Indonesia, are increasingly emphasizing the importance of deep learning in improving the quality of learning outcomes. The performance of Indonesian researchers is improving as more people pay attention to deep learning methods in transforming learning approaches. According to (Miller & & Krajcik, 2019), project-based learning (PBL) helps improve students' critical thinking skills and creativity. Deep learning is a strategic approach to meeting 21st-century learning needs. In the Indonesian context, this approach has also been shown to help students develop self-regulation skills when facing the challenges of digital learning (Wu, 2024).

In addition to independent research, one article (10%) was found that involved collaboration between Indonesia and Thailand. This indicates that research on deep learning in education is beginning to develop through international cooperation. Such collaboration can serve as a means to exchange knowledge, experiences, and perspectives in advancing educational research. UNESCO also emphasizes that international cooperation can strengthen knowledge exchange and the development of research-based educational practices. These findings suggest that although research in this field is still predominantly conducted by independent Indonesian researchers, there is already engagement within international research networks, particularly in the Southeast Asian region.

Contributions from Norway and the United States—each accounting for 10%—also indicate that the topic of deep learning in biology education is receiving attention from countries outside the Southeast Asian region. However, based on the analyzed data, the contributions from these two countries remain independent, with each represented by only one article. Therefore, this distribution is best understood as reflecting the geographical diversity of the research.

Distribution by Educational

Studies on the application of deep learning approaches in biology education have been conducted most frequently at the high school level, with 5 articles (50%); at the elementary school level, there are 2 articles (20%); while at the junior high school level, across all levels (elementary, junior high, and high school), and across high school and higher education levels, there is 1 article each (10%). According to Wardani (2026), the deep learning approach in biology education at the high school level is increasingly relevant to the demands of 21st-century learning. This approach emphasizes the importance of critical thinking as an essential skill that students must master, in line with the rapid advancement of science and technology, which

demands the ability to independently analyze, evaluate, and synthesize information, as well as to relate knowledge to real-life contexts.

Two articles on the elementary school level indicate that the Deep Learning approach is beginning to be implemented as early as elementary school. According to (Nabila et al., 2025), whose study is not among the 10 analyzed articles and is used only for comparison, the IPAS curriculum structure—which integrates various fields of study—can serve as a key tool for understanding the principles of Deep Learning. By integrating science (IPA) and social studies (IPS) rather than teaching them separately, students can grasp the connections between scientific concepts. For example, learning about water pollution not only teaches the chemical processes of pollution but also its impact on community life, the importance of environmental policies, and individual involvement in conservation.

The existence of articles that span multiple educational levels indicates that deep learning is viewed as a flexible approach that is not limited to a single level. In their study, (Wahyuni et al., 2026) developed student worksheets for a Basic Biology course that integrated Project-Based Learning with a deep learning approach. The product was found to be valid, practical, and effective for training the critical thinking skills of student teachers. These findings reinforce the idea that the deep learning approach is relevant even in higher education, although the number of studies on this topic is still limited.

Distribution of Biology Learning Materials

Based on Table 6, the distribution of biology topics in studies discussing deep learning approaches remains uneven. Of the 10 articles analyzed, Ecology and the Environment was the most frequently studied topic, appearing in 4 articles, or 40%. This topic covers discussions on the environment and ecosystems. Next, Human Physiology and Anatomy were found in 3 articles, or 30%, covering the excretory system and physiological systems. The other three topics—Biodiversity, Molecular Cell Biology, Genetics, and Applied Microbiology—were each discussed in only 1 article, or 10%.

The predominance of studies on ecology and environmental topics can be linked to the characteristics of the deep learning approach, which emphasizes a deep understanding of concepts, the development of data- and evidence-based thinking skills, and the application of knowledge in real-life situations (Entwistle, 2009; Ministry of Education, Culture, Research, and Technology, 2023). This alignment is also evident in the study by (Ningrum et al., 2026). In that study, the environmental literacy-based e-LKPD that was developed received a score of 84% and was classified as “very good.” These results indicate that the e-LKPD is capable of supporting the creation of meaningful, reflective, and enjoyable learning experiences for students during the learning process.

The topics of genetics and microbiology are abstract and microscopic in nature, thus requiring more complex instructional designs—such as visualizations, simulations, or laboratory experiments—to ensure that principles remain meaningful and contextual. Students’ readiness must also be taken into account. According to Sitorus et al. (2025), whose study is not among the 10 analyzed articles and is used only for comparison, the application of a deep learning approach in teaching molecular biology in high school is effective in transforming the learning process and strengthening students’ 21st-century skills. The integration of deep learning into the molecular biology curriculum through interactive visualization models, biological image analysis, and DNA sequence prediction has been shown to significantly enhance students’ conceptual understanding. Furthermore, according to (Miller & & Krajcik, 2019), another source outside the analyzed articles, deep learning—as a learning approach that emphasizes deep and meaningful conceptual

mastery—can be integrated into the molecular biology learning process through various appropriate strategies. This ability to synthesize information is particularly crucial for topics involving interrelated and abstract concepts, such as genetics and molecular biology.

Distribution of Student Achievement and Improvement

Based on Table 7, the application of the deep learning approach in biology education results in student achievements across four main dimensions: cognitive and thinking abilities; practical skills and the scientific process; digital literacy and science literacy; and attitudes, affective aspects, and sustainable character. Of these four dimensions, cognitive and thinking abilities are the achievements most consistently reported across various studies. (Liu et al., 2022) explain that one of the key elements of the deep learning approach is students' active engagement. This engagement encompasses not only cognitive aspects but also emotional and behavioral dimensions throughout the learning process. Fatika Alim et al (2025) also state that the deep learning approach is designed to facilitate deep, comprehensive, and transformative learning. This approach aims to develop students' conceptual understanding, cognitive and emotional skills, and character. Its implementation is grounded in the principles of mindfulness, meaningfulness, and joy—creating a pleasant learning atmosphere. These three principles are interrelated and form a learning experience oriented toward students' needs and engagement.

Further progress is evident in practical skills and scientific processes, as well as in digital literacy and science literacy. (Dinatha & Mahendra, 2025), who is also outside the 10 analyzed articles, notes that the application of a deep learning approach in science education can transform the learning process into one that is more meaningful, reflective, and contextual. Various strategies—such as Project-Based Learning, Inquiry-Based Learning, collaborative learning, and the use of technology and creativity—consistently contribute to improvements in student learning outcomes, motivation, science literacy, and higher-order thinking skills. (Rakhmawati et al., 2026) is not among the 10 analyzed articles and is used here only as a supporting comparison. Their study on environmental literacy is described below. Classes that implemented the deep learning-based Contextual Teaching and Learning (CTL) model showed a 44.12% improvement with an N-Gain score of 0.65. Meanwhile, the control class showed an increase of only 19.88% with an N-Gain value of 0.27. These external findings are consistent with the literacy outcomes in Table 7, but they are comparison material and not findings of this SLR.

From the perspective of student engagement, (Puspita et al., 2025) found that the application of deep learning in science education at the elementary school level can increase student participation while fostering the development of higher-order thinking skills. These findings align with the indicators listed in Table 7, particularly regarding the cultivation of environmental awareness, the development of collaboration skills, and the creation of a balanced learning experience.

D. CONCLUSION

Based on the results of a Systematic Literature Review (SLR) on global trends and the achievements of the Deep Learning approach in Biology education during the 2021–2026 period, it can be concluded that the figures reported here come from the 10 selected articles and do not describe all deep learning research in the world. Of these 10 articles, 7 (70%) were published in 2026, while 2022, 2023, and 2025 each produced only 1 article (10%). Methodologically, Deep Learning research in Biology education was dominated by quantitative approaches, accounting

for 50%, primarily using quasi-experimental and survey designs. Research and Development (R&D) studies accounted for 30% and used the ADDIE and 4D development models, while qualitative approaches accounted for 20% and used exploratory designs. Geographically, 7 of the 10 selected articles (70%) had authors affiliated with Indonesia, followed by Indonesia–Thailand collaborations at 10%, and Norway and the United States at 10% each. By educational level, the application of Deep Learning was most frequently conducted at the high school level, accounting for 50%, followed by elementary school at 20%, while middle school and cross-level studies each accounted for 10%. The Biology topics studied most frequently were ecology and the environment, followed by human physiology and anatomy systems. Overall, the findings indicate that the Deep Learning approach has broad potential for application in Biology education across various educational levels, learning topics, and instructional strategies. This review has limitations: the search used only one source (Google Scholar), only 10 articles were analyzed, the studies differ in methods, and the quality of the evidence was not assessed with a clear, standardized appraisal. The findings should therefore be interpreted with caution.

E. REFERENCES

- Ajibike, F. (2025). Ai-enhanced skill development: leveraging ai in biology education to develop skills in digital era. *Journal of Educational Studies, Trends and Practice*, 144-152.
- Akmal, A. N., Maelasari, N., & Lusiana, L. (2025). Pemahaman deep learning dalam pendidikan: Analisis literatur melalui metode systematic literature review (SLR). *JIIIP- Jurnal Ilmiah Ilmu Pendidikan*, 8(3), 3229–3236.
- Ardhana, D., Fajrina, S., & Fitri, R. (2025). Implementasi Problem Based Learning berbasis Deep Learning untuk Meningkatkan Berpikir Kritis Siswa pada Materi Sistem Ekskresi di SMA. *EDUBIOPRENA: Jurnal Ilmiah Pendidikan Biologi, Biologi, & Bioentrepreneurship*, 2(2), 50–58.
- Aziz, N. Z., Nafsiana, G., Kurniyati, I., Nurfadilah, S., A. Marthaliakirana, A. D., & Marpaung, D. V. (2026). Potensi kurikulum merdeka pada pembelajaran biologi melalui pendekatan deep learning: systematic literature review. *Jurnal Riset Dan Inovasi Pendidikan Sains (JRIPS)*, 5(2), 122–136.
- Cebrero, J. D. (2025). 21st century skills and science achievement among secondary school students: a systematic review. *Journal of Turkish Science Education*, 22(2), 248–268.
- Dinatha, D., & Mahendra, N. (2025). Transformasi Pembelajaran Sains melalui Deep Learning: Sebuah Kajian Sistematis. *Seminar Nasional Sosial Sains, Pendidikan, Humaniora (SENASSDRA)*, 4(3).
- Domu, I., Pinontoan, K. F., & Mangelep, N. O. (2023). Problem-Based Learning in the Online Flipped Classroom: Its Impact on Statistical Literacy Skills. *Journal of Education and E-Learning Research*, 10(2), 336–343.
- Erlina, E. (2025). Inovasi Pembelajaran Bioteknologi Melalui Deep Learning Berbasis Lingkungan di MTsN Pangdaran. *Multidisciplinary: Journal of Education an Learning*, 1(1), 48–52.
- Fitrah, M., Sofroniou, A., Yarmanetti, N., Ismail, I. H., Anggraini, H., Nissa, I. C., Widyaningrum, B., Khotijah, I., Kurniawan, P. D., & Setiawan, D. (2025). Are teachers

- ready to adopt deep learning pedagogy? The role of technology and 21st-century competencies amid educational policy reform. *Education Sciences*, 15(1344), 1–19.
- Garzon, J., Patino, E., & Marulanda, C. (2025). Systematic review of artificial intelligence in education: trends, benefits, and challenges. *Multimodal Technologies and Interaction*, 9(84), 1–19.
- Hasan Bora, M. A., Afriani, D., Artiani, L. E., Puspitasari, R., Susilawati, A., ... & Hakim, A. R. H. (2025). *Metode penelitian kualitatif*. Yayasan Tri Edukasi Ilmiah.
- Liu, E., Zhao, J., & Sofeia, N. (2022). Students' Entire Deep Learning Personality Model and Perceived Teachers' Emotional Support. *Frontiers in Psychology*, 12. <https://doi.org/10.3389/fpsyg.2021.793548>
- Miller, E. C., & Krajcik, J. S. (2019). Promoting deep learning through project-based learning: A design problem. *Disciplinary and Interdisciplinary Science Education Research*, 1(1), 1–10.
- Mnguni, L., Nuangchalerm, P., Sari, I. J., Mokhele, M., Camara, J. S., Bien, N. V, & Islami, R. A. Z. E. (2026). Preservice life science teachers' readiness for AI integration in teaching across varying socioeconomics contexts. *Discover Education*, 5(889), 1–20.
- Muhammad, S., Bello, S., & Gwandu, Z. L. (2026). Developing 21-st century skills in biology education through innovative instructional practices in secondary schools. *Journal of Studies in Science and Mathematics Education*, 6(1), 1–15.
- Nabila, S. M., Septiani, M., Fitriani, F., & Asrin, A. (2025). Pendekatan Deep Learning untuk Pembelajaran IPA yang Bermakna di Sekolah Dasar. *Primera Educatia Mandalika: Elementary Education Journal*, 2(1), 9–20.
- Ningrum, D. F. M., Leksono, S. M., & Vitasari, M. (2026). Pengembangan E-LKPD Jelajah Lereng Gunung Api Berbasis Deep Learning untuk Mendukung Literasi Lingkungan. *Jurnal Studi Guru Dan Pembelajaran*, 9(2). <https://doi.org/10.30605/jsgp.9.2.2026.9269>
- Papaneophytou, C., & Nicolaou, S. A. (2025). Promoting critical thinking in biological sciences in the era of artificial intelligence: the role of higher education. *Trends in Higher Education*, 4(24), 1–24.
- Pasaribu, A. S., Sangkuti, D., Sitanggang, J. B. D., Siregar, N. N., Sagala, N., Husna, R., Arwita, W., & Mukra, R. (2025). Analisis Media Pembelajaran Digital Berbasis Project Based Learning (PjBL) pada Mata Pelajaran Biologi untuk Peserta Didik Kelas X SMAN 18 Medan. *Mudabbir: Journal Research and Education Studies*, 5(1), 661–670. <https://doi.org/10.56832/mudabbir.v5i1.887>
- Primahesa, A., Sajidan, S., & Ramli, M. (2023). Improving Higher Order Thinking Skills in High School Biology: A Systematic Review. *Biosfer: Jurnal Pendidikan Biologi*, 16(1), 206–219. <https://doi.org/10.21009/biosferjpb.26724>
- Puspita, S. C., Wardani, S., & Permatasari, A. N. (2025). Pendekatan deep learning pada pembelajaran IPA di Sekolah Dasar Negeri 58 Mojo Sragen. *Pendas: Jurnal Ilmiah*

Pendidikan Dasar, 10(2), 318–329.

Rahayu, A. (2025). Metode penelitian dan pengembangan (R&D): Pengertian, jenis dan tahapan. *DIAJAR: Jurnal Pendidikan Dan Pembelajaran*, 4(3), 459–470.

Rahmawati, I., & Turista, D. D. R. (2026). Trends in biology learning innovations for strengthening 21st century skills toward achieving the sustainable development goals (sdgs). *Jurnal Penelitian Pendidikan IPA*, 12(1), 29–40.

Rahmeisi, N., Gani, E., & Arfriandi, A. (2025). Tinjauan literatur: pendekatan machine learning dalam deteksi serangan web. *Jurnal Ilmiah Sistem Informasi*, 4(3), 772–791.

Rakhmawati, H., Fithriyana, N. A., Sari, L. N., & Eras, M. H. (2026). Systematic literature review faktor keberhasilan dan hambatan dalam pengembangan sistem enterprise. *Jurnal Tekno Kompak*, 20(2), 232–845.

Saputro, I. N., Akbar, M. T. H., Rismawati, A. E., & Sapitri, A. (2025). Efektivitas pembelajaran melalui direction instruction model: systematic literature review. *Jurnal Pendidikan Olahraga*, 15(3), 148–161.

Utami, S. B., & Karlina, N. (2022). Analisis bibliometrik: perkembangan penelitian dan publikasi mengenai koordinasi program menggunakan vosviewer. *Jurnal Pustaka Budaya*, 9(1), 1–8.

Utari, G. D., Laila, A., & Ditasari, D. A. (2025). Pengaruh penggunaan multimedia interaktif berbasis permainan terhadap peningkatan kemampuan literasi numerasi siswa sekolah dasar. *De- Fermat: Jurnal Pendidikan Matematika*, 8(2), 830–845.

Wahyuni, R., Nursal, N., Sayuti, I., Darmadi, D., Natalina, M., & Ramona, N. (2026). *Development of project-based and deep learning-based student worksheets in Basic Biology to improve students' critical thinking skills*. https://doi.org/10.2991/978-2-38476-579-9_9

Wibowo, A., & Putri, S. (2021). *Pedoman praktis penyusunan naskah ilmiah dengan metode systematic review*. Depok: Departemen Administrasi dan Kebijakan Kesehatan Fakultas Kesehatan Masyarakat Universitas Indonesia.

Wibowo, A. A., Roviati, E., & Muspiroh, N. (2024). Application of the argument driven inquiry (ADI) model using interactive e-lkpd to improve students' argumentation skills. *Bioeduca: Journal of Biology Education*, 6(2), 135–152.

Wu, X. Y. (2024). Exploring the effects of digital technology on deep learning: a meta-analysis. *Education and Information Technologies*, 29(1), 425–458.

Yusra, I. I., & Asmara, R. (2026). Kajian bibliometrik penelitian otomasi perpustakaan di Indonesia menggunakan google scholar dan vosviewer periode tahun 2020-2025. *Jurnal Ilmu Informasi Perpustakaan Dan Kearsipan*, 15(1), 1–13.

Zajić, J. S. O., & Maksimović, J. (2022). Quasi-Experimental Research as An Epistemological-Methodological Approach in Education Research. *International Journal of Cognitive Research in Science, Engineering and Education*, 10(3), 177–183. <https://doi.org/10.23947/2334-8496-2022-10-3-177-183>



Zunifa, R. P., Garcia, M. M., Campos-Valdez, M., & Sanchez-Orozco, L. V. (2025). Pedagogical and evalative competencies for the 21st century in molecular biology education and their relationship with honors programs: a systematic literature review. *Frontiers in Education*, 1-18.