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Artificial Intelligence in Biology Education: A Systematic Review of Research Trends, Applications, and Future Directions (2020–2026)

Inteligencia Artificial en la Educación en Biología: Una Revisión Sistemática de las Tendencias de Investigación, las Aplicaciones y las Direcciones Futuras (2020–2026)

Çiğdem Çıngıl Barış[a]

[a] İstanbul University-Cerrahpaşa, Hasan Ali Yücel Education Faculty, Department of Science Education, İstanbul. Türkiye.

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ABSTRACT

Despite the accelerating integration of artificial intelligence (AI) into education, research on its use in biology education remains fragmented, making it difficult to assemble a comprehensive picture of current trends and applications. This study systematically examines research trends, methodological characteristics, AI applications, and principal findings in biology education. A systematic literature review was conducted in accordance with the PRISMA guidelines. Twenty-seven empirical studies published between 2020 and 2026 were identified through database searches and analyzed using descriptive and content analysis. The findings indicate a notable increase in publications, particularly after 2023, with university students representing the most frequently studied participant group. ChatGPT and other generative AI technologies emerged as the dominant AI tools. Taken together, the evidence indicates that AI contributes to academic achievement, cognitive skill development, personalized learning, assessment, and student motivation. Significant limitations were also identified, including reliability issues, ethical concerns, and limited support for higher-order thinking skills. This review provides a comprehensive synthesis of current research trends, AI applications, methodological approaches, and research gaps, while offering directions for future research in biology education.

RESUMEN

A pesar de la creciente integración de la inteligencia artificial (IA) en la educación, la investigación sobre su uso en la educación biológica sigue siendo fragmentada, lo que dificulta obtener una comprensión integral de las tendencias y aplicaciones actuales. Este estudio examina de manera sistemática las tendencias de investigación, las características metodológicas, las aplicaciones de la IA y los principales hallazgos en el ámbito de la educación biológica. Se llevó a cabo una revisión sistemática de la literatura siguiendo las directrices PRISMA. Se identificaron un total de 27 estudios empíricos publicados entre 2020 y 2026 mediante búsquedas en bases de datos, los cuales fueron analizados utilizando métodos de análisis descriptivo y análisis de contenido. Los resultados muestran un aumento notable en el número de publicaciones, especialmente a partir de 2023, siendo los estudiantes universitarios el grupo de participantes más estudiado. ChatGPT y otras tecnologías de inteligencia artificial generativa emergieron como las herramientas de IA predominantes. En términos generales, la IA contribuye al rendimiento académico, al desarrollo de habilidades cognitivas, al aprendizaje personalizado, a la evaluación y a la motivación de los estudiantes. Sin embargo, también se identificaron importantes limitaciones, entre ellas problemas de fiabilidad, preocupaciones éticas y un apoyo limitado para el desarrollo de habilidades de pensamiento de orden superior. Esta revisión ofrece una síntesis integral de las tendencias actuales de investigación, las aplicaciones de la IA, los enfoques metodológicos y las lagunas existentes en la investigación, al tiempo que propone orientaciones para futuras investigaciones en el ámbito de la educación biológica.

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Introduction

Artificial intelligence (AI), also known as machine intelligence, denotes the capacity of computer systems to learn from new inputs or accumulated data. The term is commonly applied when a machine mimics cognitive behaviors associated with the human brain in processes such as learning and problem-solving (Gupta et al., 2021). Although work in the field reaches back to 1943, the term "artificial intelligence" itself was coined by John

McCarthy at the Dartmouth Conference in 1956 (Ossowska et al., 2022). In 1959, Cahit Arf, in an essay entitled "*Can a Machine Think and How Can It Think?*", set out machine designs intended to demonstrate that thinking machines were possible. According to Arf, machines could be engineered to perform a range of analytical and logical functions, including the formation of analogies, the use of language, computation, and selection. From this perspective, certain correspondences emerge between the operational principles of machines and the functioning of the human brain. The decisive differences, he maintained, lie in the human brain's capacity for aesthetic awareness, its ability to make judgments, and its autonomy in deciding whether to undertake a given task (Arf, 1959).

Recent advances in AI have transformed educational practice across disciplines, science education among them. Its integration into biology education has attracted particular attention, owing to its potential to address the inherent complexity of biological systems. Biology education requires learners to reason about phenomena across multiple levels of organization, from molecular interactions to ecosystem dynamics. This multi-level structure often leads to persistent misconceptions, especially in topics such as genetics, evolution, and cellular processes (National Research Council, 2012).

AI-supported educational tools offer promising solutions to these challenges by deepening conceptual understanding and supporting individualized learning processes. Intelligent tutoring systems, adaptive learning platforms, and AI-driven feedback mechanisms diagnose student misconceptions in real time and deliver personalized guidance tailored to learners' needs (Luckin et al., 2016). AI technologies also sustain interactive and data-rich learning environments that promote deeper engagement with biological content (Holmes et al., 2019).

In biology education specifically, AI-based simulations and virtual laboratories allow students to explore complex and abstract phenomena—genetic inheritance, ecological interactions, and cellular processes among them—in more accessible and meaningful ways. Immersive and interactive environments supported by AI have been shown to increase student motivation and improve conceptual understanding in science learning contexts (Makransky & Petersen, 2019). Furthermore, AI tools enable the analysis and interpretation of large-scale biological data, aligning educational practices with contemporary developments in genomics and bioinformatics (Topol, 2019).

From a theoretical perspective, the integration of AI in biology education can be understood through the Technological Pedagogical Content Knowledge (TPACK) framework, which foregrounds the dynamic relationship between technology, pedagogy, and subject matter knowledge (Mishra & Koehler, 2006). In parallel, constructivist learning theory holds that knowledge is actively constructed through interaction and experience (Bruner, 1997). AI-supported learning environments—particularly those incorporating adaptive systems, simulations, and interactive feedback—align with these principles by allowing learners to engage actively with complex biological concepts in personalized ways.

AI may also foster higher-order thinking by supporting inquiry-based learning, hypothesis testing, and problem-solving within dynamic learning environments (Zawacki-Richter et al., 2019). When combined with pedagogical approaches such as problem-based and inquiry-based learning, AI applications have been associated with improved learning outcomes and more effective learning processes (Chen et al., 2020).

Despite these promising opportunities, the integration of AI into biology education raises important pedagogical and ethical concerns. Data privacy, algorithmic bias, the reliability of AI-generated content, and the evolving role of the teacher must be carefully weighed to ensure responsible and effective implementation (Holmes et al., 2022). Although the educational applications of AI have expanded rapidly in recent years, the literature on AI in biology education remains fragmented. Most previous review studies have examined AI in education from a general perspective or within science education without specifically addressing biology education. Furthermore, the emergence of generative AI, particularly following the public release of ChatGPT in late 2022, has substantially reshaped research trends, educational practices, and AI applications in teaching and learning. What is needed, then, is an up-to-date systematic literature review that synthesizes recent empirical evidence on biology education, identifies current research trends, and exposes existing research gaps.

Therefore, a comprehensive understanding of current research trends, AI applications, methodological approaches, and educational outcomes is essential for guiding future research and informing evidence-based practice in biology education. This study addresses that need by providing a systematic synthesis of empirical studies on the use of artificial intelligence in biology education published between 2020 and 2026. It examines publication trends, research groups, AI technologies, research methods, subject areas, and the main findings reported in the literature, and it identifies current strengths, limitations, and underexplored areas in order to ground evidence-based recommendations for future research and educational practice. By focusing exclusively on biology education, this review advances a more comprehensive understanding of how artificial intelligence is reshaping biology teaching and learning. The following research questions guided the review:

RQ1: How are the studies on the use of artificial intelligence in biology education distributed over the years?

RQ2: How are these studies on the use of artificial intelligence in biology education distributed by research group?

RQ3: Which types of artificial intelligence are used in studies on biology education?

RQ4: How are the studies on the use of artificial intelligence in biology education distributed in terms of research methods?

RQ5: Which subject areas are addressed in studies on the use of artificial intelligence in biology education?

RQ6: What are the main findings of studies on the use of artificial intelligence in biology education?

Method

Research Design

This study employed a systematic review to examine the use of artificial intelligence technologies in biology

education and to identify current trends in the field. A systematic review is a method for examining published work in a given field comprehensively and systematically, applying predefined inclusion and exclusion criteria in order to answer particular research questions. Unlike traditional narrative reviews, systematic reviews follow explicit, transparent, and reproducible procedures for identifying, selecting, evaluating, and synthesizing relevant studies, thus minimizing selection bias and strengthening methodological rigor (Wang & Notteboom, 2014).

The review adopted the five-step review protocol proposed by Denyer and Tranfield (2009). In the first step, the research questions were defined. In the second step, relevant studies were identified through database searches using selected keywords and criteria. In the third step, the studies were screened, and those failing to meet the eligibility criteria were excluded. In the fourth step, the data were analyzed and in the final step, the findings were synthesized, interpreted, and reported in accordance with the research questions.

1. Locating studies

To examine the relevant literature, articles were retrieved from three international databases: Web of Science, Scopus, and ERIC. The search strategy was developed from previous systematic reviews on artificial intelligence in education and refined through pilot searches to maximize the retrieval of relevant studies. The same conceptual search strategy was applied across all databases, with only minor syntax modifications to accommodate database-specific requirements. In each database, the terms *artificial intelligence* and *biology education* were searched across all available fields and combined with Boolean operators (AND/OR). To ensure comprehensive retrieval, the search strategy was broadened with synonyms and related terms: *artificial intelligence*, *machine learning*, and *AI* for the AI component, and *biology education*, *biology learning*, *biology teaching*, *biology instruction*, *biology curriculum*, *biology laboratory*, and *biology textbook* for the biology education component. The complete search strategy applied in each database is presented in Table 1. The literature analyzed in this study covers the period from 2020 to 2026, and the database search was completed on March 18, 2026.

Table 1. Search Strategy Used in the Databases

Database	Search fields	Search strategy
Web of Science	All available fields	(“artificial intelligence” OR “machine learning” OR AI) AND (“biology education” OR “biology learning” OR “biology teaching” OR “biology instruction” OR “biology curriculum” OR “biology laboratory” OR “biology textbook”)
Scopus	All available fields	Same conceptual search strategy with database-specific syntax
ERIC	All available fields	Same conceptual search strategy with database-specific syntax

Following the database search, all retrieved records were imported into Zotero. Separate collections were created for each database and subsequently merged into a single collection titled “Combined Folder”. Duplicate records were identified and removed. The remaining studies were then assessed for eligibility based on predefined inclusion criteria. The screening process was performed manually after duplicate removal to ensure that all retrieved studies met the predefined eligibility criteria.

The inclusion and exclusion criteria were established prior to the screening process to ensure transparency and consistency throughout the study selection process. Six criteria determined the eligibility of studies for inclusion in this review: (1) publication between 2020 and 2026; (2) relevance to the field of biology education; (3) exclusion of books, book chapters, conference proceedings, review articles, and theses; (4) adoption of an empirical research design; (5) publication in English; and (6) availability as an open-access publication. Studies that failed to satisfy one or more of these criteria were excluded. Restricting the review to open-access publications may have excluded some relevant subscription-based studies; the criterion was adopted to ensure that all included articles could be accessed in full and evaluated using consistent procedures. This decision is acknowledged as a limitation of the present review.

The study selection process followed the four phases of the PRISMA 2020 statement (identification, screening, eligibility, and inclusion) (Page et al., 2021), as illustrated in Figure 1. Articles retrieved from Web of Science (n=31), Scopus (n=26), and ERIC (n=21) were merged into a single collection. Seventeen duplicate records were removed, resulting in 61 unique articles. Of these, 34 studies fell outside the scope of the review and were excluded. The full texts of the remaining 27 articles were then carefully reviewed and assessed against the pre-established eligibility criteria.

2. Study selection and evaluation

At this stage, the 27 selected articles were examined in detail through full-text analysis. During the review process, a systematic classification was conducted by considering the AI approaches and application areas addressed in the studies. Accordingly, the articles were categorized according to their content and organized under relevant categories. Each article was coded according to predefined categories, including publication year, participant group, AI technology, research method, subject area, and principal findings. The coding framework was developed before the analysis and applied consistently across all included studies. For the 27 included studies, a data extraction matrix was created in Microsoft Excel to systematically record all coding categories and facilitate subsequent analysis.

3. Data Extraction and Verification

Following the selection of eligible studies, the relevant information was extracted and recorded in the data extraction table. To strengthen the trustworthiness of the extracted data, all coding decisions were independently reviewed by an expert in biology education. Any discrepancy identified during verification was discussed until consensus was reached, and the coding framework was refined where necessary. After the verification process, the final dataset was confirmed for analysis.

4. Analysis and Synthesis

The analysis phase sought to deconstruct individual studies into their constituent components and to examine the relationships among them. In contrast, the synthesis phase focused on establishing connections across findings drawn from different studies, moving beyond simple description to generate insights that may not be evident when studies are considered in isolation (Denyer & Tranfield, 2009). Prior to the analysis, the reviewed studies were recorded in a "Research Information Form" developed by the researcher and a biology education expert. The form covered the database from which the study was retrieved, publication year, research group, research method, subject area, and main findings. Because the aim was to identify trends in research on the use of artificial intelligence in biology education, descriptive content analysis was employed. The analysis proceeded in three stages. First, the findings of each study were coded against the predefined research questions. Second, similar codes were iteratively grouped into broader themes and categories. Finally, frequencies and percentages were calculated to identify research trends across the included studies.

5. Reporting and Interpretation of Results

The findings section presents a summary and synthesis of all articles reviewed and indicates what is known and what remains unknown about the research questions (Denyer & Tranfield 2009).

Validity and Reliability

To ensure validity, inclusion and exclusion criteria were defined prior to data collection, and the methodological quality of the studies was evaluated by both the researcher and an expert. A systematic search strategy was also established and documented in a PRISMA flow diagram, which presents every stage of the process transparently (Figure 1).

To ensure reliability, the studies recorded in the research information form were independently coded by the researchers, and inter-coder agreement was calculated using the formula proposed by Miles and Huberman (1994). The inter-coder reliability coefficient was 0.94.

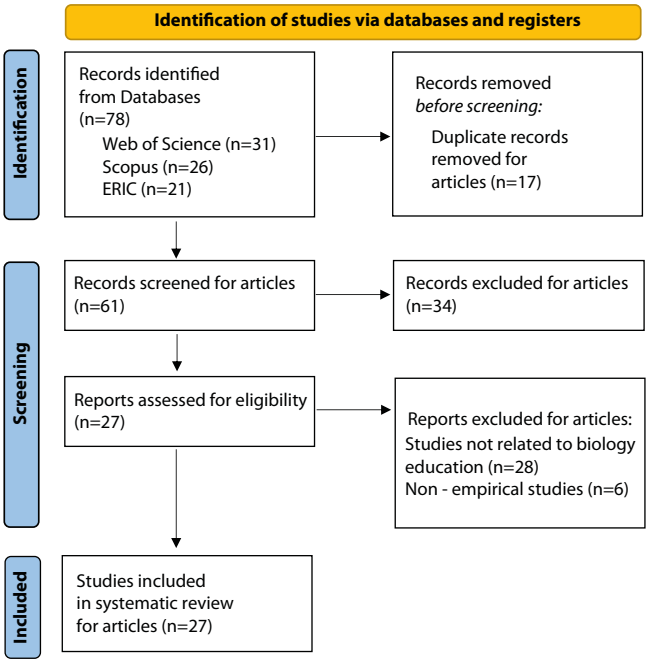

Figure 1. PRISMA 2020 Flow Diagram (Page et al., 2021)

Results

The findings are presented by answering each research question. The 27 studies included in this systematic review were analyzed with respect to publication year, research group, type of artificial intelligence, research method, subject area, and principal findings. The results are presented using tables and figures to provide a clear overview of the identified research trends. The studies included in the review are listed in Table 2.

Table 2. Overview of the Characteristics of the Reviewed Studies

No	Author(s)	Year	Research Group	Types of Artificial Intelligence	Research Methods	Subject Areas	Main Findings
S1	**Koć-Januchta et al.**	2020	University students	AI-supported digital biology book	Quantitative and qualitative method, Experimental comparative study (AI-book vs. E-book)	Molecular and cellular biology	AI-supported books improved learning outcomes, motivation, and visual material usage. Personalized feedback was identified as a future need.
S2	**Koć-Januchta et al.**	2022	University students	AI-supported digital biology book	Quantitative method	Molecular biology, cell biology	AI-supported books positively influenced cognitive load management, self-regulation, and learning outcomes.
S3	**Ariely et al.**	2023	Student response datasets (high school context)	NLP and machine learning	Qualitative method (Computational model development and experimental analysis)	Assessment, scientific explanation in biology (respiratory and circulatory systems)	Machine learning models effectively evaluated open-ended responses and showed high agreement with human raters.
S4	**Crowther et al.**	2023	No human participants (chatbots used as student models)	Generative AI (LLM-based chatbots)	Quantitative method (Experimental comparative task analysis)	Biology assessment, human physiology, cell biology	Chatbots performed poorly on higher-order biological reasoning questions requiring deeper conceptual understanding.
S5	**Dao & Le**	2023	Biology exam dataset	Generative AI (ChatGPT, Bing Chat, Google Bard)	Quantitative method (Comparative performance analysis)	Biology assessment	LLMs performed well on knowledge-level questions but struggled with higher-order thinking tasks.

No	Author(s)	Year	Research Group	Types of Artificial Intelligence	Research Methods	Subject Areas	Main Findings
S6	**Al-Muqbil**	2024	Biology teachers	General AI educational tools	Mixed method (descriptive + one-group pre-test/post-test design)	Teacher education, sustainability thinking	AI-based training significantly improved teachers' sustainable thinking skills.
S7	**Hubbard**	2024	University biology education context	AI in information literacy and digital learning tools	Qualitative method (Conceptual / theoretical framework)	Plant biology education	Students need critical AI literacy and competence-based training to evaluate AI sources effectively.
S8	**Lee et al.**	2024	Educational evaluation context	ChatGPT-4o	Qualitative method (Design-based research)	Biology assessment	ChatGPT may support online assessment systems but reliability and academic integrity issues remain.
S9	**Sripathi et al.**	2024	University biology student dataset	Large Language Models	Mixed method (qualitative coding + machine learning modeling)	Cell biology, genetics, physiology	AI models efficiently analyzed written responses and supported feedback processes.
S10	**Yin et al.**	2024	University students	Educational chatbots (Flow.ai)	Quantitative method (Experimental comparative analysis)	Cardiovascular system, motivation	Metacognitive chatbots increased learning motivation and perceived competence.
S11	**Baroud et al.**	2025	High school students	Generative AI (ChatGPT)	Quantitative method (Quasi-experimental design)	Genetics, meiosis	ChatGPT significantly improved students' academic performance and problem-solving skills.
S12	**Crowther et al.**	2025	No human participants (AI generated materials)	LLM and ChatGPT chatbots, Gemini, Claude	Qualitative method (Experimental task analysis with expert evaluation)	Physiology, anatomy, motor learning	AI generated learning objectives and exam questions but required teacher revision.
S13	**Czinczel et al.**	2025	High school students	EvoGrader machine learning tool	Mixed method experimental study	Evolution (natural selection, mutation)	AI tools effectively analyzed students' evolutionary reasoning patterns.
S14	**Großmann et al.**	2025	AI-generated lesson plans (document)	ChatGPT-4o	Qualitative document analysis	Biology education, teacher education	AI shows potential in lesson planning but lacks inquiry-based pedagogy.
S15	**Habibah et al.**	2025	High school students	AI chatbot (Gemini)	Quantitative method (Quasi-experimental)	Digestive and excretory systems	AI-supported POPBL significantly improved critical thinking and communication skills.
S16	**Jones et al.**	2025	Online biomedical educational videos dataset	Generative AI and video production	Mixed method content analysis	Biochemistry, cell biology	AI-generated videos may contain misleading information and require expert review.
S17	**Huang et al.**	2025	University students	AI perception in biomedical applications	Quantitative method (factor analysis)	Genomics, biomedical AI	Students show high interest in AI but limited knowledge and awareness of ethical issues.
S18	**Litavczová & Annuš**	2025	Primary and secondary school students and teachers	AI; digital technologies (VR, AR, interactive simulations, online platforms)	Mixed methods (survey + document analysis of textbooks)	General biology education, instructional materials, digitalization	Existing biology teaching materials, particularly older textbooks, were found to be insufficient. Digital tools such as VR and AR increased student motivation and interaction. Both students and teachers showed positive attitudes toward digital technologies. The findings highlight the need for digital transformation in biology education.
S19	**Millen**	2025	University students	Generative AI simulation tools (ChatGPT, Claude)	Quantitative method (Pilot application study)	Aging biology	AI simulations improved students' interview skills and confidence.
S20	**Rai et al.**	2025	University biology course dataset	LLMs (ChatGPT, Bard, Bing)	Quantitative method (Comparative performance study)	General biology	AI systems can pass biology exams but struggle with higher cognitive tasks.
S21	**Stanja et al.**	2025	Dataset (Student texts + AI-generated synthetic texts)	ChatGPT-3.5 Turbo	Mixed method comparative analysis	Evolution	AI-generated data can simulate student responses but require careful validation.
S22	**Tendrita & Hidayati**	2025	University students	AI-powered mind mapping	Quantitative method (Experimental design)	Biology teacher education	AI-supported mind mapping improved collaborative skills.
S23	**Thanh et al.**	2025	High school students	AI learning tools (ChatGPT, Gemini)	Mixed method (SEM + thematic analysis)	Self-regulated learning in biology	Students mainly use AI for exam preparation; trust and privacy issues remain concerns.
S24	**Tobler & Köhler**	2025	University students	Machine learning (Random Forest) ITS	Quantitative method (Experimental model-based study)	Molecular biology	Personalized learning improved student performance and reduced inequalities.
S25	**Yang et al.**	2025	University students	ChatGPT + Random Forest ML	Qualitative method (Case study with applied lab activities)	Microbiology / microbiome	AI support enabled students to build ML models and improved confidence and problem solving.
S26	**Doğru & Faulkoner**	2026	University students and academics	ChatGPT	Mixed method survey	Enzymes, assessment	Human assistants provided more accurate feedback; AI should be used as a support tool.
S27	**Hamizi & Mokmin**	2026	High school students	AI-supported VR learning	Quantitative method (Quasi-experimental factorial design)	Cell division	AI-VR environments increased engagement and academic performance.

Distribution of Studies by Publication Year

A descriptive analysis examined the distribution of the 27 included studies by publication year, and the results are displayed as a bar chart in Figure 2.

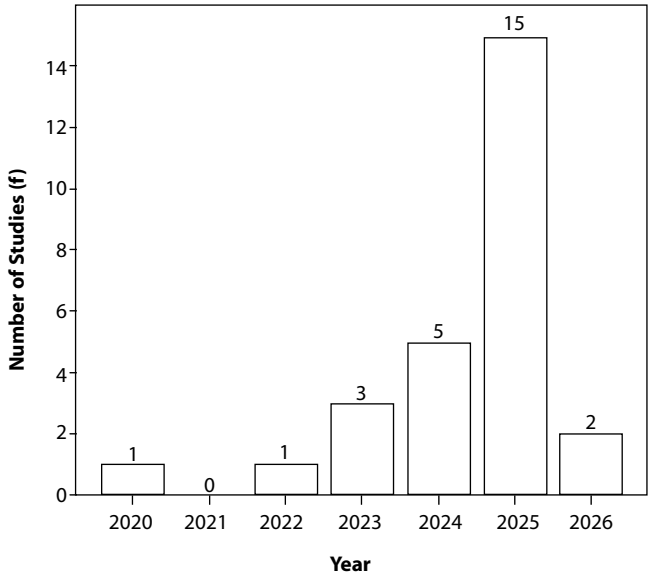

Figure 2. Distribution of the Reviewed Articles by Publication Year

As Figure 2 shows, the number of studies investigating the use of artificial intelligence in biology education rose steadily over the review period. One study was published in 2020 [S1] and one in 2022 [S2] (f=1; 3.7% each), and none appeared in 2021. The figure rose to three in 2023 [S3–S5] (f=3; 11.1%) and to five in 2024 [S6–S10] (f=5; 18.5%). The sharpest increase occurred in 2025, which accounted for 15 studies [S11–S25] (f=15; 55.6%). Two further studies had appeared by the first half of 2026 [S26–S27] (f=2; 7.4%), for a total of 27 studies included in the review.

Distribution of Studies by Research Group

Descriptive statistics served to examine the distribution of the included studies according to the research groups represented. Because some studies involved more than one research group, each group was coded and analyzed separately; the frequencies reported in Table 3 represent the total number of research groups rather than the total number of reviewed studies.

Table 3. Distribution of the Reviewed Articles by Research Group

Theme	Code	f	%	Study No
Research Group	University students	9	**31.0**	[S1], [S2], [S10], [S17], [S19], [S22], [S24], [S25], [S26]
	Dataset / Document	7	**24.1**	[S3], [S5], [S9], [S14], [S16], [S20], [S21]
	Students	6	**20.7**	[S11], [S13], [S15], [S18], [S23], [S27]
	No sample	4	**13.8**	[S4], [S7], [S8], [S12]
	Teachers / Academics	3	**10.3**	[S6], [S18], [S26]
	Total	**29**	**100**	

As Table 3 shows, university students constituted the most frequently represented research group (f=9; 31.0%). Dataset/document-based studies formed the second most common category (f=7; 24.1%), followed by studies involving school students (f=6; 20.7%). Studies without a defined sample accounted for a further noteworthy share (f=4; 13.8%). Research conducted with teachers and academics, by contrast, remained relatively rare (f=3; 10.3%).

Distribution of Studies by Types of Artificial Intelligence

Descriptive statistics served to examine the distribution of the types of artificial intelligence employed in the reviewed studies. Because several studies incorporated more than one type of artificial intelligence, each AI type was coded and analyzed separately; the frequencies reported in Table 4 therefore represent the total number of AI types identified rather than the total number of reviewed studies.

Table 4. Types of Artificial Intelligence Used in the Reviewed Articles

Theme	Code	f	%	Study No
Types of AI	ChatGPT	11	**26.8**	[S5], [S8], [S11], [S12], [S14], [S19], [S20], [S21], [S23], [S25], [S26]
	Generative AI (ML, NLP, LLMs)	10	**24.4**	[S2]-[S4], [S6], [S9], [S12], [S16], [S20], [S24], [S25]
	AI-supported Curriculum	4	**9.8**	[S7], [S17], [S18], [S22]
	Gemini	3	**7.3**	[S12], [S15], [S23]
	AI-supported Book	2	**4.9**	[S1]-[S2]
	Claude	2	**4.9**	[S12], [S19]
	Google Bard	2	**4.9**	[S5], [S20]
	Microsoft Bing	2	**4.9**	[S5], [S20]
	AI-supported VR	2	**4.9**	[S18], [S27]
	AI-supported Video	1	**2.4**	[S16]
	EvoGrader	1	**2.4**	[S13]
	Flow.ai	1	**2.4**	[S10]
	Total	**41**	**100**	

As shown in Table 4, 41 separate instances of artificial intelligence technologies were identified across the reviewed studies, since some studies incorporated more than one AI type. ChatGPT was the most frequently identified technology (f=11; 26.8%). Generative AI technologies (including machine learning, natural language processing, and large language models) constituted the second most frequently identified category (f=10; 24.4%), followed by AI-supported curricula (f=4; 9.8%). Gemini (f=3; 7.3%), Claude (f=2; 4.9%), Google Bard (f=2; 4.9%), and Microsoft Bing (f=2; 4.9%) appeared less frequently, as did AI-supported textbooks (f=2; 4.9%). The remaining technologies—including AI-supported virtual reality, AI-supported video, EvoGrader, and Flow.ai—appeared in one or two studies each.

Distribution of Studies by Research Method

Descriptive statistics served to examine the distribution of the reviewed studies according to research method. The results are presented in Figure 3.

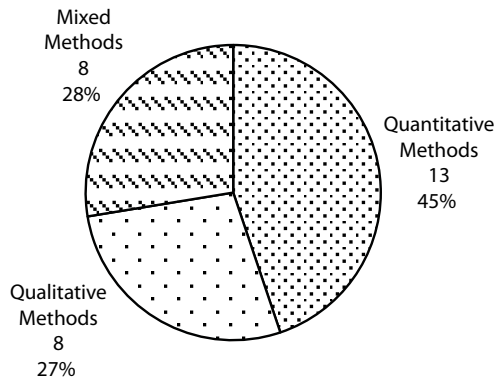

Figure 3. Distribution of the Reviewed Articles by Research Method

The reviewed studies employed quantitative, qualitative, and mixed-methods designs. As Figure 3 shows, quantitative research was the most frequently adopted approach (f=13; 45%). Qualitative methods accounted for eight studies (f=8; 27%), while mixed-methods research was employed in eight studies (f=8; 28%). Thirteen studies employed quantitative methods ([S1], [S2], [S4], [S5], [S10], [S11], [S15], [S17], [S19], [S20], [S22], [S24], [S27]), while eight studies adopted qualitative methods ([S1], [S3], [S7], [S8], [S12], [S14], [S19], [S25]). In addition, eight studies utilized mixed methods, combining the strengths of both qualitative and quantitative approaches ([S6], [S9], [S13], [S16], [S18], [S21], [S23], [S26]).

Distribution of Studies by Subject Area

Content analysis examined the distribution of the subject areas addressed in the reviewed studies. The subject areas identified across the 27 reviewed studies were coded and classified into thematic categories. Because some studies addressed more than one subject area, each subject area was coded and analyzed separately. Consequently, the frequencies reported in Table 5 represent the total number of subject-area codes rather than the total number of reviewed studies.

Table 5. Distribution of the Reviewed Articles by Subject Area

Theme	Code	f	%	Study No
Molecular and Cellular Biology	Cell, Cell Division, Genetics, Enzymes, Biochemistry	17	36.2	[S1], [S2], [S4], [S9], [S11], [S15], [S16], [S20], [S24], [S26], [S27]
Human Biology and Physiology	Circulatory system, Respiratory system, Digestive system, Excretory system, Human physiology, Anatomy	12	25.5	[S3], [S4], [S8], [S9], [S10], [S12], [S15]
Ecology and Evolutionary Biology	Ecology, Evolution	5	10.6	[S13], [S18], [S20], [S21]
Biology Education and Interdisciplinary Fields	Teacher education, Motor learning, General biology	4	8.5	[S5], [S14], [S22], [S23]
General Biological Processes	Biological processes	4	8.5	[S1], [S2], [S18], [S20]
Microbiology and Applied Biology	Microbiology, Biomedical	3	6.4	[S16], [S17], [S25]
Organismal Biology	Plant biology, Aging biology	2	4.3	[S7], [S19]
	Total	47	100	

As Table 5 shows, a total of 47 subject-area codes were identified and organized into seven thematic categories. "Molecular and Cellular Biology" was the most frequently represented category (f=17; 36.2%), with "Human Biology and Physiology" second (f=12; 25.5%). "Ecology and Evolutionary Biology" accounted for five subject-area codes (f=5; 10.6%). "Biology Education and Interdisciplinary Fields" (f=4; 8.5%), "General Biological Processes" (f=4; 8.5%), and "Microbiology and Applied Biology" (f=3; 6.4%) were represented less frequently, while "Organismal Biology" was the least frequently represented subject area (f=2; 4.3%).

Main Findings of the Reviewed Studies

Content analysis served to identify the main findings reported in the reviewed studies. The reported outcomes were coded and organized into thematic categories. Because individual studies frequently reported more than one finding, each outcome was coded independently; the frequencies below represent the total number of coded findings rather than the number of reviewed studies. A total of 23 codes, with an overall frequency of 60, were grouped into six major themes. The results are presented in Table 6.

Table 6. Main Findings of the Reviewed Articles

Theme	Code	f	%
Learning and Academic Performance	Increase in academic achievement	4	6.7
	Improvement in cognitive skills	4	6.7
	Increase in learning outcomes / retention	3	5.0
	Critical thinking / communication skills	2	3.3
	Subtotal	**13**	**21.7**
Limitations and Risks	Insufficient for higher-order thinking	4	6.7
	Reliability / error issues	3	5.0
	Ethical / privacy concerns	3	5.0
	Misleading content / quality issues	2	3.3
	Subtotal	**12**	**20.0**

Theme	Code	f	%
Effectiveness of AI in Education	AI facilitates learning	4	6.7
	Supports the learning process	3	5.0
	Provides personalized learning	2	3.3
	Increase in motivation and interaction	2	3.3
	Subtotal	**11**	**18.3**
Assessment, Evaluation, and Analysis	Automated assessment is effective	3	5.0
	Agreement with human raters	2	3.3
	Accelerates the assessment process	2	3.3
	AI exam performance (moderate level)	2	3.3
	Subtotal	**9**	**15.0**
Teacher Role and Pedagogy	Teacher guidance is necessary	4	6.7
	AI is not sufficient alone	3	5.0
	Lack of pedagogical alignment	2	3.3
	Subtotal	**9**	**15.0**
Attitudes, Motivation, and Usage	Increase in student motivation	3	5.0
	Positive attitudes toward AI	2	3.3
	Widespread use (homework/exams)	2	3.3
	Affective impact (interest, anxiety, etc.)	1	1.7
	Subtotal	**8**	**13.3**
	Total	60	100

As shown in Table 6, the identified findings were grouped into six major themes. "Learning and Academic Performance" was the largest category (f=13; 21.7%), followed by "Limitations and Risks" (f=12; 20.0%) and "Effectiveness of AI in Education" (f=11; 18.3%). "Assessment, Evaluation, and Analysis" (f=9; 15.0%), "Teacher Role and Pedagogy" (f=9; 15.0%), and "Attitudes, Motivation, and Usage" (f=8; 13.3%) accounted for the remaining themes.

Within the "Learning and Academic Performance" theme, increased academic achievement (f=4) and improvement in cognitive skills (f=4) were the most frequently reported findings, followed by increased learning outcomes and retention (f=3), and improvements in critical thinking and communication skills (f=2).

Within the "Limitations and Risks" theme, insufficient support for higher-order thinking (f=4) was the most frequently reported limitation. Reliability and error issues (f=3), ethical and privacy concerns (f=3), and misleading or low-quality AI-generated content (f=2) were also identified.

Within the "Effectiveness of AI in Education" theme, AI was most frequently reported to facilitate learning (f=4) and to support the learning process (f=3). Personalized learning (f=2) and increased motivation and interaction (f=2) were also reported.

Within the "Assessment, Evaluation, and Analysis" theme, automated assessment systems were reported to be effective (f=3). Further findings included agreement with human raters (f=2), faster assessment processes (f=2), and moderate AI examination performance (f=2).

Within the "Teacher Role and Pedagogy" theme, the need for teacher guidance was the most frequently reported finding (f=4). The reviewed studies also stressed that AI should not be used as a standalone instructional tool (f=3) and identified shortcomings in pedagogical alignment (f=2).

Within the "Attitudes, Motivation, and Usage" theme, increased student motivation (f=3) was the most frequently reported outcome, followed by positive attitudes toward AI (f=2), widespread AI use in learning activities (f=2), and affective responses such as interest and anxiety (f=1).

Discussion and Conclusion

This study systematically examined empirical research published between 2020 and 2026 on the use of artificial intelligence in biology education. Synthesizing findings from 27 studies, the review offers a comprehensive overview of publication trends, participant groups, artificial intelligence technologies, research methods, subject areas, and the educational outcomes associated with AI integration. The picture that emerges is one of rapid expansion, accompanied by pedagogical opportunities, methodological tendencies, and ethical challenges that demand further investigation.

The analysis of publication years indicates that research on artificial intelligence in biology education has increased substantially, particularly after 2023. More than half of the reviewed studies appeared in 2025, reflecting the rapid absorption of generative artificial intelligence into educational contexts. This trend largely coincides with the public release and widespread adoption of ChatGPT and other large language models, which have transformed educational practices by placing AI technologies within reach of both teachers and students (Baidoo-anu & Owusu Ansah, 2023; Kasneci et al., 2023). Similar increases have been reported in previous reviews of AI in education (González et al., 2021; Ouyang et al., 2022). However, set against these earlier reviews, the present study documents a far steeper rise after 2023, suggesting that biology education has responded with particular speed to recent technological developments. Current research trends are thus shaped not only by pedagogical demands but also by the rapid evolution and accessibility of AI technologies (Holmes et al., 2022).

The findings on research methods indicate that quantitative approaches remain the dominant methodological tradition in biology education research involving AI, with qualitative and mixed-methods studies represented at comparable levels. This predominance suggests that existing studies evaluate the effectiveness of AI applications primarily through measurable outcomes such as academic achievement, learning performance, and student attitudes. Similar methodological tendencies have been observed in educational technology research more broadly (Bond et al., 2023). The growing number of qualitative and mixed-methods studies, at the same time, reflects a rising interest in learners' experiences, classroom interactions, and teachers' perspectives on AI-supported instruction. Given the complexity of AI integration into educational environments, future research stands to benefit from mixed-methods approaches capable of pairing statistical evidence with contextual explanations (Creswell & Plano-Clark, 2018).

Turning to research groups, university students constitute the largest participant group. This finding is unsurprising, as higher education institutions generally provide greater access to digital technologies and students tend to possess higher levels of digital competence (Bond et al., 2023). Nevertheless, the relatively small number of studies involving primary and secondary school students marks an important gap in the literature. Since biology education plays a critical role in developing scientific literacy and inquiry skills from an early age, further research should investigate how AI-supported instructional approaches can be implemented effectively across different educational levels (Luckin et al., 2016).

The findings on AI technologies reveal that generative AI tools, particularly ChatGPT, dominate the current literature. Where earlier reviews emphasized intelligent tutoring systems, adaptive learning environments, and learning analytics (Zawacki-Richter et al., 2019; Ouyang et al., 2022), the present findings document a clear shift toward large language models. ChatGPT and similar systems are increasingly used for concept explanation, question generation, personalized feedback, and learning support. AI has thus evolved from a primarily analytical technology into an interactive educational partner that actively supports learning (Baidoo-anu & Owusu Ansah, 2023; Kasneci et al., 2023).

However, an important imbalance emerged in the diversity of AI technologies employed. While systems built on large language models were widely represented, AI-supported virtual reality, simulations, intelligent visualization systems, and adaptive learning environments appeared only rarely. This pattern sits awkwardly with the demands of biology education, where students frequently encounter abstract concepts and dynamic processes that require visualization and interactive exploration. Previous research has consistently demonstrated that simulations and immersive virtual environments enhance conceptual understanding of complex biological phenomena (De Jong et al., 2013; Makransky & Petersen, 2019). The current dominance of text-based AI tools therefore appears to reflect technological accessibility rather than pedagogical suitability, an observation that supports Selwyn's (2019) argument that educational technology research tracks technological innovation more closely than pedagogical priorities. Future studies should investigate a wider variety of AI technologies designed specifically to support visualization, experimentation, and inquiry-based biology learning.

The analysis of subject areas demonstrates that AI applications have been investigated predominantly in molecular and cellular biology and in human biology and physiology. These topics involve complex, abstract, and invisible processes that students often struggle to grasp, making them particularly well suited for AI-supported visualization, simulations, and personalized instructional support. Organismal biology and applied biology, by contrast, remain comparatively underrepresented despite offering considerable educational opportunity. Future research should extend AI applications into the less explored areas of biology education and so build a more balanced understanding of what artificial intelligence can offer. That the total number of subject areas exceeded the number of reviewed studies further indicates that many investigations adopted interdisciplinary perspectives, underlining the close relationship between biology education, educational technology, cognitive science, and data science.

Overall, artificial intelligence appears to exert positive effects on learning outcomes and academic performance in biology education. The reviewed studies consistently reported improvements in academic achievement, cognitive skills, learning outcomes, and personalized learning opportunities, echoing previous work showing that AI-supported learning environments positively influence student learning and engagement (Chen et al., 2020). The same studies also identified significant limitations, particularly the reliability of AI-generated content, ethical concerns, privacy issues, misleading information, and the limited capacity of current AI systems to support higher-order thinking skills. Similar concerns have been voiced in recent discussions of generative artificial intelligence (Bender et al., 2021; Kasneci et al., 2023). The findings also indicate unambiguously that teacher guidance remains indispensable throughout AI-supported learning. Artificial intelligence alone cannot be considered a sufficient instructional tool; rather, it should function as a pedagogical support system that complements teachers' expertise and enables meaningful learning experiences (Holmes et al., 2022).

These findings also reinforce the theoretical perspectives set out in the introduction. From the perspective of the TPACK framework (Mishra & Koehler, 2006), effective AI integration requires teachers to combine technological knowledge with pedagogical strategy and biology content knowledge rather than relying solely on technological innovation. Likewise, constructivist learning theory holds that meaningful learning occurs through active engagement, inquiry, and knowledge construction (Bruner, 1997). The reviewed studies suggest that AI contributes most effectively to biology education when it supports inquiry-based learning, provides adaptive feedback, facilitates problem solving, and encourages students to evaluate scientific information critically rather than simply generating answers. AI should therefore be regarded as a pedagogical tool that enhances teaching and learning rather than as a replacement for teachers.

Beyond its pedagogical contributions, AI integration raises important ethical considerations. The increasing use of generative AI in biology education demands greater attention to algorithmic bias, transparency, academic integrity, data privacy, and the accuracy of AI-generated scientific information. These issues have become increasingly prominent in recent educational AI research (Holmes et al., 2022; Kasneci et al., 2023). Accordingly, educational institutions should develop clear pedagogical and ethical guidelines to support the responsible use of artificial intelligence while ensuring that students develop critical thinking, scientific reasoning, and responsible digital citizenship.

This study has several limitations. The review was restricted to studies published between 2020 and 2026 and indexed in Web of Science, Scopus, and ERIC. Only English-language empirical studies published as open-access articles were included, which may have excluded

relevant subscription-based or non-English publications. Although these criteria strengthened methodological consistency and ensured full access to all included studies, they may have limited the comprehensiveness of the review. Future systematic reviews might draw on additional databases, different publication types, and multilingual sources to build a broader understanding of the use of artificial intelligence in biology education.

Conflict of Interests

The author declares no conflict of interest.

AI Use Statement

The author declares that artificial intelligence tools (e.g., ChatGPT) were used solely for language editing and improving clarity. The author carried out all conceptualization, analysis, and interpretation of the data. The author takes full responsibility for the content of the manuscript.

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