BIO-INOVED
Jurnal Biologi-Inovasi Pendidikan
Volume 7, Issue 2, June 2025 page. 298-307

P-ISSN : 2684-9062 | E-ISSN : 2714-9803
https://ppjp.ulm.ac.id/journal/index.php/bino
DOI: 10.20527/bino.v7i2.22001

The role of artificial intelligence in enhancing biology education: A bibliometric perspective

Arinda Eka Lidiastuti [(1)] *, Rikardus Herak [(2)], Handi Darmawan [(3)], Netti Yuniarti [(4)], Stephani Yane [(5)]

[(1)] Study Program of Biology Education, Faculty of Economics Education Social Humanities and Science Technology, Universitas Kristen Cipta Wacana, Malang, East Java, Indonesia
[(2)] Study Program of Biology Education, Faculty of Teacher Training and Education, Universitas Katolik Widya Mandira Kupang, Kupang, East Nusa Tenggara, Indonesia
[(3)] Study Program of Biology Education, Faculty of Mathematics, Science and Technology, Universitas PGRI Pontianak, Pontianak, West Kalimantan, Indonesia
[(3)] Study Program of Indonesian Language and Literature, Faculty of Language and Literature Education, Universitas PGRI Pontianak, Pontianak, West Kalimantan, Indonesia
[(3)] Study Program of Physical Sports and Health, Faculty of Sports and Health Education, Universitas PGRI Pontianak, Pontianak, West Kalimantan, Indonesia

** Corresponding Author Email: arindaekal1@gmail.com*

Article Information

Keyword:
Bibliometric; Biology; Education; PRISMA; Artificial intellegence

Kata Kunci:
Bibliometrik; Biologi; Pendidikan; Kecerdasan buatan

History:
Received : 26/02/2025
Revised : 16/06/2025
Accepted : 20/06/2025
Published : 26/06/2025

Abstract

Mapping of research trends, collaborations, and developments in the application of artificial intelligence (AI) in biology education is still inadequate and has not been systematically explored. Evidence-based insight investigations that can guide future research and provide guidance on effective AI integration strategies in biology education are needed. Biology learning, which involves abstract concepts and complex data, is expected to be integrated with AI to support the innovation of interactive learning tools, improve critical thinking skills, and enrich the learning experience. This research aims to analyze the role of AI in improving the quality of biology education through a bibliometric approach. This research uses data from Scopus with the keywords "artificial AND intelligence AND biology AND education," which includes 302 publications from 2000 to 2025. The analysis was conducted using Bibliometrix and Biblioshiny on the RStudioVR platform. The results show a significant upward trend in publications, especially after 2018, with a peak in 2023. The United States and China are the main contributors to these publications, with scientific articles (40.9%) and conference papers (25.1%) as the most dominant document types. In addition, Lecture Notes in Computer Science emerged as the most relevant source, demonstrating the important role of computer science in the development of AI for biology education. The findings are expected to provide strategic insights for more effective AI implementation in the future.

Abstrak. *Pemetaan mengenai tren penelitian, kolaborasi, dan perkembangan dalam penerapan kecerdasan buatan (AI) di bidang pendidikan biologi masih belum memadai dan belum dieksplorasi secara sistematis. Penyelidikan wawasan berbasis bukti yang dapat mengarahkan penelitian masa depan dan memberikan panduan strategi integrasi AI yang efektif dalam pendidikan biologi diperlukan. Pembelajaran biologi yang melibatkan konsep-konsep abstrak dan data kompleks diharapkan dapat diintegrasikan dengan AI untuk mendukung inovasi alat bantu pembelajaran yang interaktif, meningkatkan kemampuan berpikir kritis, dan memperkaya pengalaman belajar. Penelitian ini bertujuan untuk menganalisis peran AI dalam meningkatkan kualitas pendidikan biologi melalui pendekatan bibliometrik. Penelitian ini menggunakan data dari Scopus dengan kata kunci "artificial AND intelligence AND biology AND education" yang mencakup 302 publikasi dari tahun 2000 hingga 2025. Analisis dilakukan menggunakan Bibliometrix dan Biblioshiny pada platform RStudioVR. Hasil penelitian menunjukkan adanya tren peningkatan signifikan dalam publikasi, terutama setelah 2018, dengan puncak pada 2023. Amerika Serikat dan China menjadi kontributor utama dalam publikasi ini, dengan artikel ilmiah (40,9%) dan makalah konferensi (25,1%) sebagai jenis dokumen yang paling dominan. Selain itu, Lecture Notes in Computer Science muncul sebagai sumber paling relevan, menunjukkan peran penting ilmu komputer dalam pengembangan AI untuk pendidikan biologi. Temuan ini diharapkan dapat memberikan wawasan strategis untuk implementasi AI yang lebih efektif di masa depan.*

© 2025 BIO-INOVED : Jurnal Biologi-Inovasi Pendidikan

A. Introduction

Biology is abstract and difficult to understand. Misconceptions persist in areas such as genetics, cells, and related microorganisms (Kumandaş et al., 2019; Machová & Ehler, 2023). Such confusion causes students difficulty in achieving learning objectives. Another challenge that students can face is the high volume of information they must understand, which leads to cognitive overload (Koć-Januchta et al., 2022).

To overcome these challenges, AI offers enormous potential in improving the effectiveness of biology learning. AI has emerged as a transformative force in various sectors, including education (Karamchand, 2024). AI's ability to process large amounts of data, personalize learning experiences, and automate tasks opens up new opportunities to improve the effectiveness and efficiency of education (Adiguzel et al., 2023).

On the other hand, biology education as a dynamic and complex scientific discipline demands innovative learning approaches so that students can better understand abstract concepts. The integration of AI in biology education is expected to bridge this gap by providing tools and resources that facilitate understanding, enhance critical thinking skills, and enrich the learning experience (Alberto et al., 2024; Rane et al., 2024; Rasheed et al., 2025).

Biology is a science that is close to nature and has an important role in life (Lyon et al., 2021). Biology education aims to foster scientific literacy through rich biological content (Hogan & O'flaherty, 2021). Learning that is delivered requires innovation in teaching so that students can understand well.

In the rapidly evolving digital age, AI has become a key driver of innovation in various sectors, including education. According to a UNESCO report, global investment in AI-based education technologies is expected to reach $6 billion by 2025 (Miao et al., 2021), reflecting widespread recognition of its potential. In the context of biology education, which often involves abstract concepts and complex data, AI offers solutions for learning personalization, data visualization, and interactive simulations. Survey-based research shows that the use of AI influences prospective teachers' behavioral intentions in teaching (Adelana et al., 2024). The results show Li et al. (2023) that the use of AI can inspire students to compare similarities and differences between cells and help students understand the material better. However, despite this recognized potential, a comprehensive understanding of research trends and the impact of AI implementation in biology education is still limited.

Despite the increasing potential of AI in biology education, a thorough analysis of trends, collaborations, and research advancements in this domain remains necessary. This bibliometric analysis was undertaken to assess the scientific contributions concerning the incorporation of AI in biology education and to suggest prospective research possibilities and deficiencies. Bibliometric analysis, as a powerful method for mapping the research landscape (Ajibade et al., 2023; Liu et al., 2022), is crucial for identifying areas of focus, collaboration, and knowledge gaps.

This study employs a bibliometric methodology to examine the evolution of literature about the utilization of AI in biology teaching. The database utilized for data collecting is Scopus. The examined literature spans the years 2000-2025 to delineate contemporary trends in this domain, emphasizing publications published in indexed journals. The primary keywords utilized in the search comprise "artificial AND intelligence AND biology AND education." The use of keywords was chosen to ensure the search produced publications that were relevant and focused on the application of artificial intelligence in the context of biology education, minimizing results that were not related to the main research topic. This study analyzes the relationships within the literature by examining the increase in publishing numbers, the authors' countries of origin, the types of publications, and pertinent sources in connected works.

This study aims to fill those gaps by analyzing the existing scientific literature, providing data-driven insights into the role of AI in improving biology education, and informing the development of effective implementation strategies. This article analyzes the role of AI in improving biology education through a bibliometric lens. By examining trends and patterns in relevant scientific literature, this study aims to provide a comprehensive understanding of the potential, challenges, and development directions of AI in the context of biology education. The research questions addressed in this study are as follows:

1) What is the trend in the number of publications in AI topics in biology education from year to year?
2) Where do the authors who contribute the most to AI-related publications in biology education come from?
3) Which countries are the most productive in producing AI-related publications in biology education?
4) What types of publications appear most frequently in AI-related research in biology education?
5) What sources are most frequently used in AI-related publications in biology education?

B. Material and method

The literature analyzed in this study covers the period from 2000 to 2025, with data extracted on 4 February 2025. The Scopus databased we search "artificial AND intelligence AND biology AND education" in the title, abstract, and keywords. The total scopus data we got from 2000 to 2025 was 302 articles. The time frame from 2000 to 2025 was chosen for data collection to include recent developments and important trends in

research, especially about using artificial intelligence in biology education, and to ensure that the analysis reflected relevant technological and methodical progress over the past 25 years. The 302 findings are further divided into 124 articles, 76 conference papers, 31 reviews, 18 book chapters, and 53 other types of publications. Only English was found in 292 publications. Language is irrelevant in bibliometric analysis because it looks at publication patterns that do not require in-depth reading of an article (Abdullah, 2022), such as in conducting a systematic literature review or scoping review. Figure 1 represents the order of inclusion and exclusion that the researchers used.

The obtained data was saved in *CSV and *RIS formats. The data was then synchronized into Reference Manager (Mendeley). Bibliometric study with the Bibliometrix library and the Biblioshiny platform within RStudioVR. This software enables comprehensive analysis necessitating the deconstruction and visualization of data. Conversely, Bibliometrics is a publicly available software designed for the purpose of knowledge mapping deconstruction (Yan & Zhiping, 2023). The software facilitates continuous integration with several packages. The software is readily embraced by users and proves to be highly beneficial in the evolving domain of bibliometric analysis. Keywords and particular data from the bibliometric analysis of journal articles (author, title, abstract, keywords, citations, and affiliations) were utilized to investigate the topic's importance in recent years.

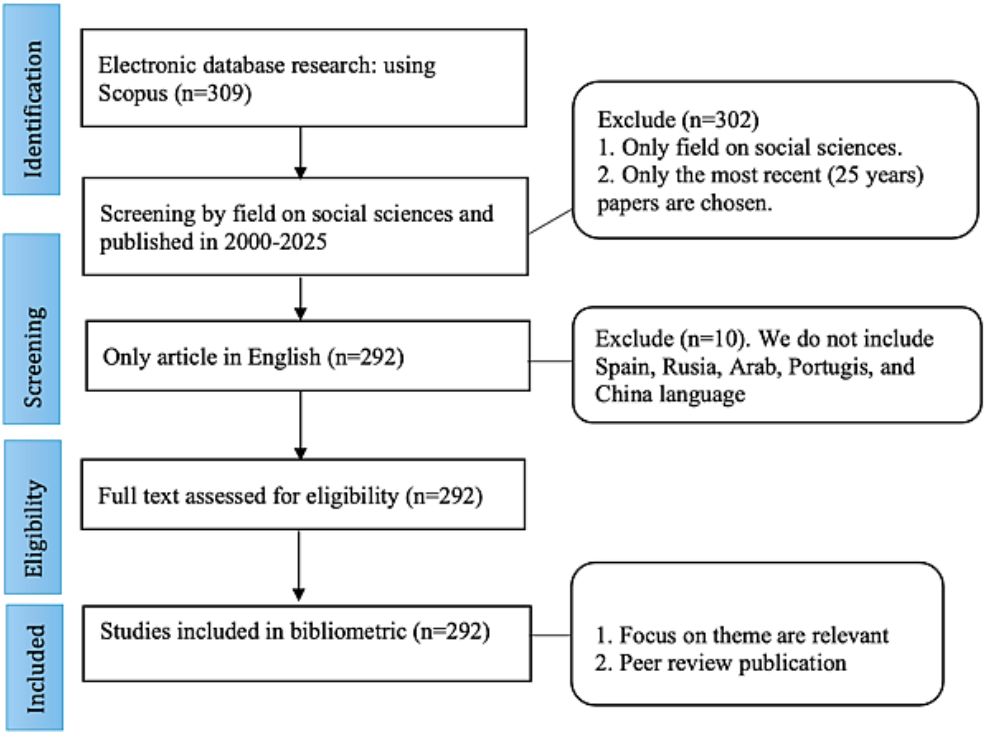

Figure 1 Number of publications

C. Results and discussion

Figure 2 shows that the number of publications over the two decades from 2000 to 2025. The graph of scientific publication production from 2000 to 2025 shows a significant upward trend. To strengthen the relevance of this study, recent literature specifically addressing the integration of AI in biology education was incorporated (Selvam, 2024), highlighting the emerging trends and applications in this field. Although it started with relatively low production at the beginning of the period, there was a noticeable acceleration after 2018. The drastic spike in 2024 is highlighted and needs to be further investigated. In general, this increase in publication production is likely driven by factors such as increased research funding, changes in publication policies, international collaboration, access to resources, and technological developments. While small fluctuations from year to year do occur, these positive trends signal the development of active research and have the potential to drive scientific progress and innovation (Broughel & Thierer, 2019).

This spike is likely triggered by large research projects or significant collaborations. However, after this peak, there is a steep decline in 2024, which may be due to the end of these large projects, changes in publication policies, or other external factors affecting research productivity. Overall, this graph depicts a slow growth in scientific production over two decades, with a sharp spike in 2023 followed by a significant decline the following year.

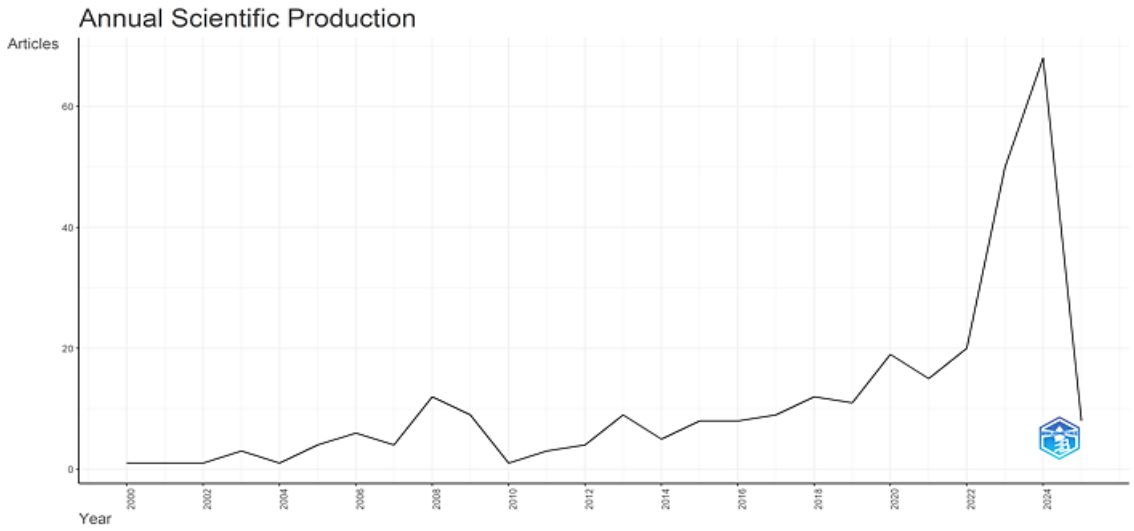

Figure 2 Number of publications

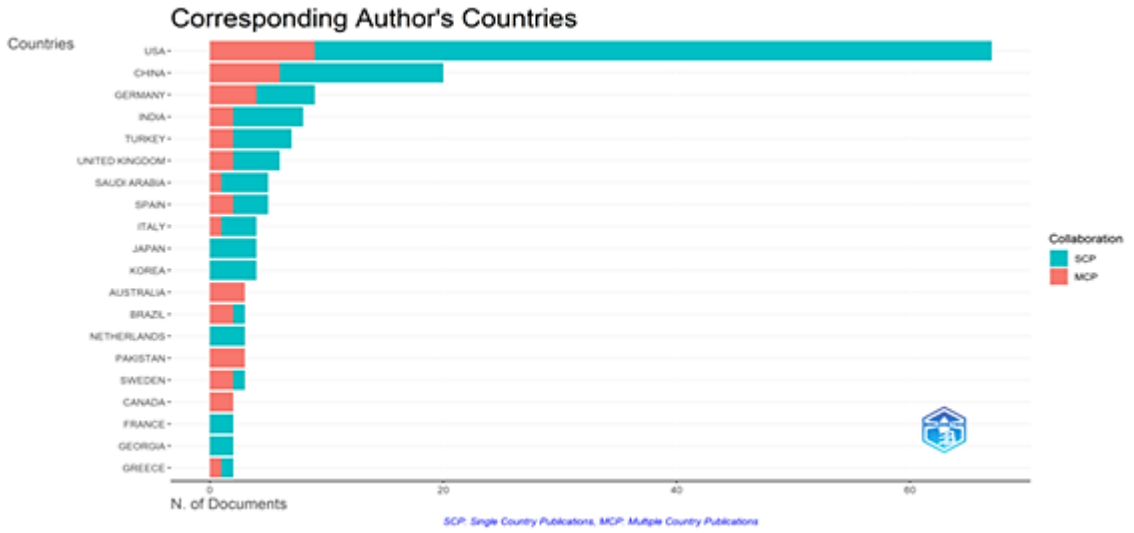

Figure 3 Author's country

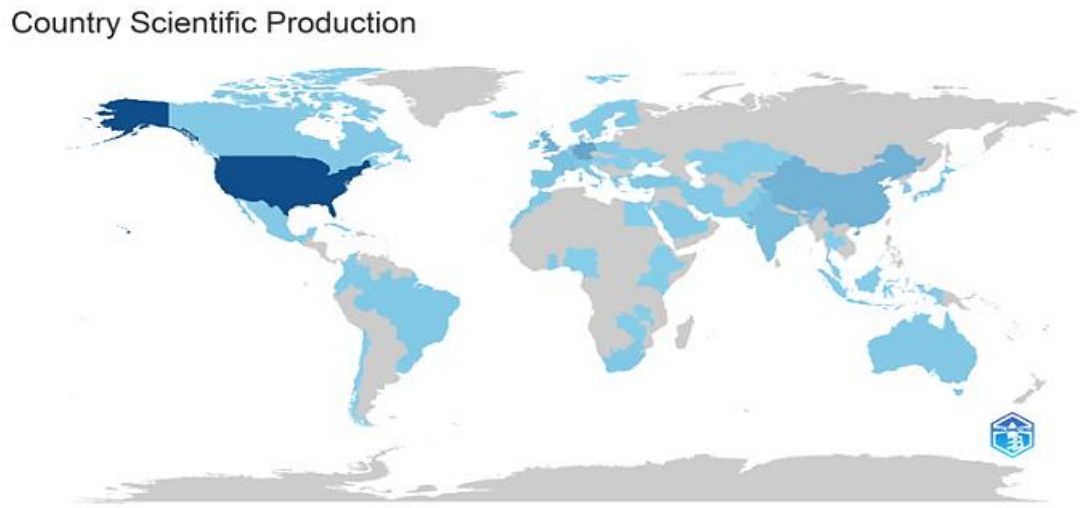

Figure 4 Country production

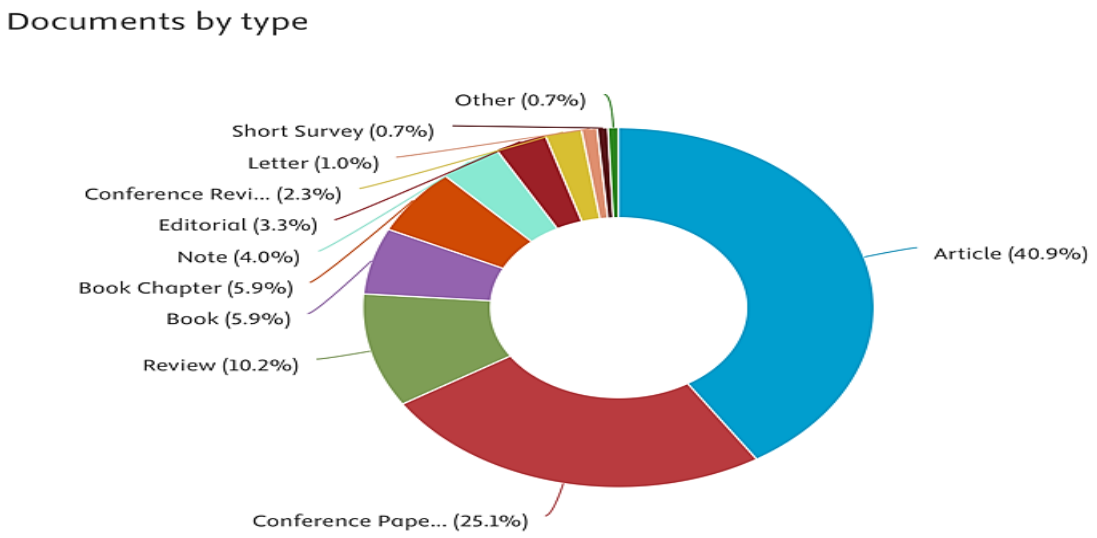

Figure 5 Type of publications

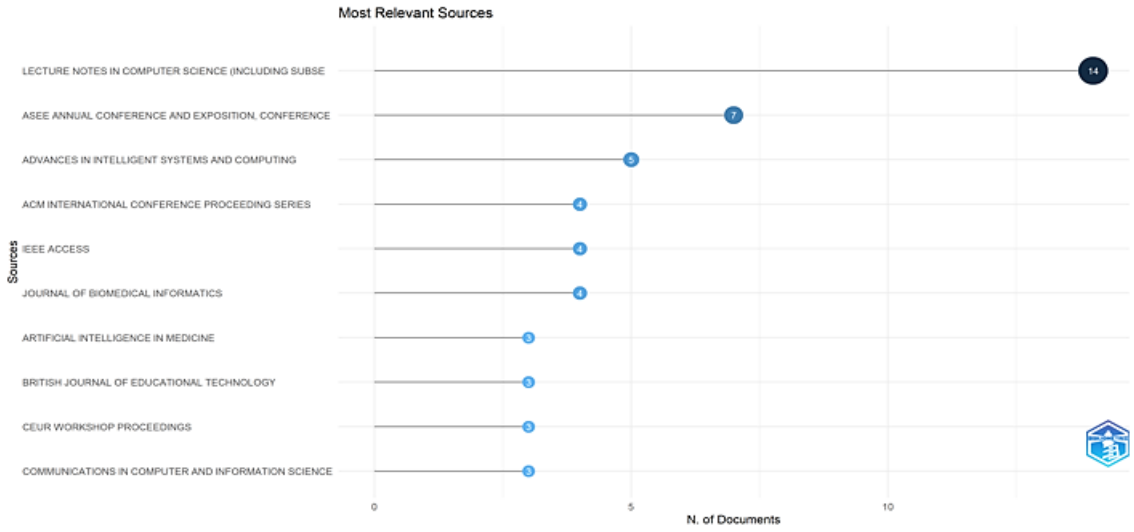

Figure 6 Relevant sources

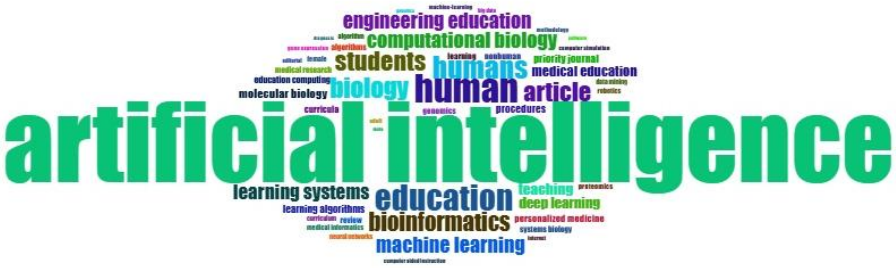

Figure 7 Most relevant keywords in publications related to the use of AI in biology education

Figure 3 shows the countries that contributed to the writing of the publication. The graph shows the country of origin of correspondent authors contributing to publications related to AI in the field of biology education.

Countries can be categorized as either Multiple Country Publications (MCPs) or Single Country Publications (SCPs) based on significant variables related to research focus, infrastructure, international collaboration, and resource capabilities. MCPs

generally emerge when the research subject is intricate or global, such as technology, global health, or climate change, necessitating international collaboration. Due to the complexity of these critical challenges, scholars worldwide collaborate to produce publications. Nations with strong international research networks, sufficient money, and research resources are more inclined to engage in MCPs due to their ability to access global collaborations and contribute to worldwide research.

SCPs are more likely to emerge when research is confined to a national setting or focuses on specialized topics. Publications from countries such as the US or China, which possess strong research capabilities and substantial domestic financing, often only feature researchers from those nations. The advancement of research infrastructure has enabled researchers to function independently without necessitating international collaboration. The decision to cooperate or not is also affected by political and economic factors. MCPs are predominantly generated by governments that endorse or facilitate international collaboration, while SCPs are primarily produced by nations that emphasize domestic research or struggle to engage with global networks.

Urgent global demands, the nation's ability to fund and support domestic research, and the aspiration for collaboration to create more comprehensive and transnational answers significantly influence the differences between MCPs and SCPs. The inclusion of a nation in both groups signifies its ability to balance independent research capabilities with participation in broader international collaboration (Kohus et al., 2022).

The graph shows two different types of publications based on how the authors worked together: Single Country Publications (SCP), which only have authors from one country (shown in blue), and Multiple Country Publications (MCP), which have authors from more than one country working together (shown in red). Based on the graph, the United States (USA) occupies the top position with the most number of publications, most of which are SCPs, indicating that research in this country is mostly conducted domestically without international collaboration. In second place, China shows a fairly balanced proportion of SCPs and MCPs, reflecting a combination of domestic and collaborative research. Other countries such as Germany, India, and Turkey also make significant contributions, although the proportion of international collaboration varies.

Interestingly, some countries, such as Australia, Pakistan, and Sweden, have a relatively high proportion of MCPs, indicating a strong tendency to conduct collaborative research across countries. In addition, countries such as Saudi Arabia, Spain, Italy, Japan, and Korea show moderate contributions, while nations such as the Netherlands, Brazil, Canada, France, Georgia, and Greece have relatively smaller contributions. Overall, this graph indicates that the United States and China are the main contributors to AI publications in biology education, with differences in collaboration patterns. While the United States focuses more on domestic research, China shows a balance between domestic and collaborative research. Some countries with smaller publication contributions show higher levels of international collaboration, reflecting the importance of global networks in the advancement of research in this field (Freshwater et al., 2006; Jacob & Meek, 2013).

According to the findings of the nation with the highest output in AI inside biology education, as illustrated in Figure 4. Countries exhibiting the highest scientific output are denoted in dark blue, including the United States, signifying a substantial contribution to research and development. Countries exhibiting moderate to low levels of scientific output are denoted in light blue, indicating moderate contributions to global research. Countries lacking data or exhibiting minimal scientific contributions are represented in gray. The map depicts global patterns in scientific research and innovation, highlighting nations that excel in scientific output while also outlining areas where certain countries require additional assistance to enhance their research capabilities.

The United States, China, and various European countries lead in research output regarding AI in biology education due to several critical elements. They possess substantial investments in research and supporting infrastructure, with entities like as the National Institutes of Health (NIH) in the United States financing this research. Prominent institutions like MIT and Stanford significantly contribute to the advancement of AI in education. Moreover, sophisticated technology and a proficient workforce in computer science and biology facilitate the utilization of AI to develop interactive learning aids that enhance biology teaching (Huang et al., 2021). Collaborative efforts between academia and industry, exemplified by partnerships with prominent corporations like Google and IBM, expedite the integration of AI into biology teaching (Amini et al., 2020; Danielson et al., 2022).

Figure 5 shows the types of publications from 2000 to 2025. The graph shows the types of documents published related to the use of AI in the field of biology education. Based on the graph, research articles (articles) are the most dominant document type with a proportion of 40.9%. These articles generally contain original research results, data analysis, and discussions that directly contribute to knowledge in the field of AI and biology education, reflecting the researchers' primary focus on delivering new findings and innovations. In second place, conference papers accounted for 25.1% of the total publications. This shows that academic forums and conferences play an important role as a platform for sharing recent findings, international collaboration, and discussion of innovative ideas, in line with the evolving nature of AI

as a technology. In addition, reviews accounted for 10.2% of the publications, indicating an interest in summarizing and evaluating previous research, providing a broader understanding for new researchers, and formulating trends and challenges in the field.

Other document types that also contributed significantly were books and book chapters, at 5.9% each. The presence of books and book chapters indicates a comprehensive approach and in-depth explanation of the application of AI in biology education, which is useful for education and long-term reference. Meanwhile, notes contributed 4.0%, usually including brief research results or preliminary findings that are significant enough to share. Editorials also accounted for 3.3%, serving as opinions or commentaries on important issues in the field. Document types such as conference reviews (2.3%), letters (1.0%), and short surveys (0.7%) complement publications with additional discussion, short responses, or brief evaluations of a particular topic. Finally, the other category (0.7%) includes documents that do not fall under the main classification, such as technical reports or supplementary materials.

Overall, this graph shows that research articles and conference papers are the most widely used document types for disseminating AI-related knowledge in biology education. This reflects the research focus on developing new knowledge and discussing innovative ideas through scientific forums. The presence of reviews, books, and book chapters confirms the need for more comprehensive understanding and in-depth theory. Meanwhile, editorials, notes and other types of documents enrich the scientific discourse with different perspectives and preliminary findings. This pattern suggests that research in AI for biology education is rapidly evolving with the need for collaboration and dynamic exchange of ideas at the global level (Natu & Aparicio, 2022).

Figure 6 shows relevant sources for AI publications in biology education. Based on the graph, Lecture Notes in Computer Science (Including Subseries) takes the top spot with 14 documents, indicating that research in this area has a strong foundation in computer science, which is essential for developing AI technologies used in biology education. AI in biology is used to analyze complex biological data, such as ecosystem modeling, simulation of biological processes, and genome analysis. This is the main place where researchers talk about algorithms, machine learning, and other AI technologies that are useful for biology education, especially when making AI-based learning tools that can help students understand difficult biological ideas.

In second place, the ASEE Annual Conference and Exposition contributed 7 documents, which shows that the conference forum plays an important role in sharing the latest findings and innovations related to AI in biology education. The conference is often the venue to present research related to the use of AI in virtual laboratory simulations, evolutionary mapping, and interactive biology experiments that enable practical learning without the need for physical laboratories. Additionally, Advances in Intelligent Systems and Computing (5 papers), ACM International Conference Proceeding Series (4 papers), and CEUR Workshop Proceedings (3 papers) make conference proceedings the best place to publish research on how intelligent and computational systems can be used to solve biological problems like identifying species based on images, analyzing cell growth patterns, and predicting how proteins will interact with each other.

On the other hand, journals that focus on technology and informatics, like IEEE Access (4 documents) and Communications in Computer and Information Science (3 documents), show that putting AI into biology education through technology and computation is very important. These technologies are used in the development of adaptive learning models that can be tailored to the needs of students based on their understanding of biological concepts, such as genetics and physiology. The Journal of Biomedical Informatics (4 documents) and Artificial Intelligence in Medicine (3 documents) show the close relationship between AI, biology education, and the healthcare field, reflecting how AI is used in medical biology education to help understand human anatomy, diagnose diseases, and simulate medical procedures. Also, the British Journal of Educational Technology (3 documents) focuses on the educational technology side of things. It talks about how AI is being used to create interactive biology lessons, like augmented reality (AR) and virtual reality (VR)-based learning that lets students virtually explore the structures of cells, organs, and organisms.

This graph shows that publications about AI in biology education come from a number of different sources. This shows that the approach is multidisciplinary, involving computer science, educational technology, and biomedical informatics. The dominance of Lecture Notes in Computer Science signifies the importance of computer science foundations in developing AI technologies that can change the way biological concepts are taught and understood. Meanwhile, conferences and conference proceedings such as the ASEE Annual Conference and ACM International Conference play a central role as key forums for sharing the latest innovations, such as the use of AI in modeling virtual ecosystems or simulating genetic experiments. The existence of journals such as IEEE Access and Journal of Biomedical Informatics shows the research focus on the application of AI to understand complex biological phenomena and its application in the context of education and healthcare. This pattern shows that using AI in biology education isn't just about the technical side of things; it's also about how it can be used in the real world to teach and learn biology (Tariq

et al., 2024), with the help of global forums that encourage people from different fields to work together (Flores-Vivar & García-Peñalvo, 2023).

Figure 7 distribution of frequently used words in publications. These is a word cloud depicting the most relevant keywords in publications related to the use of AI in biology education. The size of the word reflects its frequency or importance in the analyzed literature, where the larger the size of the word, the more frequently it appears. The word "artificial intelligence" emerged as the most dominant word, indicating that AI is a central topic in these publications. This confirms that research in this field focuses on how AI can be utilized to improve learning and research processes in biology. In addition, the word "education" also looms large, reflecting the primary focus on developing more interactive, adaptive, and personalized methods of learning biology with the help of AI. Words like "humans" and "students" show special attention to human biology education and how AI is used to personalize the learning process so as to accommodate individual needs in understanding biological concepts.

In the context of biology, the presence of words such as "biology" and "molecular biology" indicates the coverage of general biological topics down to the molecular level, indicating the use of AI in analyzing DNA structures, proteins, and complex biological processes. In addition, terms such as "computational biology" and "bioinformatics" indicate the role of computational biology and bioinformatics, where AI is used to analyze large-scale biological data, such as genomic and proteomic data. This is particularly relevant for education, as it helps students understand complex biological data analysis techniques. Words like "machine learning" and "deep learning" indicate that machine learning and deep learning algorithms are the most widely used AI technologies. These technologies can help create predictive models, simulate biological processes, and analyze biological data patterns, thus enriching the learning process in biology (Ching et al., 2018). The presence of the terms "learning systems" and "learning algorithms" also indicates a focus on AI-based learning systems, which allow customization of learning materials based on students' needs and learning pace.

Furthermore, words such as "engineering education" and "medical education" indicate the link between biology education, engineering education, and medical education. This is relevant because AI is used in medical simulation and molecular biology training, which are important for practical understanding in biology and health sciences. Words such as "teaching" and "curricula" indicate a focus on AI-based teaching methods and curriculum development for biology education, including the use of technologies such as augmented reality (AR) and virtual reality (VR) to visualize difficult biological concepts. In addition, the presence of terms such as "genomics", "proteomics", and "systems biology" indicates that research in this field encompasses a multidisciplinary approach, where AI is used to analyze and understand various aspects of complex modern biology.

Overall, this word cloud reveals that AI plays an important role in biology education, with a strong emphasis on learning technologies such as machine learning and deep learning to support more effective and personalized teaching processes. Topics such as bioinformatics, computational biology, and molecular biology are frequently discussed, suggesting that AI plays a major role in helping analyze complex biological data (Zhang et al., 2022). This research reveals that the integration of AI in biology education can accelerate the evaluation process and provide more accurate feedback, enhancing students' profound understanding of biological concepts. In addition, the presence of education-related words such as students, education, and teaching shows that this research is oriented towards improving the quality of biology learning. This pattern shows that a multidisciplinary approach combining technology, biology, and education is necessary to create new and useful AI-based biology learning methods.

D. Conclusion

The results of this study show that AI has an important role in improving the quality of biology education, especially in assisting the understanding of complex biological concepts through technologies such as machine learning, deep learning, and interactive simulations. Bibliometric analysis revealed that the number of publications related to AI and biology education has increased significantly, with the highest peak in 2023. The United States and China are the main contributors, reflecting the high global interest in this topic. The most published document types are scientific articles and conference papers, signaling researchers' focus on developing new knowledge and discussing innovative ideas. In addition, Lecture Notes in Computer Science was the most relevant source, highlighting the importance of computer science foundations in the application of AI to biology education. Overall, this study shows that a multidisciplinary approach between computer science, education, and biology is essential for creating innovative and effective AI-based biology learning methods. It is suggested that more research be done on how AI can be used in biology curriculum development and simulation-based learning, as well as how it affects how well students learn at different grade levels. Future research should focus on: (1) the incorporation of AI in the development of biology curricula to foster a more adaptive and interactive learning environment, (2) the efficacy of AI-driven simulations across various educational levels to evaluate their potential in enhancing comprehension of biological concepts, and (3) the influence of adaptive learning on student

performance, which will aid in assessing how AI can customize educational materials to meet individual learning requirements and capabilities. Subsequent research in this domain is anticipated to yield more robust empirical evidence about the relevance and efficacy of AI in biology education, while also contributing significantly to the advancement of creative, technology-driven biology pedagogy.

E. References

Abdullah, K. H. (2022). Publication trends in biology education: A bibliometric review of 63 Years. *Journal of Turkish Science Education*, *19*(2), 465–480. DOI: https://doi.org/10.36681/tused.2022.131

Adelana, O. P., Ayanwale, M. A., & Sanusi, I. T. (2024). Exploring pre-service biology teachers' intention to teach genetics using an AI intelligent tutoring - based system. *Cogent Education*, *11*(1). DOI: https://doi.org/10.1080/2331186X.2024.2310976

Adiguzel, T., Kaya, M. H., & Cansu, F. K. (2023). Revolutionizing education with AI: Exploring the transformative potential of ChatGPT. *Contemporary Educational Technology*, *15*(3), ep429. DOI: https://doi.org/10.30935/cedtech/13152

Ajibade, S. S. M., Zaidi, A., Bekun, F. V., Adediran, A. O., & Bassey, M. A. (2023). A research landscape bibliometric analysis on climate change for last decades: Evidence from applications of machine learning. *Heliyon*, *9*(10), e20297. DOI: https://doi.org/10.1016/j.heliyon.2023.e20297

Alberto, M. C. L., Viviana, B. V. C., Vladimir, B. E. C., & Fernanda, P. A. P. (2024). Innovative strategies to strengthen teaching-researching skills in chemistry and biology education: a systematic literature review. *Frontiers in Education*, *9*(July), 1–19. DOI: https://doi.org/10.3389/feduc.2024.1363132

Amini, L., Chen, C. H., Cox, D., Oliva, A., & Torralba, A. (2020). Experiences and insights for collaborative industry-academic research in artificial intelligence. *AI Magazine*, *41*(1), 70–81. DOI: https://doi.org/10.1609/aimag.v41i1.5201

Broughel, J., & Thierer, A. D. (2019). *Technological innovation and economic growth: A brief report on the evidence.* Virginia: Mercatus Center at George Mason University. DOI: https://doi.org/10.2139/ssrn.3347294

Ching, T., Himmelstein, D. S., Beaulieu-Jones, B. K., Kalinin, A. A., Do, B. T., Way, G. P., Ferrero, E., Agapow, P. M., Zietz, M., Hoffman, M. M., Xie, W., Rosen, G. L., Lengerich, B. J., Israeli, J., Lanchantin, J., Woloszynek, S., Carpenter, A. E., Shrikumar, A., Xu, J., … Greene, C. S. (2018). Opportunities and obstacles for deep learning in biology and medicine. *Journal of the Royal Society Interface*, *15*(141), 20170387. DOI: https://doi.org/10.1098/rsif.2017.0387

Danielson, D. T., Student, M., Wendzel, N. C., Pathologist, S., Knollmann-ritschel, B., & Muir, J. M. (2022). Rules of engagement: Promoting academic-industry partnership in the era of digital pathology and artificial intelligence. *Academic Pathology*, *9*(July), 1–8. DOI: https://doi.org/10.1016/j.acpath.2022.100026

Flores-Vivar, J. M., & García-Peñalvo, F. J. (2023). Reflections on the ethics, potential, and challenges of artificial intelligence in the framework of quality education (SDG4). *Comunicar*, *30*(74), 35–44. DOI: https://doi.org/10.3916/C74-2023-03

Freshwater, D., Sherwood, G., & Drury, V. (2006). International research collaboration: Issues, benefits and challenges of the global network. *Journal of Research in Nursing*, *11*(4), 295–303. DOI: https://doi.org/10.1177/1744987106066304

Hogan, D., & O'flaherty, J. (2021). Addressing education for sustainable development in the teaching of science: the case of a biological sciences teacher education program. *Sustainability (Switzerland)*, *13*(21), 12028. DOI: https://doi.org/10.3390/su132112028

Huang, J., Saleh, S., & Liu, Y. (2021). A review on artificial intelligence in education. *Academic Journal of Interdisciplinary Studies*, *10*(3), 206–217. DOI: https://doi.org/10.36941/AJIS-2021-0077

Jacob, M., & Meek, V. L. (2013). Scientific mobility and international research networks: Trends and policy tools for promoting research excellence and capacity building. *Studies in Higher Education*, *38*(3), 331–344. DOI: https://doi.org/10.1080/03075079.2013.773789

Karamchand, G. K. (2024). Artificial intelligence: Insights into a transformative technology. *Journal of Computing and Information Technology*, *3*(1), 131–137. Retrieved from https://universe-publisher.com/index.php/jcit/article/view/74

Koć-Januchta, M. M., Schönborn, K. J., Roehrig, C., Chaudhri, V. K., Tibell, L. A. E., & Heller, H. C. (2022). "Connecting concepts helps put main ideas together": cognitive load and usability in learning biology with an AI-enriched textbook. *International Journal of Educational Technology in Higher Education*, *19*(1), 11. DOI: https://doi.org/10.1186/s41239-021-00317-3

Kohus, Z., Demeter, M., Szigeti, G. P., Kun, L., Lukács, E., & Czakó, K. (2022). The influence of international collaboration on the scientific impact in V4 Countries. *Publications*, *10*(4), 35. DOI: https://doi.org/10.3390/publications10040035

Kumandaş, B., Ateskan, A., & Lane, J. (2019). Misconceptions in biology: A meta-synthesis study of research, 2000–2014. *Journal of Biological Education*, *53*(4), 350–364. DOI: https://doi.org/10.1080/00219266.2018.1490798

Li, J., Ouyang, J., Liu, J., Zhang, F., Wang, Z., Guo, X., Liu, M., & Taylor, D. (2023). Artificial Intelligence-based online platform assists blood cell morphology learning: A mixed-methods sequential explanatory designed research. *Medical Teacher*, *45*(6), 596–

603. DOI: https://doi.org/10.1080/0142159X.2023.2190483

Liu, Y., Cheng, X., Han, X., Cheng, X., Jiang, S., Lin, Y., Zhang, Z., Lu, L., Qu, B., Chen, Y., & Zhang, X. (2022). Global research landscape and trends of lung cancer immunotherapy: A bibliometric analysis. *Frontiers in Immunology*, *13*(December), 1–24. DOI: https://doi.org/10.3389/fimmu.2022.1032747

Lyon, P., Keijzer, F., Arendt, D., & Levin, M. (2021). Reframing cognition: Getting down to biological basics. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *376*(1820), 20190750. DOI: https://doi.org/10.1098/rstb.2019.0750

Machová, M., & Ehler, E. (2023). Secondary school students' misconceptions in genetics: Origins and solutions. *Journal of Biological Education*, *57*(3), 633–646. DOI: https://doi.org/10.1080/00219266.2021.1933136

Miao, F., Holmes, W., Huang, R., & Zhang, H. (2021). *AI and education: A guidance for policymakers*. Unesco Publishing. DOI: https://doi.org/ DOI: https://doi.org/10.54675/PCSP7350

Natu, S., & Aparicio, M. (2022). Unveiling the dynamics of AI applications: A review of reviews using scientometrics and BERTopic modeling. *Journal of Innovation & Knowledge*, *7*(4), 100248. DOI: https://doi.org/10.1016/j.jik.2022.100248

Rane, N. L., Choudhary, S. P., & Rane, J. (2024). Education 4.0 and 5.0: Integrating artificial intelligence (AI) for personalized and adaptive learning. *Journal of Artificial Intelligence and Robotics*, *1*(1), 29–43. DOI: https://dx.doi.org/10.2139/ssrn.4638365

Rasheed, A. A., Okebukola, P. A., Assistants, E., Agbanimu, D., Onowugbeda, F., Gbeleyi, O., Peter, E., & Adam, U. (2025). *Role of AI in enhancing teaching/learning, research and community service in higher education foreword by Cynthia Jackson-Hammond*. Sterling Publisher.

Selvam, A. A. A. (2024). Exploring the impact of artificial intelligence on transforming physics, chemistry, and biology education. *The Cuvette*, *2*(2), 1–31. DOI: https://doi.org/10.21428/a70c814c.747297aa

Tariq, R., Casillas-Muñoz, F. A., Hassan, S. T., & Ramírez-Montoya, M. S. (2024). Synergy of internet of things and education: Cyber-physical systems contributing towards remote laboratories, improved learning, and school management. *Journal of Social Studies Education Research*, *15*(2 Special issue), 305–352. Retrieved from http://jsser.org/index.php/jsser/article/view/5358

Yan, L., & Zhiping, W. (2023). Mapping the literature on academic publishing: A bibliometric analysis on WOS. *SAGE Open*, *13*(1), 1–16. DOI: https://doi.org/10.1177/21582440231158562

Zhang, Y., Luo, M., Wu, P., Wu, S., Lee, T. Y., & Bai, C. (2022). Application of computational biology and artificial intelligence in drug design. *International Journal of Molecular Sciences*, *23*(21), 13568. DOI: https://doi.org/10.3390/ijms232113568