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Artificial Intelligence in Education Research During the Last Ten Years: A Review and Bibliometric Study

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Binar Kurnia Prahani[1](✉), Iqbal Ainur Rizki[1], Budi Jatmiko[1], Nadi Suprapto[1], Tan Amelia[2]
[1] Universitas Negeri Surabaya, Surabaya, Indonesia
[2] Universitas Dinamika, Surabaya, Indonesia
binarprahani@unesa.ac.id

Abstract—Research on Artificial Intelligence in Education (AIED) has increased rapidly in recent years, so efforts are needed to understand the status of trends and their development to support and focus these trends. The specific objectives of this study are to analyze document type, source document, contributed country, language, top affiliation, sponsorship funding, top source title, subject area, research station, visualization of mapping research trends across and top 50 cited publications, reviewing some of the top-cited publications on AIED research over the last ten years using bibliometric analysis. The metadata used is the Scopus database and a mapping application using VOSviewer with 457 documents. The bibliometric results show that the development of AIED research has increased exponentially over the last five years. The most common types of documents are articles, journal document sources, and China's most productive country. English being the most significant language, the most prolific author was Kalles, D, some of the top prolific affiliates with four publications, while the most sponsored funding was the National Natural Science Foundation of China and the National Science Foundation. "Journal of Physics: Conference Series" is the primary source, the most research subject area is Computer Science, for the top-cited author is Holmes, W. Mapping of research trends shows that AIED research trends in the last ten years are: 1) it's an application to students; 2) the subject of education in engineering educations; 3) teaching methods; 4) e-learning based education; 5) education system; 6) curriculum included AI. AIED integration could revolutionize the education system.

Keywords—AIED, bibliometric, education

1 Introduction

The development of the Industrial Revolution 4.0 has led to a rapid increase in digital technology, one of which is Artificial Intelligence (AI) technology [1–4]. AI is a simulation of the intelligence possessed by humans, which is modeled in machines and programmed to think like humans [5]. This technology is the main driver for the presence of modern technologies, such as big data, self-driving cars, robotics, and the Internet of

Things [2,6–9]. In addition, the application of AI has penetrated all aspects, such as technology, industry, medical, business, and education.

More specifically, AI in education (AIED) has an important role in improving the quality of the education sector because its application can make it easier for teachers and students to carry out learning activities in many subjects [10,11]. For example, Chen and Liu [12] developed a personalized computer-assisted mathematics problem-solving system and found it effective for improving students' performance and learning attitudes. Moreover, recent literature on AIED [13–18] clearly identified the main problem of the learning process in which AI can offer a more important contribution. This is also supported by the AI Index Report 2021 [19], the number of courses that teach students the skills necessary to build or deploy a practical AI model on the undergraduate and graduate levels in 2020 has increased by 102.9% and 41.7%, respectively, in the last four academic years.

Research publications on AIED also continue to increase every year. A simple method that can be done is to search Scopus with the keyword "Artificial Intelligence or AI Education or Educational", find results in 2017 as many as 14 results, while in 2021 as many as 257 results. This shows that AIED research topics have increased rapidly over time. Therefore, its need efforts to find out and understand the status and trends a research topic to develop and be properly supported [20], especially in AIED. Bibliometric studies can be a solution to understand research trends, patterns, novelty, and impactful studies [21–25]. This study can also assess the contribution of research to the development of knowledge – particularly about AIED – using a statistical approach and provide a broader understanding of the entire discipline at a relatively low cost [26].

Previous research [27] has conducted bibliometric analysis and systematic reviews on AI trends in mathematics education so that the range of information obtained is still not wide enough. In addition, studies by [18,28,29] have performed bibliometric analysis on AIED, but this study uses the Web of Science database for data mining and uses the Science Mapping Analysis Tool application to perform the mapping. Recommendations for these studies are to conduct bibliometric analysis on other databases (such as Scopus or Google Scholar) and other applications to map research trends (such as VOSviewer, Histcite, etc.) so that a broader understanding of the topic being studied can be obtained. Therefore, this study will conduct a bibliometric analysis on AIED in the last ten years (2011-2021) using metadata in the Scopus database and the VOSviewer mapping application. This research is expected to find out patterns, research trends, novelty, and future education in the AIED field. Specifically, the objectives of this research are as follows:

1. Analyzing document types, document sources, and countries that have contributed to AIED research over the past ten years.
2. Analyzing the language, authors, top affiliates, and sponsorship funding of AIED research over the past ten years.
3. Analyzing top source titles, subject areas, and research citations on AIED research over the last ten years.

4. Identifying the results of the visualization of research trend mapping on AIED over the last ten years.
5. Identifying the results of visualization of research trend mapping in the top 50 cited publications in AIED research over the last ten years.
6. Reviewing some of the top-cited publications in AIED research.

2 Methods

This research is descriptive, using bibliometric analysis of metadata from the Scopus database (www.scopus.com) [30–33]. This database was chosen because it has the largest academic database globally with citations that provide abstracts from various scientific and research literature that have been reviewed so that it is effective for visualizing, tracking, and analyzing publications [34]. The research procedure followed five stages, as shown in Figure 1 [35–37].

Fig. 1. Five stages of carrying out a bibliometric study

2.1 Defining search keywords

The search string used in document search is "TITLE (Artificial AND Intelligence OR AI AND Education OR Educational)" with a year limit between 2011-2021.

2.2 Initial search results

Data mining was carried out on January 28, 2022. Based on the results of this search, 576 documents were found.

2.3 Refinement of the search

The findings are then filtered specifically for documents in journals and conference proceedings because these documents contain primary research results that are more credible and up-to-date than books, book chapters, editorials because they go through a peer-reviewing process by experts. After filtration, 457 documents were obtained to be extracted into files with the extension .ris and .csv for further processing.

2.4 Compiling the initial data statistics

Statistical data is obtained through the *.ris* file insertion process uses the VOSviewer application to map, visualize, and analyze AIED trends in the last ten years [38]. For example, VOSviewer can create publication mappings, country mappings, citation patterns, keyword patterns, and authorship patterns [39]. Statistical data was then supported by further analysis through *.csv* files using Microsoft Excel to make the data obtained more detailed.

2.5 Data Analysis

Data analysis was carried out descriptively to determine document type, document source, language, country, top affiliation, sponsorship funding, top source title, subject area, research citation, authorship, and keywords in 457 related documents. Analysis can also be done by looking at the node's size and the link's strength based on the results of mapping and visualization using the VOSviewer application. Finally, data analysis was continued by reviewing the top 5 cited articles based on the findings and recommendations.

3 Results and discussion

3.1 Year-wise distribution, document types, document sources, and countries contributed to AIED research

The distribution of research publications on AIED over the last ten years can be seen in Figure 2. It can be seen that the development of AIED research tends to stagnate in 2011-2016, but from 2017 to 2021, there will be an exponential increase. This finding is consistent with research [18,28] which shows that AIED research has relatively increased every year, especially in the last five years. Therefore, it is predictable that the research and application of AIED will become more extensive and allow the formation of more consolidated pathways in the future. This shows a clear revolution in how the integration of AI in teaching and learning takes place and the aspects that educators must consider.

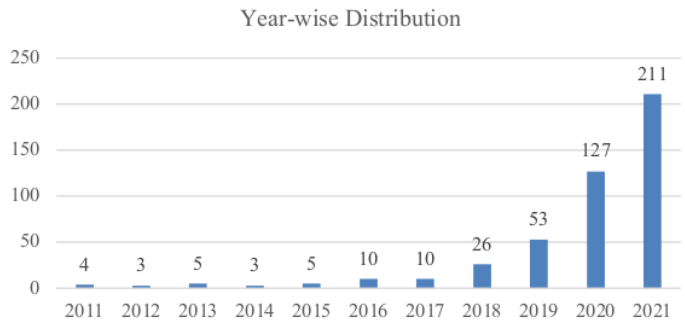
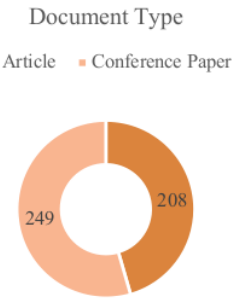
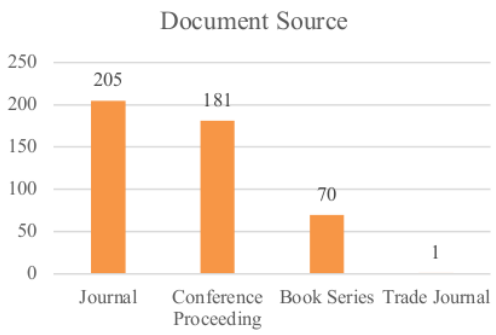


Fig. 2. Year-wise distribution graph on AIED publications

The types and sources of documents in AIED research for the last ten years can be seen in Figure 3. Based on the search results after filtering, a total of 457 documents were obtained, consisting of 249 articles and 208 conference papers. In addition, the sources for published documents are journals of 205 items, 181 items of conference proceedings, 70 items of book series, and 1 item of trade journals. Most researchers publish in journals because they are of high quality compared to other sources.



(a)



(b)

Fig. 3. Document type and source of AIED research

The metric results show that 76 countries have contributed to AIED research over the last ten years. Figure 4 shows the top 10 countries that have contributed to AIED research. China leads the productivity with 201 articles, followed by the USA with 50 articles, then Russia with 22 articles, and so on. This is because the State Council of China published *Next generation artificial intelligence development plan* with a clear plan that AI should be broadly applied in all education levels so that the generation in China has talent in the field of AI [40]. However, this finding is different from the study by [18,28] that the USA is the most productive country in AIED research. If the publication is regulated without 2011-2022, the USA will be the most productive country with 15 items published. In addition, another factor that causes this difference is the difference in the databases used, where they use the Web of Science database while we use the Scopus database. In addition, it can also be analyzed that developing countries have relatively few AIED publications because the wealth of a country influences technological progress. This is in line with research by [41] that developing countries have fewer AI publications in higher education.

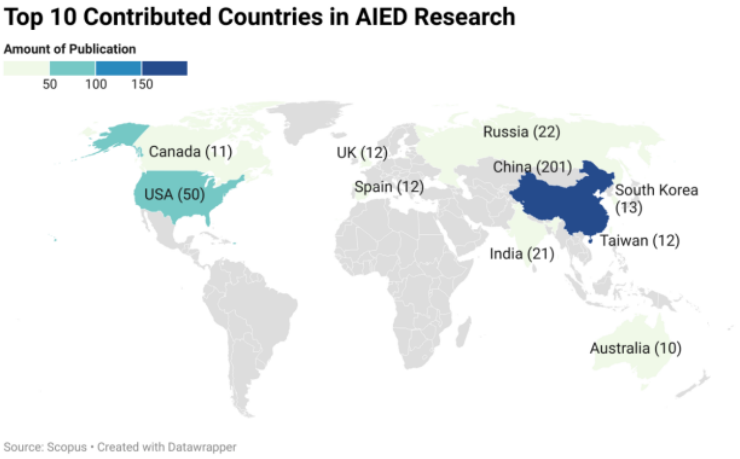


Fig. 4. Top 10 contributed countries in AIED research during the last ten years

The mapping of countries based on clusters can be seen in Figure 5. There are 17 clusters with the main cluster of 6 countries, consisting of China which is connected to the Czech Republic, India, Malaysia, Thailand, and the UAE with red nodes. The second cluster consists of 5 countries: Hong Kong, Italy, Japan, Taiwan, and the USA, with green nodes. The third cluster consists of 4 countries: New Zealand, South Africa, Spain, and Turkey, with blue nodes. The fourth cluster consists of 4 countries consisting of Brazil, Morocco, Saudi Arabia, and the UK with yellow nodes. The fifth cluster of 4 countries consists of Germany, Portugal, Romania, and Serbia with purple nodes. The sixth cluster with 4 countries consisting of Australia, Canada, Singapore, and South Korea with indigo-colored nodes. The seventh cluster with 4 countries consisting of Austria, Estonia, Finland, and Sweden with nodes colored in orange. While other clusters have less than 4 countries, some of them are not connected to each other. Collaboration between countries on AIED research has been relatively good, as indicated by more than 70 countries with 457 publications.

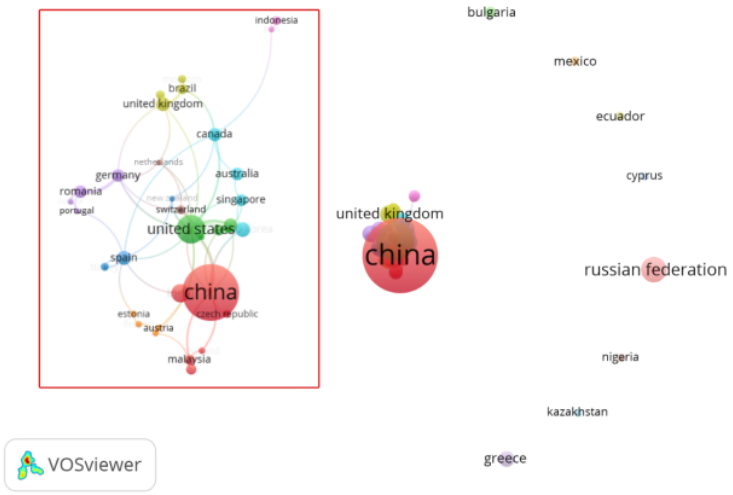


Fig. 5. Cluster mapping by country

3.2 Language, top affiliation, and funding sponsor

Table 1 shows data on the top 5 languages, authors, affiliations, and sponsorship funding for AIED research over the last ten years. English became the most significant language with 443 articles, followed by Chinese and Russian with 4 articles, and Portuguese and Spanish with 3 articles. It is clear that the researcher chose English because it is a global language to reach all countries in the world. Based on the authorship, Kalles, D. is recognized as the most prolific writer with 3 articles while others have less than 3 articles.

Based on the affiliations, University Politehnica of Bucharest, Nanyang Technological University, National Institute of Education, Deggendorf Institute of Technology, and Beijing Normal University has 4 article publications each. This shows that publications on AIED are not focused on just one affiliate in one country because no affiliate is more prominent than the others. Meanwhile, the most sponsored funding was by the National Natural Science Foundation of China and the National Science Foundation with 5 articles, followed by the Ministry of Education and Science of the Russian Federation with 4 articles, the *Bundesministerium fur Bildüng und Forschung* and the Education Department of Jilin Province as sponsors. 3 articles each.

Table 1. Top 5 language, authorship, affiliation, and funding sponsor of AIED research during the last ten years

Top Language		Top Authorship		Top Affiliation		Top Funding Sponsor	
Language	***Total***	***Author***	***Total***	***Affiliation***	***Total***	***Funding Sponsor***	***Total***
English	443	Kalles, D.	3	University Politehnica of Bucharest	4	National Natural Science Foundation of China	5
Chinese	4	Bhattacharjee, K.K.	2	Nanyang Technological University	4	National Science Foundation	5
Russian	4	Binder, L.	2	National Institute of Education	4	Ministry of Education and Science of the Russian Federation	4
Portuguese	3	Chang, Y.S.	2	Deggendorf Institute of Technology	4	*Bundesministerium fur Bildüng und Forschung*	3
Spanish	3	Des Jardins, M.	2	Beijing Normal University	4	Education Department of Jilin Province	3

3.3 Top source title, subject area, and research citation

Table 2 shows the top 10 source titles, subject areas, and cited authors from AIED research over the past ten years. In the top source title, "Journal of Physics: Conference Series" is the main source in AIED research publications with 30 articles. This followed by "Advances In Intelligent Systems And Computing" with a total of 23 articles, and the ACM International Conference Proceeding Series, with 17 articles. So it can be seen that most researchers publish AIED research in conference papers. "International Journal of Emerging Technologies In Learning" was also included but ranked 10th. When viewed from the subject area, it is clear that Computer Science (281), Engineering (149), and Social Sciences (147) are in the top 3 because they are very relevant to AIED. Other top subject areas are Mathematics (71), Decision Sciences (51), Physics and Astronomy (38), Environmental Science (21), Business, Management, and Accounting (20), Medicine (18), and Energy (16).

Table 2. Top 10 source title, subject area, and cited author on AIED research during the last ten years

Top Source Title		Top Subject Area		Top Cited Author	
Source Title	***Total***	***Subject Area***	***Total***	***Author***	***Cited by***
nal of Physics: Conference Series	30	Computer Science	281	Holmes, W.	50
Advances In Intelligent Systems And Computing	23	Engineering	149	Luckin, R.	45
M International Conference Proceeding Series	17	Social Sciences	147	Norvig, P.	42
nal Of Intelligent And Fuzzy Systems	16	Mathematics	71	Roll, I.	37
Communications In Computer And Information Science	11	Decision Sciences	51	Koedinger, K.R.	35

Proceedings 2021 2nd International Conference On Artificial Intelligence And Education Icaie 2021	10	Physics and Astronomy	38	Wang, Y.	34
Lecture Notes In Computer Science Including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics	9	Environmental Science	21	Li, Y.	31
Lecture Notes In Electrical Engineering	8	Business, Management, and Accounting	20	Aleven Y.	30
Sustainability Switzerland	8	Medicine	18	Vanlehn, K.	30
International Journal Of Emerging Technologies In Learning	7	Energy	16	Wang J.	28

Based on the top-cited author, Holmes, W. is recognized as the author with the most citations on AIED research over the last ten years, namely 50 citations per 457 publications. Followed by Luckin, R. 45 citations; Norvig P. 42 citations; Roll I. 35 citations; Wang, Y. 34 citations; and other authors with fewer citations. The visualization mapping between the cited authors also has 9 cluster links as shown in Figure 6. The first cluster with red nodes (n=127), the second cluster with green nodes (n=42), the third cluster with blue nodes (n= 39), a fourth cluster with yellow nodes (n=26), and several other clusters with fewer items. Holmes, W. and Luckin R. are the main cited authors because they have the most citations and high link strength but belong to the third cluster.

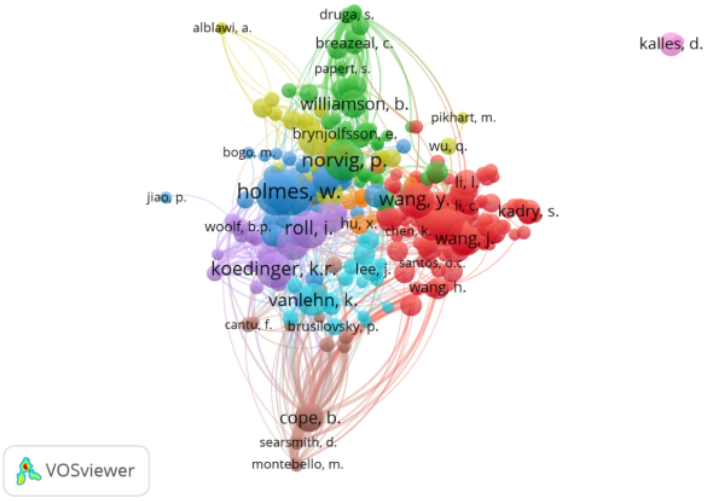


Fig. 6. Mapping visualization of the top-cited author on AIED research during the last ten years

3.4 Research trend mapping visualization

The most occurrence keywords are analyzed before mapping out the visualization of AIED research trends over the last ten years, as shown in Table 3. It can be seen that the most frequently occurring keywords and the highest total link strength are AI, respectively 377 and 1624. It is clear that AI is the main keyword in AIED research. While the second order is Students with occurrence 104 and total link strength 613. Followed by Education, AI technologies, Engineering Educations, Teaching, E-Learning, Education Computing, Learning Systems, and Curricula. Based on this pattern, it can be found that the trends of AIED research in the last ten years are: 1) it's application to students; 2) the subject of education in engineering educations; 3) teaching methods; 4) e-learning based education; 5) education system; 6) curriculum included AI. This finding is similar to research by [28,42,43] which found that the most frequently used keywords were AI, education, machine learning, robotics, education computing, student, and e-learning.

Table 3. Top 10 keywords of all and top 50 cited AIED research during last ten years

All AIED research			Top 50 cited research		
Keyword	***Occurence***	***Total Link Strength***	***Keyword***	***Occurence***	***Total Link Strength***
Artificial Intelligence	377	1624	Artificial Intelligence	215	185
Students	104	613	Education	38	57
Education	78	371	Machine Learning	18	40
Artificial Intelligence Technologies	72	410	Higher Education	15	25
Engineering Educations	68	405	Physical Education	13	19
Teaching	52	291	Technology	12	18
E-Learning	52	284	E-Learning	9	10
Education Computing	51	311	Artificial Intelligence Education	8	8
Learning Systems	41	251	Big Data	7	4
Curricula	38	212	Artificial Intelligence Technology	7	2

Figure 7 shows a visualization mapping of AIED research trends over the last ten years to find research novelty from this domain. The mapping results show 14 focus clusters for AIED research topics. The main cluster with red nodes (n=72) focuses on AI subjects such as human, machine learning, radiology, technology, augmented reality, virtual reality, physician, etc. The second cluster with green nodes (n=70) focuses on AI methods such as neural networks, decision makers, development directions, data mining, etc. The third cluster with blue nodes (n=54) focuses on AI applications such as education policies, online learning, ecosystems, methods of teachings, smart cities, etc. The fourth cluster with yellow nodes (n=51) focuses on AI media, such as computer-aided instruction, natural language processing, digital storage, etc. The fifth cluster with purple nodes (n=47), focuses on AI goals such as critical thinking, curriculum,

innovation, innovative talents, teaching and learning, etc. Other clusters have more minor keyword occurrence and research focus.

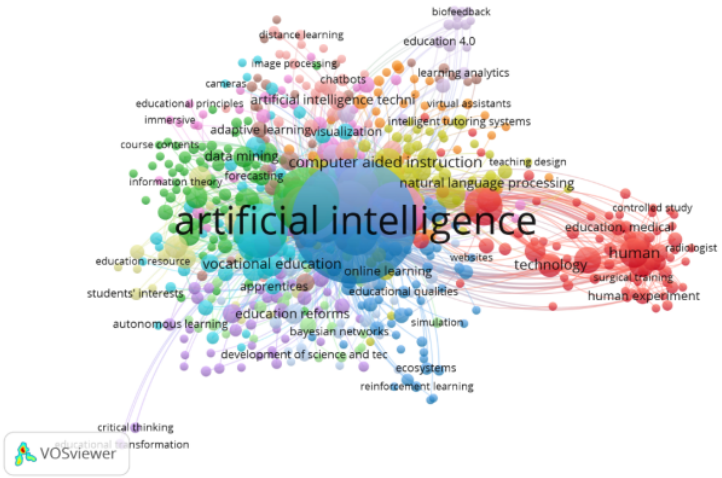


Fig. 7. Mapping visualization of keywords co-occurrence on all AIED research during last ten years

The way to find novelty based on the mapping results is to look at the relationship between smaller or fewer keywords. For example, the application of AI that focuses on higher education has been widely researched in the last ten years because many keywords have been found. Meanwhile, there is not much research on K-12 schools against AI because relatively few keywords are found. Other examples include AI analysis of education policy, course content, individualization, etc. This is an opportunity and potential for current and future research on AIED.

Figure 8 shows some examples of more specific keyword mapping results on education, students, learning systems, curriculum, and teaching. Figure 8a-8c is the top trends research in AIED during the last ten years, while Figure 8d-8e is the opposite. If researchers want to explore AIED on top trends, they still have a great opportunity because top trends have a wider range and are flexible in their application. This is because AIED can reform education in many aspects. Meanwhile, for fewer trends such as Figure 8d-8e, it can be used as alternative research, especially for researchers who want to explore AIED focusing on curriculum and teaching. For example, if a researcher wants to study AI in a curricula field (see Figure 8d), he can focus on aspects of e-learning, learning systems, deep learning, and teaching. If a researcher wants to research rarer aspects, he can try teaching methods, college students, educational robots, virtual reality.

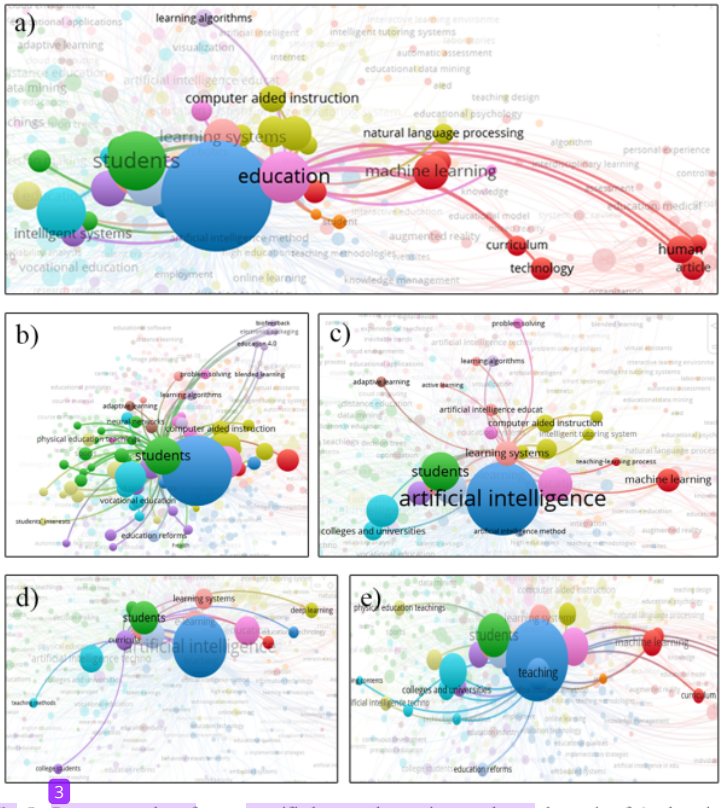


Fig. 8. Some examples of more specific keyword mapping results on the topic of a) education, b) students, c) learning systems, d) curriculum, and e) teaching

3.5 Trend visualization of top 50 cited articles

Still in Table 3, in the top 50 cited articles in AIED research over the last ten years, the keywords that appear most often and the total link strength are the same as AIED research as a whole, namely AI. The only difference lies in the keywords machine learning (18), higher education (15), physical education (13), technology (12), AI Education (8), and Big Data (7). So it can be seen that these keywords greatly influence AIED research. Researchers can conduct studies on these aspects because they have a high citation rate and impactful studies. While the visualization mapping can be seen in Figure 9. The mapping results show 18 clusters, with the main cluster (red node, n=17) focusing on AIED products, such as intelligent tutoring systems, gamification,

educational robotics, etc. The second cluster (green node, n=13) focuses on AIED in learning, such as learning styles, adaptive learning, reinforcement learning, teaching evaluation, etc. The third cluster (blue node, n=11) focuses on AI-integrated media, such as LMS, virtual reality, chatbots, data analysis, etc. Some other clusters have fewer items.

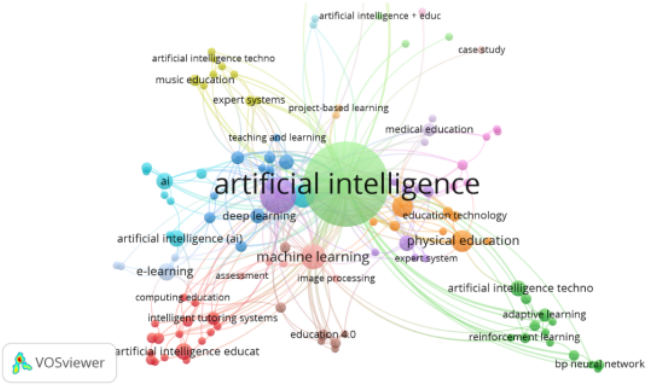


Fig. 9. Mapping visualization of keywords co-occurence on top 50 cited AIED research during last ten years

3.6 Review of top 5 cited publications on AIED

The review was conducted on the top 5 publications cited as impactful studies on AIED research during the last ten years, as shown in Table 4. Each article was analyzed based on the findings and recommendations in the article. The majority of the top-cited articles discussed "can AIED change the education system by replacing teachers?" and in our opinion, the answer is not completely because AI is "just" intelligence that can imitate human reasoning, but AI does not have feelings or hearts. So AI can "teach" students, but it cannot "educate" students. In line with the opinion [18] that AI-based technology can support the learning process, this will not substitute for teaching roles. The review results of several other articles also discuss the integration of AI in higher education, adaptive learning based on student abilities, and the use of robots in education.

Table 4. Review of top 5 cited publications on AIED

Author(s)	Citation	Findings	Recommendations
Popenici, S.A.D; Kerr, S [44]	145	The exploration of technological advances and the speed with which new technologies are adopted in higher education can predict the future nature of higher education in the world. This is because artificial intelligence has become part of the structure in universities. Moreover, it is time for universities to rethink their functions and pedagogical models and their future relationship with AI solutions and their owners.	There is a need for research on the ethical implications of AI developmental control and the possibility of undermining the wealth of knowledge and human perspectives by monopolizing multiple entities.
Roll, I; Wylie, R. [45]	115	Education has shifted beyond the traditional AIED model, and this pivot offers many opportunities and challenges. In the last two decades, the processes of growth, maturation, and evolution in AIED have been impressive. AIED, as a community, must continue this work and play to our strengths and success.	Researchers suggest two research studies that need to be conducted on AIED to impact education in the next 25 years: 1) an evolutionary process that focuses on classroom practice, collaboration with teachers, diversification of domains and technology; 2) a revolutionary process to embed technology in students' daily lives.
Almohamadi, K.; Hargas H.; Alghazzawi, D.; Aldabbagh, G. [46]	87	AI techniques are very helpful in developing and imitating human reasoning and decision-making processes in a teaching and learning framework. AI can also address uncertainty and facilitate the development of contexts that promote effective learning. This capability is critical in ensuring that both the learner and the system used can improve through continuous learning mechanisms.	Related to those findings, each student has a different learning process so there needs to be an adaptive education system. Thus, it is very important to create an accurate profile and model of students based on an analysis of their personal knowledge, affective, psychomotor and personality states. Then, the data can be used and utilized efficiently in developing an adaptive learning environment.
Timms, M.J. [47]	79	The school will continue to exist in some form over the next 25 years, and teachers will continue to supervise and assist students in their learning. The prediction is that educational cobots will help teachers in future classrooms and provide examples of today's robotic work.	This will lead to new challenges that will stimulate AIED so much that we can expand our teaching-learning models and methods. In addition, the next practical step is to conduct workshops on Educational Cobots and Smart Classrooms at AIED or related conferences such as Human-Robot Interaction.
Chassignol, M.; Khoroshavin, A.; Klimnova, A.; Bliyatdinova, A. [48]	57	AI will change and reshape the educational landscape, but AI will not completely replace our traditional education systems. Nevertheless, several points of AI intervention in education, namely 1) AI provides many opportunities for the development of massive open online courses; 2) Intelligent tutoring systems create digital profiles of students and provide them with private tutors; 3) AI can help students with health problems to learn effectively.	This work can contribute to existing knowledge in the AIED field to attract researchers and professionals in technology-enhanced learning, lecturers, students, and people who care about our education's state of the art.

4 Conclusions

This research is the first study to analyze bibliometrics and review the top-cited publications on AIED research during the last ten years using the Scopus database and the VOSviewer application. This field has become one of the research interests that has experienced significant development and improvement and the development of technology and the industrial revolution. There are five conclusions in this study as follows:

1. The development of AIED research has increased exponentially over the last five years, with the most types of documents being articles (249) and journal document sources (205), while the most productive country in researching AIED is China (201).
2. English is the most significant language (443); the most prolific authors are Kalles, D(3); the top affiliates who research the most AIED are University Politehnica of Bucharest, Nanyang Technological University, National Institute of Education, Deggendorf Institute of Technology, and Beijing Normal University (4); the most sponsored funding is the National Natural Science Foundation of China and the National Science Foundation (5).
3. In the top source title, "Journal of Physics: Conference Series" is the main source in AIED research publications (30). The most research subject areas are Computer Science (281), Engineering (149), and Social Sciences (147). For the top-cited author, Holmes, W. is recognized as the most citations author (50).
4. Research trend mapping shows that AIED research trends in the last 10 years are: 1) its application to students; 2) the subject of education in engineering educations; 3) teaching methods; 4) e-learning based education; 5) education system; 6) curriculum included AI.
5. In the top 50 cited articles, frequently used keywords are AI (n=215), Education (38), machine learning (18), higher education (15), physical education (13), technology (12). Therefore, researchers can conduct studies on these aspects because they have a high citation rate and impactful studies.
6. The review results in the top 5 cited articles tend to examine the impact of AI in education: can it change the education system by replacing teachers? Several other articles also discuss the integration of AI in higher education, adaptive learning based on student abilities, and robots in education. These articles become fundamental for future research, so they have great citations and impact AIED topics' development.

The implication of this research is to find some examples of novelty in AIED research so that this study can be used as a reference for future research in AIED. The types of research presented to make it possible to define a profile of the types of documents that can be presented so that the research path can be more focused. This research can also find the most relevant issues about AIED in Scopus and the authors that had the most significant impact and identify the scientists' main lines of research in each defined period. Thus, it also contributes to limiting the next trend that can be developed in this research area.

5 Acknowledgement

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7 Authors

Dr. Binar Kurnia Prahani, M.Pd. is a lecturer at the Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Surabaya. Research interest in AI in education, HOTs, and physics learning innovation (email: binarprahani@unesa.ac.id)

Iqbal Ainur Rizki is a third-year undergraduate student in the Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Surabaya.

Prof. Dr. Budi Jatmiko, M.Pd. is a Professor at the Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Surabaya. Research interest in digital learning, HOTs, and physics learning innovation.

Nadi Suprapto, Ph.D. is a Associate Professor in the Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Surabaya. Research interests in bibliometrics, local wisdom of physics, philosophy, and physics education curriculum.

Tan Amelia, S.Kom., M.MT. is researcher in Universitas Dinamika, Surabaya, Indonesia. Research interest in computer, software engineering, and requirement prioritization.

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