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Trends in the Use of Artificial Intelligence in Science Education: Bibliometric & Biblioshiny Analysis (1975-2024)

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Abstract: This research was conducted to look at research trends in the Scopus database regarding the study of Artificial Intelligence in Science Education. Using the PRISMA method, researchers selected and determined 146 documents that were ready to be analyzed using bibliometric and biblioshiny methods with the help of the R program and Vosviewer. From the results of the analysis carried out, it was concluded that research on Artificial Intelligence in Science Education in the Scopus Database started from 1975 to 2024, with an 8-fold increase in the number of publications, and 13 times the number of citations in the last 7 years. China was the country with the highest contribution to this research, showing 17(11.64%) publications and 418(13.65%) citations. "BMC Medical Education" is the most productive source with an h-index of 4. Jose Carpio Cañada from Universidad de Huelva in Spain is the most productive author with an h-index of 2. Y. K. Dwivedi et al., (2021) with 1159(37.85%) citations is the source with highest citation. There are 58 keywords divided into 9 clusters, with the keywords "Digital Technologies", "ChatGPT", and "Systems Thinking" being the main recommendations in the field of artificial intelligence in science education.

Keywords: Artificial intelligence; Bibliometric; Biblioshiny; Science education

Introduction

Education is a fundamental pillar in ensuring sustainable survival (Alam, 2023; Martínez-Peláez et al., 2023; Ramadhani et al., 2024). Educational design is specifically prepared to support the interests of the earth and all the creatures that inhabit it (Mayola et al., 2023). Through education, individuals are empowered with the fundamental knowledge, skills and understanding to understand complex environmental challenges, and to develop innovative solutions (Dwivedi et al., 2024; Ramírez-Montoya et al., 2024; Zafrullah, Fitriani, et al., 2023). The existence of a strong education system not only provides benefits for individuals, but also plays an important role in maintaining the sustainability of the ecosystem and building a more inclusive and sustainable society as a whole (Aziz et al., 2023; Raza et al., 2023). By strengthening access to quality education, we boost the ability of individuals to contribute positively to their environment, creating meaningful change for the planet's future. One important part of education is the existence of schools.

School is an essential place in shaping one's character and knowledge (Hermino et al., 2020; Zafrullah et al., 2024). As a formal educational institution, school not only functions as a means of transferring knowledge, but also as a place to develop students' social, emotional and moral skills (Feraco et al., 2023). Through interactions with teachers and peers, students learn to work together, appreciate differences, and understand values that are important in social life (Lansford, 2022; Van den Beemt et al., 2020; Zafrullah, Ibrahim, et al., 2024). Schools are also an integral part of everyday life, providing routines and structures that help shape discipline and responsibility. Schools are important because they are where the younger generation is prepared to face future challenges and contribute positively to the progress of the nation (Iivari et al., 2020; Tejedor et al., 2020; Zafrullah et al., 2021). With all their roles, schools not only educate

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academically, but also shape individuals who are characterized and ready to face the dynamics of life. One part of the school that is very important is classroom learning.

Classroom learning is a key component in the formal education system, where the process of transferring knowledge and skills takes place in a structured and systematic manner (Bizami et al., 2023; González-Pérez et al., 2022; Zafrullah, Sultan, et al., 2024). Classroom learning is essential as it provides a conducive environment for students to receive subject matter directly from competent teachers, as well as allowing for in-depth interaction and discussion on various topics (Kahveci, 2023; Rasmitadila et al., 2023). In the classroom, students can ask questions, get clarification and receive immediate feedback, making the learning process more effective and efficient. Classroom learning is highly prioritized because of the teacher's role as a facilitator and motivator in guiding students through a curriculum that has been designed to achieve specific educational goals (Hughes, 2024; Rajib et al., 2024; Zafrullah, Zetriuslita, et al., 2024). In addition, the classroom learning experience also trains students to be disciplined, respect time, and cooperate with others, which are important skills in everyday life. Therefore, although technology and alternative learning methods are constantly evolving, classroom learning remains the main foundation in education that is irreplaceable. The learning that exists and must be learned in the classroom is science learning.

Science learning is learning that becomes the main foundation in education, because natural science includes various concepts and principles that underlie our understanding of the world (Hartono et al., 2022; P. Kumar et al., 2023; Mellyzar et al., 2022). Science learning covers many things in everyday life, ranging from natural phenomena, health, technology, to the environment (Lang, 2021; Maulidah et al., 2021; Ramadhanti et al., 2021; Yulihapsari et al., 2023). Its existence is very important because the sciences taught in science subjects, such as biology, chemistry, and physics, provide a deep understanding of how the universe works and the various processes that occur in it (Alika et al., 2021; Rengkuan et al., 2022; Sultan et al., 2023). Through science learning, students learn to think critically, solve problems, and make decisions based on scientific data and evidence. In addition, science learning also teaches practical skills, such as conducting experiments, collecting data, and analyzing results, which are very useful in various aspects of life (Albay et al., 2021; Doyan et al., 2020; Nurwahidah et al., 2022). Thus, science learning not only enriches students' academic horizons, but also prepares them to face real challenges in an increasingly complex and science-based world. Learning in science education can be utilized by using many things, one of which is by using artificial intelligence.

Artificial intelligence is a technological innovation that is growing and has great potential in various fields, including education (Hakim et al., 2023; Zhang et al., 2021). Artificial intelligence can be utilized in all kinds of education, including science education. In the context of science education, artificial intelligence is helpful by providing tools and platforms that enable more interactive and personalized learning. Through AI technology, students can enjoy scientific simulations, virtual experiments, and concept explanations tailored to their level of understanding (Kim et al., 2022; Zafrullah, Suyanto, et al., 2023). In addition, artificial intelligence can also assist teachers in designing a more effective curriculum, analyzing student progress, and providing quick and precise feedback (Hakim et al., 2023; Hooda et al., 2022; Yufeia et al., 2020). Thus, artificial intelligence not only improves the efficiency of the learning process, but also enriches students' learning experience, making science education more interesting and accessible.

The use of artificial intelligence in science education has sparked the interest of researchers to conduct further research in this field. In response to this trend, the authors were interested in conducting a bibliometric analysis that aims to identify developments, trends and research focuses related to the use of artificial intelligence in the context of science education. A bibliometric analysis can provide valuable insights into how much research has been conducted in this domain, who is involved, and the main themes or topics that are the focus of research. With a deeper understanding of the status and dynamics of research, the authors can make a more significant contribution in developing knowledge and applications of artificial intelligence in improving the effectiveness of science learning.

Method

This research is a quantitative study that describes research trends regarding artificial intelligence in the field of science education using bibliometric analysis. Bibliometric analysis is a method used to measure and analyze various aspects of scientific publications, such as the number of publications, citation patterns, and collaboration between authors, with the aim of understanding the development and direction of research in a particular field (M. Kumar et al., 2023; Pessin et al., 2022; Ülker et al., 2023; Ulwiyah, 2023; Zafrullah, Bakti, et al., 2023). Through this approach, trends and dynamics in research on artificial intelligence in science education can be identified, providing deep insight into the most researched topics, the influence of specific researchers, as well as the relationships between

various concepts and theories developing in the scientific literature. Before carrying out the analysis, researchers selected documents using the PRISMA method to obtain the number of documents analyzed.

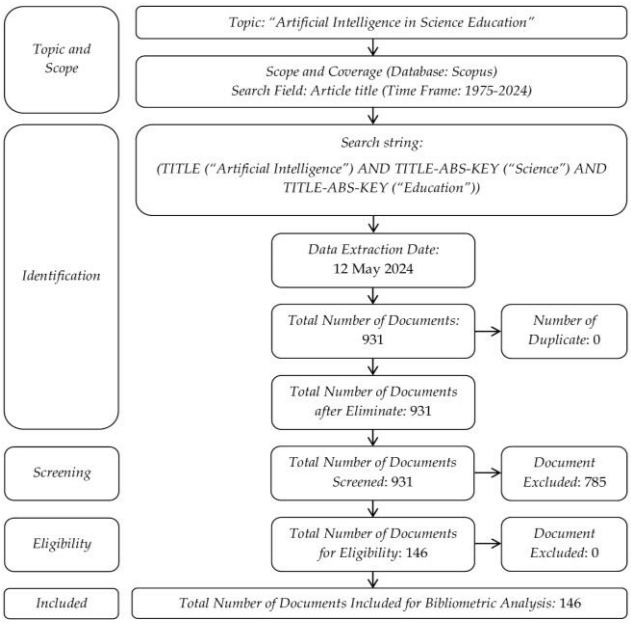

Figure 1. PRISMA method for document selection

By determining topics and keywords, 931 documents were obtained at the identification stage. At the screening stage, the author limited only "Articles" and the topic "Social Sciences", so that 785 documents were excluded and left 146 documents that survived until the Included stage. After getting the number of articles, the author then analyzed them using the R Program and Vosviewer applications in order to interpret the results of the bibliometric analysis.

Result and Discussion

Researchers interpret the results of the analysis, namely main information, publication and citation trends, most productive and collaboration between countries, most productive affiliations, the most productive source, most productive authors, document with the higher citations, focus research, and keywords novelty.

Main Information

The main information includes several important points which are analyzed using biblioshiny, namely research time, number of authors, number of sources, annual growth rate, and others.

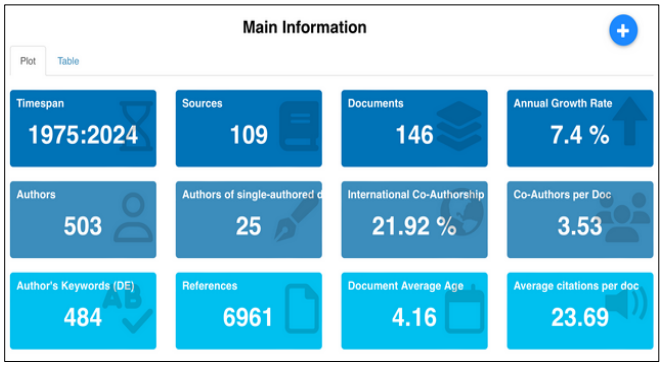

Figure 2. Main information

This research covers the period from 1975 to 2024, with a total of 146 documents taken from 109 of the world's leading Scopus sources. A total of 503 authors were involved in this research, with 25(4.97%) acting as sole authors. Collaboration with international authors reached 21.92%, indicating significant interest from overseas authors to participate in this research.

Publication and Citation Trends

Researchers interpret publication trends and citation trends from year to year using the R Program to see the dynamics and patterns that develop in the field of Artificial Intelligence in the field of Science Education.

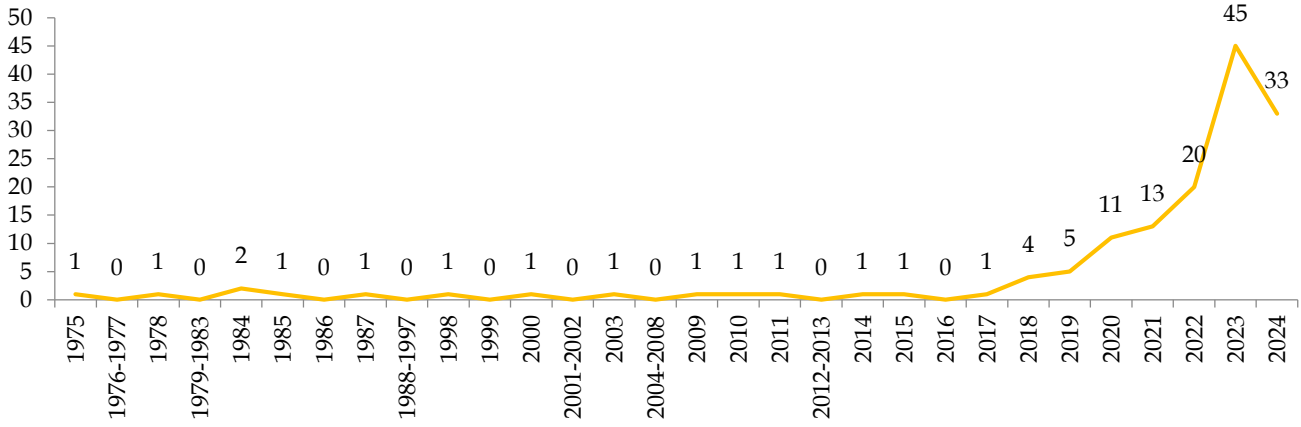

Figure 3. Publication trends from 1975 to 2024 about artificial intelligence research in science education

This research began in 1975 to 2024, with there being a fairly long period where no publications were published on this topic, namely from 1988 to 1997. In the period from 1975 to 2017, the number of publications was only 15(10.27%). This number increased significantly in the period 2018 to 2024, with a total of 131(89.73%) publications, an eight-fold increase.

This increase is due to a variety of factors, including rapid technological advances and increasing interest in artificial intelligence in science education. Apart from that, the increasing availability of research funding and international collaboration has also contributed to an increase in the number of publications. Greater attention from the scientific community and governments to the importance of innovation in science education through artificial intelligence technologies has also played an important role in driving the growth of research in this area.

Table 1. Citation Trends from 1975 to 2024 on the Topic of Artificial Intelligence in Science Education

Years	Total of Publication	Total of Citation	Number of Citation*	h-index
1975	1(0.68%)	21(0.61%)	1(0.91%)	1
1976-1977	-	-	-	-
1978	1(0.68%)	41(1.20%)	1(0.91%)	1
1979-1983	-	-	-	-
1984	2(1.36%)	17(0.5%)	2(1.83%)	2
1985	1(0.68%)	17(0.5%)	1(0.91%)	1
1986	-	-	-	-
1987	1(0.68%)	11(0.32%)	1(0.91%)	1
1988-1997	-	-	-	-
1998	1(0.68%)	17(0.5%)	1(0.91%)	1
1999	-	-	-	-
2000	1(0.68%)	7(0.2%)	1(0.91%)	1
2001-2002	-	-	-	-
2003	1(0.68%)	1(0.03%)	1(0.91%)	1
2004-2008	-	-	-	-
2009	1(0.68%)	36(1.08%)	1(0.91%)	1
2010	1(0.68%)	28(0.84%)	1(0.91%)	1
2011	1(0.68%)	5(0.15%)	1(0.91%)	1
2012-2013	-	-	-	-
2014	1(0.68%)	1(0.03%)	1(0.91%)	1
2015	1(0.68%)	29(0.87%)	1(0.91%)	1
2016	-	-	-	-
2017	1(0.68%)	-	-	-
2018	4(2.73%)	243(7.30%)	4(3.66%)	4
2019	5(3.42%)	400(12.02%)	4(3.66%)	4
2020	11(7.53%)	326(9.79%)	10(9.17%)	8
2021	13(8.90%)	1277(38.38%)	12(11%)	6
2022	20(13.69%)	424(12.74%)	20(18.34%)	9
2023	45(30.82%)	528(15.87%)	37(33.94%)	11
2024	33(22.60%)	30(0.90%)	8(7.33%)	3

* : Obtained from the number of documents cited from that year

Research on artificial intelligence in science education shows a trend of relatively few publications with some years with no citations at all, such as from 1988 to 1997. As of 2017, there were only a total of 231(6.67%) citations. However, starting in 2018, there was a significant spike in the number of citations, with the number 3228(93.32%), or a 13-fold increase in the number of citations. The year 2021 also stands out with a very high number of citations, namely 1277(38.38%) citations, showing the significant impact of the research published in that year.

Overall, the entire period of years contributed to the understanding and development of research in this area, although to varying degrees. The early years helped lay the foundation for later research, although with minimal contributions in terms of number of publications and citations. The period after 2018 saw a significant increase, not only in the number of publications but also in impact measured through citations. This reflects rapid technological developments, increasing attention to artificial intelligence in science education, and increased collaboration and research support. Recent years, especially 2023 and 2024, confirm this growth trend with the number of publications and citations continuing to increase, indicating growing interest and investment in this field.

Most Productive and Collaboration Between Countries

The author interprets the contribution of countries in conducting research on the use of artificial intelligence in science education in Table 2 and see collaboration between countries on Figure 4.

Table 2. The Top 10 Countries with the Highest Publications 9 (Source: R Program)

Rank	Country	Continent	Total of Publications	Percentage	Total of Citations	Percentage
1st	China	Asia	17	11.64%	418	13.65%
2nd	United States	North America	17	11.64%	345	11.27%
3rd	Australia	Australia	10	6.85%	238	7.77%
4th	Spain	Europe	8	5.48%	168	5.49%
5th	United Kingdom	Europe	6	4.11%	1223	39.94%
6th	Turkey	Asia	5	3.42%	40	1.31%
7th	Brazil	South America	3	2.05%	15	0.49%
8th	Canada	North America	3	2.05%	143	4.67%
9th	Germany	Europe	3	2.05%	28	0.91%
10th	India	Asia	3	2.05%	113	3.69%

China and the United States are the two countries with the highest contributions to this research, ranking first and second respectively. China, as the largest country in Asia, shows significant figures with 17(11.64%) publications and 418(13.65%) citations. The United States, which is a global research power, recorded a comparable number of publications and citations, namely 17(11.64%) publications and 345(11.27%) citations. Their contributions highlight the important role of Asia and North America in artificial intelligence research in science education.

In addition, representatives from all continents also contributed to this research. Australia, as a representative of Oceania, is ranked third with 10(6.85%) publications and 238(7.77%) citations, while Spain as a European country is ranked fourth with 8(5.48%) publications and 168(5.49%) citations. On the other hand, Turkey, Brazil, Canada, Germany and India also made significant contributions to this research. This shows that artificial intelligence research in science education is a topic that is attracting attention from many parts of the world, with collaboration across continents resulting in broader and deeper understanding in this field.

Figure 4. International collaboration (at least 2 papers) between countries in the field of artificial intelligence in science education

With the appearance of two papers, 19 countries collaborated with each other and the United States had the largest circle compared to other countries. So the United States has the highest cooperation regarding cooperation with other countries in Figure 4. This shows that in this research, countries from various parts of the world synergized and collaborated widely, creating an inclusive and mutually supportive environment for progress in the field of science education using artificial intelligence.

Most Productive Affiliations

The author carried out an analysis by looking at the ten most productive affiliations and collaborations between authors with the aim of understanding the dynamics and patterns of collaboration in research on artificial intelligence in the field of science education. This analysis helps identify the institutions that are most active and influential in producing publications, and reveals how researchers from various affiliations collaborate on research projects.

Geisel School of Medicine at Dartmouth in Hanover, United States, took the top spot with 12(8.21%) articles published, demonstrating significant contributions to research on artificial intelligence in the field of science education. McGill University in Montreal, Canada, and the University of Calabar in Nigeria each followed with 10(6.84%) articles. Swansea University in the United Kingdom also shows high productivity with 9(6.16%) articles. Curtin University in Perth, Australia, contributed 8(5.47%) articles, while King Faisal University in Al Ahsa, Saudi Arabia, and Stanford University in the United States each published 7(4.79%) articles. Universidad de Huelva in Spain and University of Brasília in Brazil also contributed with 7(4.79%) articles each, as well as Changchun University of Technology in China with 5(4.79%) articles.

Contributions from affiliates across continents demonstrate that research on artificial intelligence in science education is a global endeavor. From North America to Africa, Europe, Australia, Asia, and South America, every continent has significant representation in the list of most productive affiliates. This reflects the collaborative and universal nature of research in this field, where researchers from diverse geographic and cultural backgrounds come together to advance knowledge and innovation. This global participation also shows the potential to strengthen and expand international collaboration networks, which will further encourage the development and application of artificial intelligence in science education in various parts of the world.

Table 3. The Top 10 Affiliations with the Highest Publication in Scopus Database (Source: R Program)

Rank	Affiliation	City	Country	Continent	No. of Article
1st	Geisel School of Medicine at Dartmouth	Hanover	United States	North America	12(8.21%)
2nd	McGill University	Montreal	Canada	North America	10(6.84%)
3rd	University of Calabar	Calabar	Nigeria	Africa	10(6.84%)
4th	Swansea University	Swansea	United Kingdom	Europe	9(6.16%)
5th	Curtin University	Perth	Australia	Australia	8(5.47%)
6th	King Faisal University	Al Ahsa	Saudi Arabia	Asia	7(4.79%)
7th	Stanford University	Stanford	United States	North America	7(4.79%)
8th	Universidad de Huelva	Huelva	Spain	Europe	7(4.79%)
9th	University of Brasília	Brasília	Brazil	South America	7(4.79%)
10th	Changchun University of Technology	Changchun	China	Asia	5(4.79%)

Figure 5. Analysis of collaboration between affiliates on artificial intelligence research in science education using biblioshiny

The existence of several of these groups indicates strong regional and international collaboration between various institutions, with University College London being the main center of this network. This indicates that University College London has a central role in research on artificial intelligence in the field of science education, not only through significant publication contributions but also as a main hub in a global collaboration network. The existence of these various collaborative groups reflects the close relationship between institutions in various parts of the world, which together encourage the development and application of artificial intelligence technology in science education through productive and innovative collaboration.

The Most Productive Source

Next, the author carries out an analysis by focusing on the most productive sources in the field of artificial intelligence in the context of science education, using the h-index as the main parameter. This step was carried out with the aim of identifying the main contributors in the field and understanding the impact and relevance of their work on the development of science education through the application of artificial intelligence.

Based on an analysis of journals that focus on artificial intelligence in science education, it can be seen that the highest h-index belongs to "BMC Medical Education" and "Computers and Education: Artificial Intelligence," each with an h-index value of 4. "BMC Medical Education," published by BioMed Central Ltd of the United Kingdom, recorded a total of 229(7.47%) citations with 4(2.73%) publications, indicating significant influence in this field. On the other hand, "Computers and Education: Artificial Intelligence" published by Elsevier B.V. from the Netherlands, has 310(10.12%) citations with 5(3.42%) publications, confirming the importance of this journal in supporting research and development of artificial intelligence in science education.

United Kingdom dominates this journal list with several prominent publications such as "BMC Medical Education" and "Computers and Education," as well as "British Journal of Educational Technology," which is also included in the first quartile (Q1) with an h-index of 3, total citations 64(2.09%), and 3(2.05%) publications. This dominance shows that institutions in the United Kingdom play an important role in advancing research in the field of artificial intelligence in education. However, contributions from other journals spread across various countries such as the Netherlands, Ireland, Russian Federation, Switzerland, Austria and Singapore are also no less important. All of these journals, whether in the first, second or third quartiles, make significant contributions to the dissemination of knowledge and development of artificial intelligence technology in science education.

Table 4. The Top 10 Productive Sources about Artificial Intelligence in Science Education with the Higher h-Index

Rank	Journal	SQ[a]	Publishing[a]	Country[a]	h[b]	TC[c]	NP[d]
1st	BMC Medical Education	Q1	BioMed Central Ltd	United Kingdom	4	229(7.47%)	4(2.73%)
2nd	Computers and Education: Artificial Intelligence	Q1	Elsevier B.V.	Netherlands	4	310(10.12%)	5(3.42%)
3rd	British Journal of Educational Technology	Q1	Wiley-Blackwell Publishing Ltd	United Kingdom	3	64(2.09%)	3(2.05%)
4th	International Journal of Engineering Education	Q3	Tempus Publications	Ireland	3	31(1.01%)	4(2.73%)
5th	Vysshee Obrazovanie v Rossii	Q3	Moscow Polytechnic University	Russian Federation	3	19(0.62%)	3(2.05%)
6th	Artificial Intelligence	Q1	Elsevier B.V.	Netherlands	2	62(2.02%)	2(1.36%)
7th	Computers and Education	Q1	Elsevier B.V.	United Kingdom	2	70(2.28%)	2(1.36%)
8th	Education Sciences	Q2	Multidisciplinary Digital Publishing Institute (MDPI)	Switzerland	2	141(4.60%)	4(2.73%)
9th	International Journal of Emerging Technologies in Learning	Q2	International Association of Online Engineering	Austria	2	23(0.75%)	2(1.36%)
10th	International Journal of Information and Education Technology	Q3	International Journal of Information and Education Technology	Singapore	2	49(1.60%)	2(1.36%)

a = Scopus Quartile, data accessed from 14 May 2024 at www.scimagojr.com; b = h-index at Scopus Database; c = Total of Citation, data accessed by R Program; d = Total of Publication, data accessed by R Program.

Most Productive Authors

Researchers also analyzed by looking at the most productive authors in the field of artificial intelligence in science education. It aims to identify individuals who have made a major and influential contribution to the development and application of artificial intelligence in this field. By knowing the most productive authors, researchers can understand research trends, introduced innovations, and gain insight into the direction and potential for further developments in the use of artificial intelligence to improve science education.

Table 5. The Top 10 Productive Authors about Artificial Intelligence in Science Education with the Highest h-Index

Rank	Authors	Affiliation	Country	h[a]	TC[b]	NP[c]
1st	Jose Carpio Cañada	Universidad de Huelva	Spain	2	34(1.11%)	2(1.36%)
2nd	Grant Cooper	Curtin University	Australia	2	191(6.23%)	3(2.05%)
3rd	Kadir Demir	Dokuz Eylül University	Turkey	2	39(1.27%)	2(1.36%)
4th	Xiaodong Huang	Capital Normal University	Taiwan	2	13(0.42%	2(1.36%)
5th	Gwo-Jen Hwang	National Taiwan University of Science and Technology	Taiwan	2	265(8.65%)	2(1.36%)
6th	Xin Liu	Chinese Academy of Sciences	Taiwan	2	16(0.52%)	2(1.36%)
7th	Tomás de J. Mateo Sanguino	Universidad de Huelva	Spain	2	34(1.11%)	2(1.36%)
8th	Yun-Fang Tu	Fu Jen Catholic University	Taiwan	2	36(1.17%)	2(1.36%)
9th	Gert Aarts	Swansea University	United Kingdom	1	1159(37.85%)	1(0.68%)
10th	Celina Aparecida Almeida Pereira Abar	Pontifícia Universidade Católica de São Paulo	Brazil	1	3(0.09%)	1(0.68%)

a = h-index at Scopus Database; b = Total of Citation, data accessed by R Program; c = Total of Publication, data accessed by R Program.

Based on the analysis of the most productive authors in the field of artificial intelligence in science education, it can be seen that the highest h-index is owned by a number of authors with an h-index value of 2. These authors include Jose Carpio Cañada from the Universidad de Huelva in Spain, Grant Cooper from Curtin University in Australia, and Kadir Demir from Dokuz Eylül University in Turkey. Grant Cooper stands out with 191(6.23%) citations and 3(2.05%), demonstrating the significant impact of his work in this field. Other authors such as Gwo-Jen Hwang of the National Taiwan University of Science and Technology in Taiwan, who also has 2(1.36%) publications, achieved the highest total citations among them with 265(8.65%), indicating substantial contributions to research and development artificial intelligence in science education.

Taiwan dominates this list with four authors contributing significantly. Apart from Gwo-Jen Hwang, there are Xiaodong Huang from Capital Normal University, Xin Liu from the Chinese Academy of Sciences, and Yun-Fang Tu from Fu Jen Catholic University. Taiwan's dominance shows that the country has a strong and supportive research environment in the field of artificial intelligence in science education. Although authors from other countries such as Spain, Australia, Turkey, the United Kingdom, and Brazil also contributed, the collective contribution of all these authors enriches the understanding and development of artificial intelligence applications in science education. Thus, although there are differences in the number of publications and total citations, each author plays an important role in expanding knowledge and innovation in this field.

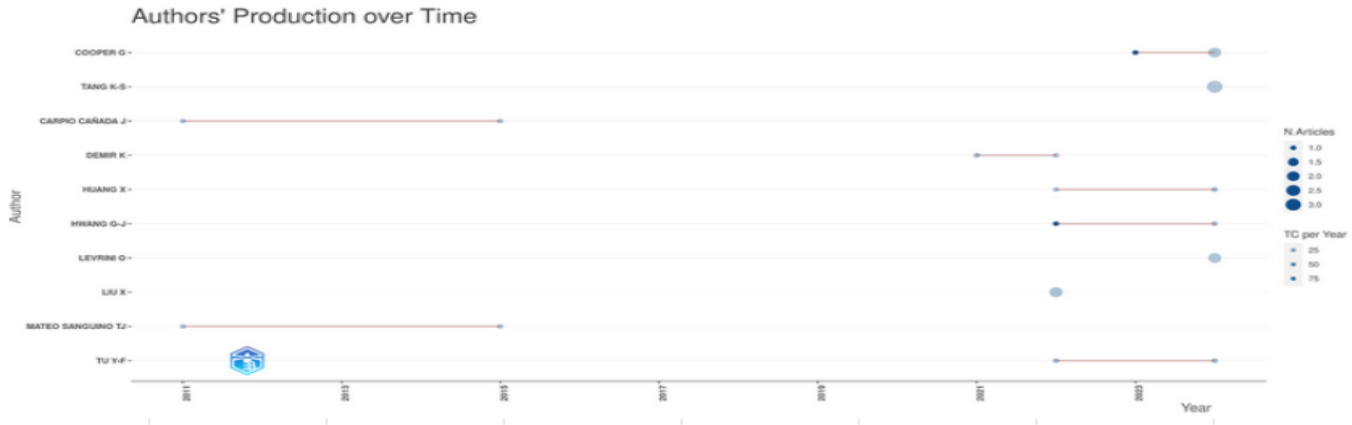

Figure 6. The author's production over time, analysis using biblioshiny

In contrast to Table 5, Figure 6 shows the overall number of publications without looking at the h-index. Jose Carpio Cañada, for example, had two articles published in 2011 and 2015 respectively, with total citations of 5 and 29. This shows that although his productivity is not high in the number of articles, the impact of the articles published in 2015 is quite significant. Grant Cooper from Curtin University shows striking progress, with one article in 2023 which received 189 citations, and two articles in 2024 which only received a total of 2 citations, indicating that the latest articles may still need time to be recognized and accumulate citations.

Other authors such as Kadir Demir, Xiaodong Huang, and Gwo-Jen Hwang also made significant contributions. Kadir Demir has two articles with fairly even total citations in 2021 and 2022, namely 33 and 6. Xiaodong Huang, with his two articles in 2022 and 2024, collected total citations of 2 and 11, indicating an increase in recognition for his work. Gwo-Jen Hwang, a writer from the National Taiwan University of Science and Technology, recorded an unusually high number of citations with 256 for the 2022 article, and an additional 9 citations for the 2024 article. This shows that Hwang's research is widely recognized and has had an impact significant in the field of artificial intelligence in science education. Overall these data illustrate that author productivity is measured not only by the number of publications but also by the citation impact which shows how much their research contribution is recognized and used by the academic community.

Document with the Higher Citations

The author carried out an analysis by looking at the highest total citations for a document. It aims to identify the works that have had the greatest impact and most significant influence in the field of artificial intelligence on science education. This analysis also helps in evaluating the individual contributions of authors and determining future research directions that have the potential to have a major impact on technological developments and applications of artificial intelligence in science education.

Analysis of the highest total citations shows that the document with the greatest impact in the field of artificial intelligence on science education is the work of Dwivedi et al. (2021) with 1159(37.85%) citations. This research highlights the multidisciplinary challenges and opportunities emerging from the application of artificial intelligence, as well as relevant research, practice and policy agendas. The work of Hwang et al. (2022) is in second place with 256(8.36%) citations, highlighting the role and potential research issues of the metaverse in education from an artificial intelligence perspective. Meanwhile, Cooper's (2023) study exploring the use of generative artificial intelligence in science education received 191(6.23%) citations, indicating significant interest in artifial intelligence applications such as ChatGPT for science education.

Table 6. The Top 10 Documents with the Highest Citation about Artificial Intelligence in Science Education

Rank	Citation	Title	Total Citations	Citation Evolution in the last 5 years*				
				2020	2021	2022	2023	2024
1st	(Y. K. Dwivedi et al., 2021)	Artificial Intelligence (AI): Multidisciplinary perspectives on emerging challenges…	1159(37.85%)	55	174	253	395	290
2nd	(Hwang et al., 2022)	Definition, roles, and potential research issues of the metaverse in education:…	256(8.36%)	0	0	41	147	70
3rd	(Cooper, 2023)	Examining science education in ChatGPT: An exploratory study…	191(6.23%)	0	0	0	97	94
4th	(Wartman et al., 2018)	Medical education must move from the information age…	161(5.25%)	22	24	30	49	22
5th	(Hinojo-Lucena et al., 2019)	Artificial intelligence in higher education: A bibliometric study on …	126(4.11%)	17	16	25	43	19
6th	(Winkler-Schwartz et al., 2019)	Artificial intelligence in medical education: best practices using machine learning…	123(4.01%)	13	27	32	29	20
7th	(Han et al., 2019)	Medical education trends for future physicians in the era of advanced …	122(3.98%)	23	42	28	22	7
8th	(Sharma et al., 2020)	Artificial intelligence and effective governance: A review, critique and research agenda	113(3.69%)	6	15	31	35	26
9th	(Wong et al., 2020)	Broadening artificial intelligence education in K-12: Where to start?	77(2.51%)	1	11	22	24	19
10th	(Huang et al., 2023)	Effects of artificial Intelligence–Enabled personalized recommendations…	67(2.18%)	0	0	1	36	30

* : Source by (www.scopus.com), data accessed from 14 May 2024

All the documents analyzed make broad and varied contributions to the field of artificial intelligence in science education. Each work contributes new understanding, perspectives and innovations that support the development of more effective and efficient learning approaches. Some documents highlight the multidisciplinary challenges and opportunities of artificial intelligence as well as relevant research agendas, while others examine the application of artificial intelligence in the context of medical and science education. There is also research exploring the role of artificial intelligence technologies such as the metaverse and the use of generative artificial intelligence in enhancing the learning experience. Additionally, several works highlight best practices in integrating artificial intelligence in educational settings, such as machine learning-based surgical simulations and the implementation of personalized recommendations to improve student engagement and learning outcomes. Overall, the contributions of these documents provide a solid foundation for the development and application of artificial intelligence in science education, helping to enrich the scientific literature and supporting innovation in modern educational practices.

Focus Research and Keywords Novelty

The author conducted an analysis using VOSviewer to identify research focus and the novelty of keywords in the literature. The aim is to investigate emerging research patterns and trends in the field of artificial intelligence in science education. By analyzing new emerging clusters and keywords, researchers can understand the most relevant and innovative research directions, as well as identify areas that require further attention.

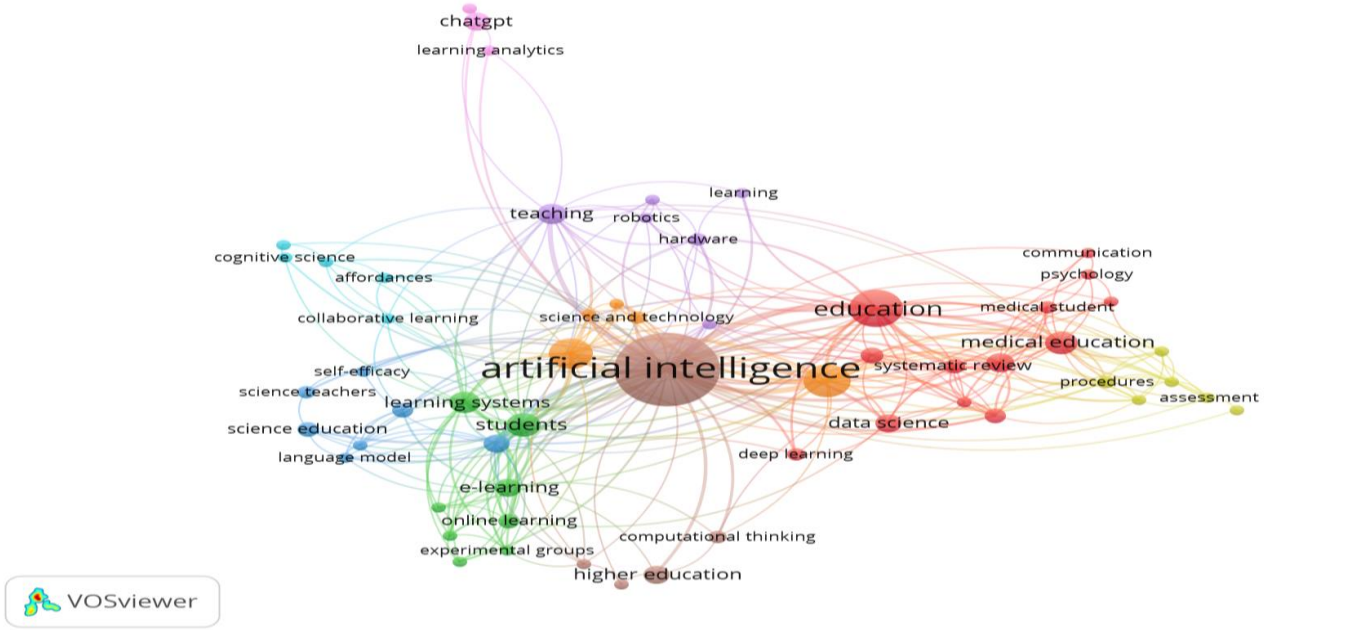

Figure 7. Focus Research (Keyword Occurance ≤ 2). Analysis with Vosviewer

By using Keyword Occurance ≤ 2, researchers get 58 keywords which are divided into 9 clusters. Furthermore, researchers gave the name of each cluster according to the grouping of existing keywords.

The red cluster titled "Enhancing Cognitive Development" highlights efforts in integrating advanced technologies in science education to enrich the learning process and develop students' cognitive abilities. Through deep learning approaches and the application of artificial intelligence, this cluster aims to improve students' understanding of science materials, facilitate collaborative learning, and integrate relevant curriculum with developments in information technology (Purwantara et al., 2023; Qin et al., 2023). By exploring the interaction between artificial intelligence and science education, this cluster makes a valuable contribution in strengthening the foundation for innovative educational approaches that are more adaptive and effective for students.

The green cluster entitled "Innovative Teaching Strategies" examines the application of artificial intelligence in science education to create more effective and engaging teaching methods. This cluster focuses on using AI-based learning systems to increase student motivation, optimize online learning, and improve classroom teaching techniques (Sayed et al., 2023; Shoaib et al., 2024). Research in this cluster also evaluates the effectiveness of experimental groups in secondary

education, which use artificial intelligence to improve student learning outcomes. As such, this cluster provides insights into how artificial intelligence can be used to design innovative and adaptive teaching strategies in science education.

Table 7. Keyword Grouping at Vosviewer

Rank	Color	Cluster Name	Keywords
1st	Red (13 items/22.41%)	Enhancing Cognitive Development	Communication, Cooperative Behaviour, Curriculum, Data Science, Deep Learning, Education, Integration, Medical Education, Medical Student, Physician, Psychology, Systematic Review, Technology
2nd	Green (8 items/13.79%)	Innovative Teaching Strategies	E-learning, Experimental Group, Improving Classroom Teaching, Learning Systems, Motivation, Online Learning, Secondary Education, Students
3rd	Blue (7 items/12.06%)	AI-Enhanced Teaching Tools	Computational Linguistic, Computer Aided Instruction, Education Computing, Language Models, Science Education, Science Teachers, Self-efficacy
4th	Yellow (6 items/10.34%)	AI-Driven Skill Evaluation	Assessment, Clinical Competence, Educational Measurement, Procedures, Systems Thinking, Virtual Reality
5th	Purple (6 items/10.34%)	Interactive Learning Technologies	Hardware, Inquiry-based Learning, Learning, Project-based Learning, Robotics, Teaching
6th	Light Blue (5 items/8.62%)	Smart Educational Robotics	Affordances, Cognitive Science, Collaborative Learning, Learning Science, Science Community
7th	Orange (5 items/8.62%)	Intelligent Learning Platforms	Decision Making, Engineering Education, Experts Systems, Machine Learning, Science and Technology
8th	Brown (5 items/8.62%)	Innovative Educational Technologies	Artificial Intelligence, Computational Thinking, Emerging Technologies, Higher Education, STEM Education
9th	Pink (3 items/5.17%)	Intelligent Learning Environments	ChatGPT, Digital Technologies, Learning Analytics

Source: Vosviewer, data accessed from 14 May 2024

The Blue Cluster entitled "AI-Enhanced Teaching Tools" examines the use of artificial intelligence in science education to enhance teaching tools and teacher capabilities. The focus of this research includes the application of computer-assisted language and instruction models to support science teachers in delivering material more effectively. In addition, this cluster explores how artificial intelligence can improve teachers' self-efficacy, helping them to feel more confident in using advanced technologies in teaching (Yang et al., 2024). As such, this research contributes to the development of more sophisticated and technology-based teaching methods in science education.

The Yellow Cluster entitled "AI-Driven Skill Evaluation" examines how artificial intelligence can be used to assess and improve competencies in science education. Research in this cluster focuses on using technologies such as virtual reality and thinking systems to measure students' clinical and procedural skills (Fromm et al., 2021). By integrating artificial intelligence in the assessment process, the cluster aims to provide a more objective, efficient and in-depth evaluation method, which in turn helps in developing students' scientific and practical competencies more effectively. This research contributes to the development of more sophisticated and targeted educational measurement tools in science.

The purple cluster entitled "Interactive Learning Technologies" explores the use of artificial intelligence to enhance interactive learning methods in science education. The focus of this cluster is on the application of robotics and smart hardware that support project- and inquiry-based learning, allowing students to engage more actively in the learning process (Jawaid et al., 2020). By integrating artificial intelligence, the cluster aims to create a dynamic and practical learning environment, where students can explore science concepts through hands-on and interactive experiences (Salinas-Navarro et al., 2024). This research contributes to creating more engaging and effective teaching strategies, capable of developing practical and problem-solving skills in students.

The Light Blue cluster entitled "Smart Educational Robotics" explores the application of artificial intelligence to enrich interactive learning methods in science education. The cluster focuses on the use of smart robotics and innovative hardware to support project- and inquiry-based learning approaches (Schina et al., 2021). By integrating AI technologies, the cluster aims to create a more dynamic and practical learning environment, allowing students to participate actively and directly in science experiments (Zhou, 2023). This research assists in designing more engaging and effective teaching strategies, improving students'

practical skills and problem-solving abilities in the context of science.

The orange cluster entitled "Intelligent Learning Platforms" investigates the integration of artificial intelligence in science education to create intelligent and adaptive learning platforms. The focus is on the application of expert systems, machine learning and other artificial intelligence technologies to support decision-making in the context of engineering and science education (Sihare, 2024). By leveraging these technologies, the cluster aims to improve the efficiency and effectiveness of the learning process, provide a more personalized learning experience, and assist students in understanding and mastering complex concepts in science and technology. Research in this cluster contributes to the development of innovative and adaptive learning platforms, which can enhance students' learning capabilities in science and technology.

The brown cluster entitled "Innovative Educational Technologies" explores the integration of innovative educational technologies in science education, with a focus on developing learning platforms that blend artificial intelligence with computational thinking and emerging technologies. The cluster aims to enhance the learning experience of students in higher education and STEM, by leveraging the power of AI in designing relevant curricula and supporting interactive and adaptive teaching (Mrayhi et al., 2024). Using these technologies, the cluster helps in preparing students to understand and face the challenges of an increasingly connected and technology-driven modern world. Research in this cluster contributes to the development of innovative learning strategies, which can enhance students' understanding and interest in science and technology, and prepare them for the rapidly evolving demands of the future.

The pink cluster entitled "Intelligent Learning Environments" examines the use of digital technologies and artificial intelligence in creating intelligent and connected learning environments. The focus is on the integration of ChatGPT and other digital technologies to develop responsive and adaptive learning platforms. This cluster also utilizes learning analytics to understand student learning patterns and provide timely feedback, improving teaching and learning effectiveness. Thus, research in this cluster contributes to the development of dynamic and innovative learning environments, which utilize artificial intelligence to enhance students' learning experience in science education.

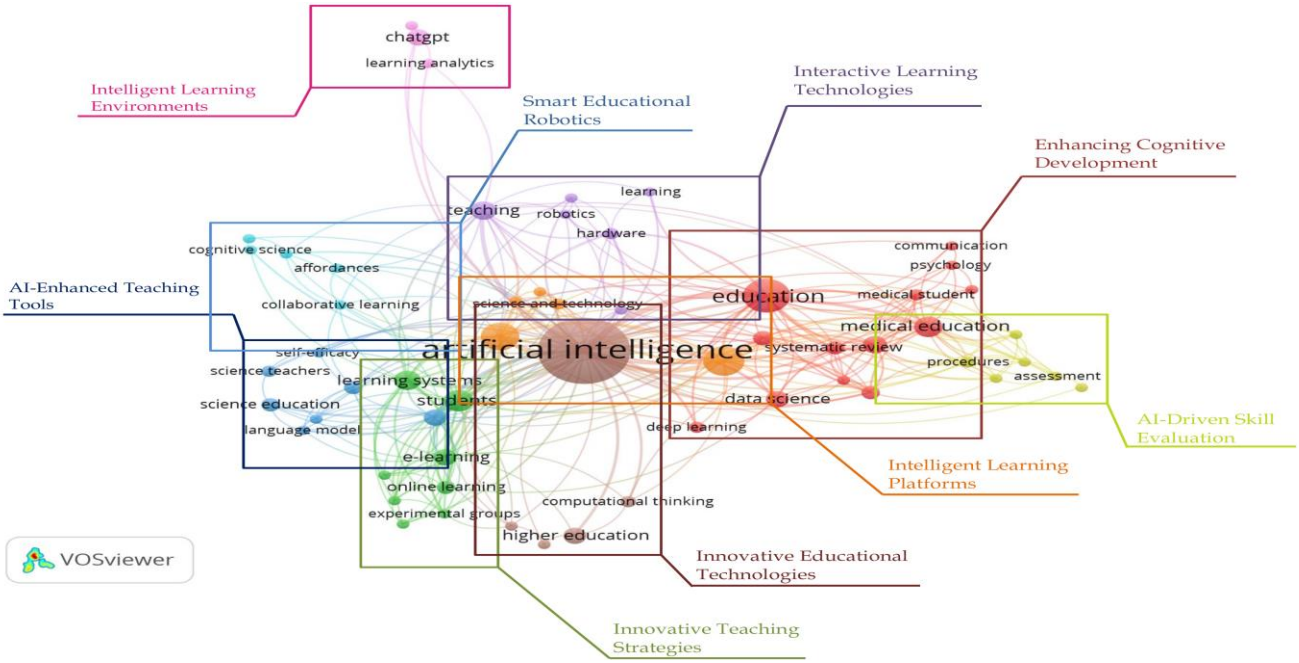

Figure 8. Focus research after group rename

Across the clusters, it can be concluded that AI has become a key element in the development of innovative and effective science education. From the development of responsive and adaptive learning strategies to more objective and in-depth assessment of student skills, artificial intelligence has played an important role in improving the learning process. The use of advanced technologies such as intelligent robotics, smart learning platforms and interactive learning environments show the great potential of artificial intelligence in creating more engaging, efficient and effective learning experiences for students in science education. By continuing to integrate artificial intelligence into various aspects of education, it can be expected that a more

adaptive, personalized, and results-oriented approach to learning will continue to evolve in the field of science.

After analyzing Focus Research, researchers then analyzed the novelty of keywords with the Overlay Visualization menu. This aims to provide research recommendations related to Artificial Intelligence in Science Education.

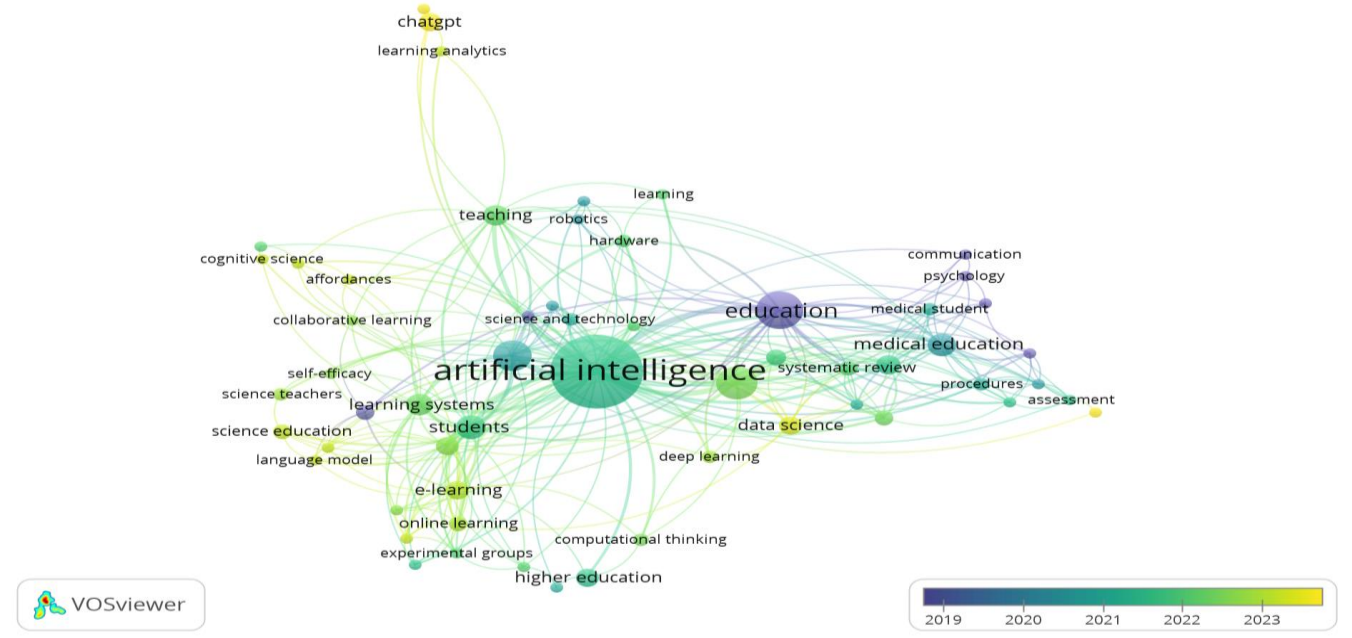

Figure 9. Overlay visualization in vosviewer

In the overlay visualization menu, yellow keywords are keywords that are newly used. This can be used as an indicator of novelty and recommendations for further research in a field. From Figure 9, it can be seen that the yellow color indicates keywords originating from 2023 and above, so the keywords are still newly used. The identification of these new keywords is important to understand the latest trends and emerging research directions. Keywords such as “Digital Technologies”, “ChatGPT”, and “Systems Thinking” are the main recommendations in the field of artificial intelligence in science education. The use of these keywords reflects recent innovations and great potential for further exploration. Research focusing on digital technologies, utilization of ChatGPT, and application of systems thinking in science education can pave the way for more advanced and effective learning methods. Therefore, future research should consider these new buzzwords to develop more innovative and relevant approaches in the field of artificial intelligence-based science education.

Conclusion

From the results of the analysis carried out, it was concluded that research on Artificial Intelligence in Science Education in the Scopus Database started from 1975 to 2024, with an 8-fold increase in the number of publications, and 13 times the number of citations in the last 7 years. China was the country with the highest contribution to this research, showing 17(11.64%) publications and 418(13.65%) citations. "BMC Medical Education" is the most productive source with an h-index of 4. Jose Carpio Cañada from Universidad de Huelva in Spain is the most productive author with an h-index of 2. Dwivedi et al. (2021) with 1159(37.85%) citations is the source with highest citation. There are 58 keywords divided into 9 clusters, with the keywords "Digital Technologies", "ChatGPT", and "Systems Thinking" being the main recommendations in the field of artificial intelligence in science education.

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Author Contributions

Article writing was done by R.T.A, Data collection and data analysis were done by Z.Z and A.M.R, direction, guidance, review of ideas, concepts, methodology, analysis were done by A.J.

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Conflicts of Interest

The authors declare no conflict of interest.

References

Abdul Aziz, N. A., Mohd Ariffin, N. F., Ismail, N. A., & Alias, A. (2023). Community Participation in the Importance of Living Heritage Conservation and Its Relationships with the Community-Based Education Model towards Creating a Sustainable Community in Melaka UNESCO World Heritage Site. *Sustainability*, *15*(3), 1935. https://doi.org/10.3390/su15031935

Alam, G. M. (2023). Sustainable education and sustainability in education: the reality in the era of internationalisation and commodification in education—is higher education different? In *Sustainability* (Vol. 15, Issue 2, p. 1315). MDPI. https://doi.org/10.3390/su15021315

Albay, E. M., & Eisma, D. V. (2021). Performance task assessment supported by the design thinking process: Results from a true experimental research. *Social Sciences & Humanities Open*, *3*(1), 100116. https://doi.org/10.1016/j.ssaho.2021.100116

Alika, O., & Radia, E. H. (2021). Development of Learning Media Based on Cross Puzzle Game in Science Learning to Improve Learning Outcomes. *Jurnal Penelitian Pendidikan IPA*, *7*(2), 173–177. https://doi.org/10.29303/jppipa.v7i2.667

Bizami, N. A., Tasir, Z., & Kew, S. N. (2023). Innovative pedagogical principles and technological tools capabilities for immersive blended learning: a systematic literature review. *Education and Information Technologies*, *28*(2), 1373–1425. https://doi.org/10.1007/s10639-022-11243-w

Cooper, G. (2023). Examining science education in ChatGPT: An exploratory study of generative artificial intelligence. *Journal of Science Education and Technology*, *32*(3), 444–452. https://doi.org/10.1007/s10956-023-10039-y

Doyan, A., Susilawati, S., & Hardiyansyah, H. (2020). Development of Natural Science Learning Tools with Guided Inquiry Model Assisted by Real Media to Improve Students' Scientific Creativity and Science Process Skills. *Jurnal Penelitian Pendidikan IPA*, *7*(1), 15. https://doi.org/10.29303/jppipa.v7i1.485

Dwivedi, R. K., Bisen, S., Yadav, M., & Yadav, A. (2024). Coding and Computational Thinking: Empowering Students for the Digital Age. In *Navigating Innovative Technologies and Intelligent Systems in Modern Education* (pp. 10–24). IGI Global. https://doi.org/10.4018/979-8-3693-5370-7.ch002

Dwivedi, Y. K., Hughes, L., Ismagilova, E., Aarts, G., Coombs, C., Crick, T., Duan, Y., Dwivedi, R., Edwards, J., Eirug, A., Galanos, V., Ilavarasan, P. V., Janssen, M., Jones, P., Kar, A. K., Kizgin, H., Kronemann, B., Lal, B., Lucini, B., … Williams, M. D. (2021). Artificial Intelligence (AI): Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy. *International Journal of Information Management*, *57*, 101994. https://doi.org/https://doi.org/10.1016/j.ijinfomgt.2019.08.002

Feraco, T., Resnati, D., Fregonese, D., Spoto, A., & Meneghetti, C. (2023). An integrated model of school students' academic achievement and life satisfaction. Linking soft skills, extracurricular activities, self-regulated learning, motivation, and emotions. *European Journal of Psychology of Education*, *38*(1), 109–130. https://doi.org/10.1007/s10212-022-00601-4

Fromm, J., Radianti, J., Wehking, C., Stieglitz, S., Majchrzak, T. A., & vom Brocke, J. (2021). More than experience?-On the unique opportunities of virtual reality to afford a holistic experiential learning cycle. *The Internet and Higher Education*, *50*, 100804. https://doi.org/10.1016/j.iheduc.2021.100804

González-Pérez, L. I., & Ramírez-Montoya, M. S. (2022). Components of Education 4.0 in 21st century skills frameworks: systematic review. *Sustainability*, *14*(3), 1493. https://doi.org/10.3390/su14031493

Hakim, M. L., & Angga, M. (2023). ChatGPT Open AI: Analysis of Mathematics Education Students Learning Interest. *Journal of Technology Global*, *1*(01), 1–10. Retrieved from https://penaeducentre.com/index.php/JTeG/article/view/35

Han, E.-R., Yeo, S., Kim, M.-J., Lee, Y.-H., Park, K.-H., & Roh, H. (2019). Medical education trends for future physicians in the era of advanced technology and artificial intelligence: an integrative review. *BMC Medical Education*, *19*, 1–15. https://doi.org/10.1186/s12909-019-1891-5

Hartono, H., Susanti, R., & Ariska, M. (2022). Science Process Skills Analysis of Junior High School Students in South Sumatera Using Test Basic of Process Skill (BAPS). *Jurnal Penelitian Pendidikan IPA*, *8*(5), 2184–2190. https://doi.org/10.29303/jppipa.v8i5.2276

Hermino, A., & Arifin, I. (2020). Contextual character education for students in the senior high school. *European Journal of Educational Research*, *9*(3), 1009–1023. https://doi.org/10.12973/eu-jer.9.3.1009

Hinojo-Lucena, F.-J., Aznar-Díaz, I., Cáceres-Reche, M.-P., & Romero-Rodríguez, J.-M. (2019). Artificial intelligence in higher education: A bibliometric study on its impact in the scientific literature. *Education Sciences*, *9*(1), 51. https://doi.org/10.3390/educsci9010051

Hooda, M., Rana, C., Dahiya, O., Rizwan, A., & Hossain,

M. S. (2022). Artificial intelligence for assessment and feedback to enhance student success in higher education. *Mathematical Problems in Engineering*, *2022*(5215722). https://doi.org/10.1155/2022/5215722

Huang, A. Y. Q., Lu, O. H. T., & Yang, S. J. H. (2023). Effects of artificial Intelligence–Enabled personalized recommendations on learners' learning engagement, motivation, and outcomes in a flipped classroom. *Computers & Education*, *194*, 104684. https://doi.org/10.1016/j.compedu.2022.104684

Hughes, S. (2024). Teaching assistants as facilitators of learning and engagement: Promoting social justice for students with special educational needs and disabilities (SEND). In *Social Justice in Practice in Education* (pp. 156–174). Routledge.

Hwang, G.-J., & Chien, S.-Y. (2022). Definition, roles, and potential research issues of the metaverse in education: An artificial intelligence perspective. *Computers and Education: Artificial Intelligence*, *3*, 100082. https://doi.org/10.1016/j.caeai.2022.100082

Iivari, N., Sharma, S., & Ventä-Olkkonen, L. (2020). Digital transformation of everyday life–How COVID-19 pandemic transformed the basic education of the young generation and why information management research should care? *International Journal of Information Management*, *55*, 102183. https://doi.org/10.1016/j.ijinfomgt.2020.102183

Jawaid, I., Javed, M. Y., Jaffery, M. H., Akram, A., Safder, U., & Hassan, S. (2020). Robotic system education for young children by collaborative- project-based learning. *Computer Applications in Engineering Education*, *28*(1), 178–192. https://doi.org/10.1002/cae.22184

Kahveci, H. (2023). The Positive and Negative Effects of Teacher Attitudes and Behaviors on Student Progress. *Journal of Pedagogical Research*, *7*(1), 290–306. https://doi.org/10.33902/JPR.202319128

Kim, J., Merrill Jr, K., Xu, K., & Kelly, S. (2022). Perceived credibility of an AI instructor in online education: The role of social presence and voice features. *Computers in Human Behavior*, *136*, 107383. https://doi.org/10.1016/j.chb.2022.107383

Kumar, M., George, R. J., & PS, A. (2023). Bibliometric analysis for medical research. *Indian Journal of Psychological Medicine*, *45*(3), 277–282. https://doi.org/10.1177/02537176221103617

Kumar, P., Sahani, J., Rawat, N., Debele, S., Tiwari, A., Emygdio, A. P. M., Abhijith, K. V, Kukadia, V., Holmes, K., & Pfautsch, S. (2023). Using empirical science education in schools to improve climate change literacy. *Renewable and Sustainable Energy Reviews*, *178*, 113232. https://doi.org/10.1016/j.rser.2023.113232

Lang, J. M. (2021). *Small teaching: Everyday lessons from the science of learning*. John Wiley & Sons.

Lansford, J. E. (2022). Annual Research Review: Cross-cultural similarities and differences in parenting. *Journal of Child Psychology and Psychiatry*, *63*(4), 466–479. https://doi.org/10.1111/jcpp.13539

Martínez-Peláez, R., Ochoa-Brust, A., Rivera, S., Félix, V. G., Ostos, R., Brito, H., Félix, R. A., & Mena, L. J. (2023). Role of digital transformation for achieving sustainability: mediated role of stakeholders, key capabilities, and technology. *Sustainability*, *15*(14), 11221. https://doi.org/10.3390/su151411221

Maulidah, N., & Wulandari, F. (2021). Literature Study: Improving Understanding of Science Concepts Using Science Comics for Elementary School Students. *Jurnal Penelitian Pendidikan IPA*, *7*(1), 80. https://doi.org/10.29303/jppipa.v7i1.509

Mayola, E., Ayuni, R. T., & Adhelia, C. (2023). Development of Instruments for Learning Independence for High School Students: Construct Validity and Reliability. *Beginner: Journal of Teaching and Education Management*, *1*(2), 91–103. https://doi.org/10.61166/bgn.v1i2.40

Mellyzar, M., Alvina, S., & Zahara, S. R. (2022). Influence of POGIL and MFI Models on Science Literacy and Science Process Skills for Junior High School. *Jurnal Penelitian Pendidikan IPA*, *8*(4), 2201–2209. https://doi.org/10.29303/jppipa.v8i4.2121

Mrayhi, S., Khribi, M. K., Belhadj, H., & Jemni, M. (2024). Designing future education for all: principles and frameworks. In *Envisioning the Future of Education Through Design* (pp. 147–177). Springer. https://doi.org/10.1007/978-981-97-0076-9_7

Nurwahidah, I., Widiyawati, Y., Sari, D. S., Masykuri, M., & Budiyanto, C. W. (2022). Penggunaan integrasi moodle science learning berbasis proyek pada tema kebisingan kota. *Jurnal Penelitian Pendidikan IPA*, *8*(4), 2322–2329. https://doi.org/10.29303/jppipa.v8i4.1469

Pessin, V. Z., Yamane, L. H., & Siman, R. R. (2022). Smart bibliometrics: an integrated method of science mapping and bibliometric analysis. *Scientometrics*, *127*(6), 3695–3718. https://doi.org/10.1007/s11192-022-04406-6

Purwantara, S., Ashari, A., Nurhadi, N., Sariyono, K. E., Syarafina, A. Z., & Afriyani, R. (2023). Teaching the fundamentals of geography to generation-z students with collaborative learning in Indonesia. *The Geography Teacher*, *20*(1), 29–34. https://doi.org/10.1080/19338341.2023.2192749

Qin, R., & Yu, Z. (2023). Extending the UTAUT model of tencent meeting for online courses by including community of inquiry and collaborative learning

constructs. *International Journal of Human–Computer Interaction*, 1–19. https://doi.org/10.1080/10447318.2023.2233129

Rajib, M. K. H., & Jahan, R. (2024). Exploring Embedded Contextual Factors and Their Contribution to Facilitating Autonomous Learning. *EIKI Journal of Effective Teaching Methods*, *2*(2). https://doi.org/10.59652/jetm.v2i2.200

Ramadhani, A. M., & Retnawati, H. (2024). Computational Thinking and its Application in School: A Bibliometric Analysis (2008-2023). *International Conference on Current Issues in Education (ICCIE)*, 329–338. https://doi.org/10.2991/978-2-38476-245-3_35

Ramadhanti, D., Kuswanto, H., Hestiana, H., Yasaroh, S., & Azalia, A. (2021). Use of Tracker Application on Kinetic Orbital Art (KOA) and Magic Gyroscope as Physics Learning Media. *Jurnal Penelitian Pendidikan IPA*, *7*(4), 562–567. https://doi.org/10.29303/jppipa.v7i4.790

Ramírez-Montoya, M.-S., & Portuguez-Castro, M. (2024). Expanding horizons for the future with an open educational model for complex thinking: external and internal validation. *On the Horizon: The International Journal of Learning Futures*, *32*(1), 32–48. https://doi.org/10.1108/OTH-12-2023-0042

Rasmitadila, R., Rachmadtullah, R., Samsudin, A., Nurtanto, M., & Jauhari, M. N. (2023). Limited face-to-face learning on students in inclusive classrooms during the Covid-19 pandemic: Perceptions of elementary school teachers in Indonesia. *Cogent Education*, *10*(1), 2213612. https://doi.org/10.1080/2331186X.2023.2213612

Raza, H., Ali, A., Rafiq, N., Xing, L., Asif, T., & Jing, C. (2023). Comparison of higher education in Pakistan and China: A sustainable development in student's perspective. *Sustainability*, *15*(5), 4327. https://doi.org/10.3390/su15054327

Rengkuan, M., Simal, F., Leasa, M., & Maelan, M. (2022). Mitigation of Learning Loss and Teacher Awareness: Qualitative Study in Science Practicum. *Jurnal Penelitian Pendidikan IPA*, *8*(4), 2143–2149. https://doi.org/10.29303/jppipa.v8i4.1796

Salinas-Navarro, D. E., Vilalta-Perdomo, E., Michel-Villarreal, R., & Montesinos, L. (2024). Designing experiential learning activities with generative artificial intelligence tools for authentic assessment. *Interactive Technology and Smart Education*. https://doi.org/10.1108/ITSE-12-2023-0236

Sayed, W. S., Noeman, A. M., Abdellatif, A., Abdelrazek, M., Badawy, M. G., Hamed, A., & El-Tantawy, S. (2023). AI-based adaptive personalized content presentation and exercises navigation for an effective and engaging E-learning platform. *Multimedia Tools and Applications*, *82*(3), 3303–3333. https://doi.org/10.1007/s11042-022-13076-8

Schina, D., Esteve-González, V., & Usart, M. (2021). An overview of teacher training programs in educational robotics: characteristics, best practices and recommendations. *Education and Information Technologies*, *26*(3), 2831–2852. https://doi.org/10.1007/s10639-020-10377-z

Sharma, G. D., Yadav, A., & Chopra, R. (2020). Artificial intelligence and effective governance: A review, critique and research agenda. *Sustainable Futures*, *2*, 100004. https://doi.org/10.1016/j.sftr.2019.100004

Shoaib, M., Sayed, N., Singh, J., Shafi, J., Khan, S., & Ali, F. (2024). AI Student Success Predictor: Enhancing Personalized Learning in Campus Management Systems. *Computers in Human Behavior*, 108301. https://doi.org/10.1016/j.chb.2024.108301

Sihare, S. R. (2024). Student Dropout Analysis in Higher Education and Retention by Artificial Intelligence and Machine Learning. *SN Computer Science*, *5*(2), 202. https://doi.org/10.1007/s42979-023-02458-w

Sultan, J., Suyanto, S., & Ibrahim, Z. S. (2023). The Relationship between Critical Thinking and Learning Outcomes in Science and Mathematics Subjects Reviewed from Meta Analysis. *Jurnal Penelitian Pendidikan IPA*, *9*(8), 493–498. 10.29303/jppipa.v9i8.3862

Tejedor, S., Cervi, L., Pérez-Escoda, A., & Jumbo, F. T. (2020). Digital literacy and higher education during COVID-19 lockdown: Spain, Italy, and Ecuador. *Publications*, *8*(4), 48. https://doi.org/10.3390/publications8040048

Ülker, P., Ülker, M., & Karamustafa, K. (2023). Bibliometric analysis of bibliometric studies in the field of tourism and hospitality. *Journal of Hospitality and Tourism Insights*, *6*(2), 797–818. https://doi.org/10.1108/JHTI-10-2021-0291

Ulwiyah, S. (2023). Rasch Model Analysis on Mathematics Test Instruments: Biblioshiny (1983-2023). *Mathematics Research and Education Journal*, *7*(2), 1–13. https://doi.org/10.25299/mrej.2023.vol7(2).14550

Van den Beemt, A., MacLeod, M., Van der Veen, J., Van de Ven, A., Van Baalen, S., Klaassen, R., & Boon, M. (2020). Interdisciplinary engineering education: A review of vision, teaching, and support. *Journal of Engineering Education*, *109*(3), 508–555. https://doi.org/10.1002/jee.20347

Wartman, S. A., & Combs, C. D. (2018). Medical education must move from the information age to the age of artificial intelligence. *Academic Medicine*, *93*(8), 1107–1109. https://doi.org/10.1097/ACM.0000000000002044

Winkler-Schwartz, A., Bissonnette, V., Mirchi, N., Ponnudurai, N., Yilmaz, R., Ledwos, N., Siyar, S., Azarnoush, H., Karlik, B., & Del Maestro, R. F. (2019). Artificial intelligence in medical education: best practices using machine learning to assess surgical expertise in virtual reality simulation. *Journal of Surgical Education*, *76*(6), 1681–1690. https://doi.org/10.1016/j.jsurg.2019.05.015

Wong, G. K. W., Ma, X., Dillenbourg, P., & Huan, J. (2020). Broadening artificial intelligence education in K-12: Where to start? *ACM Inroads*, *11*(1), 20–29. https://doi.org/10.1145/3381884

Yang, Y.-F., Tseng, C. C., & Lai, S.-C. (2024). Enhancing teachers' self-efficacy beliefs in AI-based technology integration into English speaking teaching through a professional development program. *Teaching and Teacher Education*, *144*, 104582. https://doi.org/10.1016/j.tate.2024.104582

Yufeia, L., Salehb, S., Jiahuic, H., & Syed, S. M. (2020). Review of the application of artificial intelligence in education. *Integration (Amsterdam)*, *12*(8), 1–15. https://doi.org/10.53333/IJICC2013/12850

Yulihapsari, D., Anif, S., & Muhibbin, A. (2023). Science Process Skills in Implementation Food Test Practicum in Junior High School. *Jurnal Penelitian Pendidikan IPA*, *9*(2), 714–720. https://doi.org/10.29303/jppipa.v9i2.3020

Zafrullah, Z., Bakti, A. A., Riantoro, E. S., Kastara, R., Prasetyo, Y. B. A., Rosidah, R., Fitriani, A., Fitria, R. L., Ramadhani, A. M., Ulwiyah, S., Nabilah, N., Rifqiyah, F., Ibrahim, Z. S., & Sultan, J. (2023). Item Response Theory in Education: A Biblioshiny Analysis (1987-2023). *Journal of Education Global*, *1*(1 SE-Articles), 101–114. Retrieved from https://penaeducentre.com/index.php/JEdG/article/view/30

Zafrullah, Z., Fitriani, A., Ramadhani, A. M., & Hidayah, S. M. N. (2023). Transformasi Adobe Flash dalam Dunia Pendidikan: Analisis Bibliometrik (2006-2023). *Indo-MathEdu Intellectuals Journal*, *4*(3), 1652–1666. https://doi.org/10.54373/imeij.v4i3.387

Zafrullah, Z., Hardi, V. A., Nabilah, N., & Fitriani, A. (2024). Transforming the Utilization of ChatGPT in Education: A Bibliometric Analysis. *Innovative: Journal Of Social Science Research*, *4*(1), 5316–5329. https://doi.org/10.31004/innovative.v4i1.5578

Zafrullah, Z., Ibrahim, Z. S., Ariawan, R., Ulwiyah, S., & Ayuni, R. T. (2024). Research on Madrasas in International Publications: Bibliometric Analysis with Vosviewer. *COMPETITIVE: Journal of Education*, *3*(2), 116–127. https://doi.org/10.58355/competitive.v3i2.93

Zafrullah, Z., Sultan, J., Ayuni, R. T., & Uleng, A. T. (2024). Analisis Kemandirian Belajar Matematika Siswa Berdasarkan Gender dan Aspek di Sekolah Menengah Atas. *Perspektif Pendidikan Dan Keguruan*, *15*(1), 29–38. https://doi.org/10.25299/perspektif.2024.vol15(1).16189

Zafrullah, Z., Suyanto, S., Wahyuni, A., Ayuni, R. T., & Novilanti, F. R. E. (2023). Development of Android-based Learning to Improve Computational Thinking Skills in Junior High School. *Jurnal Cendekia: Jurnal Pendidikan Matematika*, *7*(2), 1309–1320. https://doi.org/10.31004/cendekia.v7i2.2239

Zafrullah, Z., & Zetriuslita, Z. (2021). Learning interest of seventh grade students towards mathematics learning media assisted by Adobe Flash CS6. *Math Didactic: Jurnal Pendidikan Matematika*, *7*(2), 114–123. https://doi.org/10.33654/math.v7i2.1272

Zafrullah, Z., Zetriuslita, Z., Rezeki, S., & Suripah, S. (2024). Development of Interactive Multimedia Learning Mathematics Learning Media using Adobe Flash CS6. *Mathematics Research and Education Journal*, *8*(1), 17–28. https://doi.org/10.25299/mrej.2024.vol8(1).14499

Zhang, K., & Aslan, A. B. (2021). AI technologies for education: Recent research & future directions. *Computers and Education: Artificial Intelligence*, *2*, 100025. https://doi.org/10.1016/j.caeai.2021.100025

Zhou, C. (2023). Integration of modern technologies in higher education on the example of artificial intelligence use. *Education and Information Technologies*, *28*(4), 3893–3910. https://doi.org/10.1007/s10639-022-11309-9