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Research Article

Past, Present, and Future of Artificial Intelligence in Education: A Bibliometric Study

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Abstract: With the rapid advancement in technology, artificial intelligence has permeated every aspect of daily life. Education is no exception. Artificial intelligence in education (AIEd) has attracted great interest in the academic field. This bibliometric study aims to analyze and document the literature on AIEd from its emergence to 2023. AIEd-related publications were analysed for patterns, trends, and potential research gaps in the field. The search parameters were 'Artificial Intelligence in Education' in the article title, abstract, or topic. In order to examine the evolution of the concept holistically, no date restrictions were applied. The search, therefore, covered studies published from 1989 to 2023, with the first publication indexed in the Web of Science database marking the beginning of the timeline. The Web of Science was used as the main database and 905 studies were screened during the search. The Biblioshiny of R Software was used for descriptive and network analysis. The annual growth rate was calculated as 18.7%, indicating significant interest in the field. The results also showed that China, the USA, the UK, Australia, and Spain are the leading countries in the field of AIEd. Through thematic analysis, trending topics and engine, core, emerging, and niche themes were uncovered. Based on the research findings, the current study takes a forward-looking stance and goes beyond merely summarizing the past and present to provide insights on future linkages.

Keywords: Artificial Intelligence, Aied, Bibliometric, Education

1. Introduction

Technology has advanced significantly in recent years. These advancements have impacted the education field, similar to many other fields. Owing to these advancements in technology, artificial intelligence (AI) has ushered in a new era in education and is seen as a driving force of technology (Arslan, 2020). First coined in the second half of the 20th century by McCarthy (Cope et al., 2021), artificial intelligence refers to 'the science of endowing programs with the ability to change themselves for the better as a result of their own experiences' (Schank, 1987, p. 64). AI is a promising technology designed to develop computer systems that perform intelligent and adaptive behaviors, reflecting the ability to learn from their environment. Hence, AI can be described as a system that mimics the human brain to complete specified tasks and can recursively improve through experience gained from that task (İşler & Kılıç, 2021).

The field of application of AI is prevalent from medicine to tourism. While AI has found innovative applications across several industries, its incorporation into the education industry is still in the early phase (Alam, 2021). Despite several attempts at basic commercial usage, the application of AI technologies in the educational field has not yet reached its potential. Within the educational landscape, AI is not a standalone entity but rather seamlessly embedded within broader technological trends. The primary focus of developmental research revolves around developing AI technologies rather than exploring their real-world applications. This focus has led to a slower progression of AI into new fields such as education.

Despite its slow progress in the educational field, the benefits of AI cannot be overlooked. AI has already been integrated into several aspects of the teaching-learning process, from adaptive assessments to automated assessment constructions (Swiecki et al., 2022). For example, automated grading is among the several benefits of AI. AI-supported automated grading systems can replicate a teacher's actions in terms of assessing and evaluating a student's assignment. Offering personalised learning paths is

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another benefit of AI. Many AI applications in the educational field customise learning by providing learners with individualised learning plans and instructions; analysing learners' needs, strengths, and interests; and subsequently tailoring the teaching-learning process. Another benefit of AI lies in its ability to facilitate adaptive learning approaches (Owoc et al., 2019). In contrast to conventional classroom education, which is mostly one-size-fits-all, AI-based adaptive learning systems are crafted to optimise the teaching-learning process. One way that these systems use to maximise learning efficacy is to gather and analyse students' behavioural data and provide timely personalised feedback accordingly (Cui et al., 2018), which, in turn, enhances learners' educational experiences.

As AI offers numerous advantages, it has garnered substantial scholarly attention. As a result of researchers' active promotion and investigation of the concept, considerable scholarly output has been produced about AIEd. While scholarly output is crucial in several aspects, such as establishing a foundation for future research and enabling knowledge dissemination, synthesising and interpreting this increasing volume of scientific research are essential. Hence, several review studies on AIEd have been conducted (Crompton & Burke, 2023; Xu & Ouyang, 2022; Zawacki-Richter et al., 2019). Some of those review studies adopted a systematic review strategy. For example, Xu and Ouyang (2022) executed a systematic review study to identify, classify, and summarise the studies portraying the wide-ranging roles of AIEd. Several databases, such as Scopus, Science Direct, and Web of Science, were scanned. However, they limited the time period between 2005 and the first eight months of 2021. Narrowing down their focus on the context of the teaching-learning process, Xu and Ouyang (2022) systematically analysed 164 publications and reported only 51 of them due to space restrictions. As a result of their systematic review, Xu and Ouyang (2022) proposed a conceptual framework based on AI's roles in instructional and learning processes. In the framework, three roles of AI were proposed: "AI as a new subject", "AI as a direct mediator", and "AI as a supplementary assistant" (Xu & Ouyang, 2022, p. 4213). According to the framework, in the first category, AI substitutes for the original subjects; in the second category, AI serves as a direct mediator to link subjects; and in the last category, AI has the role of a supplementary assistant and indirectly supports subjects. In another study, Crompton and Burke (2023) systematically reviewed publications on AI in higher education between 2016 and 2022. A wide range of databases, including EBSCO, JSTOR, and Web of Science, Crompton and Burke (2023) scanned to review 138 studies. While the previously conducted systematic reviews suggested that most of the studies were published in the USA, this trend has recently changed, and China overtook the USA in terms of the number of publications. Another significant finding of Cropmton and Burke's (2023) review lies in its categorisation of the themes based on the usage of AI in higher education. Hence, they reached five categories: '(1) Assessment/Evaluation, (2) Predicting, (3) AI Assistant, (4) Intelligent Tutoring System (ITS), and (5) Managing Student Learning' (Crompton & Burke, 2023, p. 19-20).

In addition to systematic reviews, bibliometric studies have been conducted within the field of AIEd (Chen et al., 2022; Guan et al., 2022; Prahani et al., 2022). These bibliometric studies are highly important as they provide quantitative insights into publication trends, citation patterns, and scholarly impact within the field of AIEd. For instance, in his bibliometric study, Talan (2021) explored the distributions of publications based on country and year; provided a citation pattern analysis of institutions, authors, journals, and documents; and mapped co-authors, co-citations, and co-occurrence analyses on the AIEd website. Examining the publications on AIEd within the past two decades (2001-2021), Talan (2021) used the Web of Science as the database and several keywords related to the term AIEd such as "artificial intelligence" OR "machine intelligence" OR "neutral network*" OR "machine learn*" OR "deep learn*" OR "natural language process*" OR "thinking computer system" OR "expert system" OR "evolutionary computation". Hence, Talan (2021) identified a total of 2,686 publications on the topic. His results were in line with the previous literature in terms of the distribution of the publications by country, a steady increase in the number of publications each year, the distribution of top journals on AIEd, and the leading authors. However, his analysis revealed that institutions located

in Taiwan and Australia, in addition to the previously identified influential institutions in the USA and UK have emerged as influential in AIEd.

A more recent bibliometric study, conducted by Metli (2023), screened 6498 studies published between 1984 and 2022 in the Web of Science and indexed them in "SCI_EXPANDED, SSCI, ESCI". Like in Talan's study (2021), Metli (2023, p. 285) also extended his search keywords to "Artificial Intelligence" OR "Deep Learning" OR "Machine Learning" OR "Natural Language Processing". In contrast to Talan (2021), Metli (2023) revealed that China and India were among the top five leading countries in terms of producing the most publications, alongside the USA, the UK, and Australia. Another noteworthy finding of Metli (2023) was the evolution of keyword popularity. The analysis documented the shift of certain concepts over time. It was revealed that while e-learning and higher education were popular terms in 2020, artificial intelligence, machine learning, and deep learning gained popularity in 2021.

Apart from the abovementioned studies, various other scientific studies were also conducted on AIEd. Some employed narrative overview methods to predict the potential impact of artificial technologies on the teaching-learning process and anticipate potential changes in the educational field (Chassignol et al., 2018). Others have focused only on AI in higher education (Bearman, 2023; Hinojo-Lucena et al., 2019; Maphosa & Maphosa, 2023; Zawacki-Richter et al., 2019). However, other scholars have investigated the AIEd concept, narrowing their focus down to a specific country or region, such as in China (Knox, 2020) or Turkey (İçen, 2020). Recognising that all these studies have significantly contributed to the literature and that the article growth rate increases by 22.68% each year (Metli, 2023), it is of great importance to conduct an up-to-date and holistic bibliometric study that complements previous studies. A new bibliometric study is indispensable for understanding the dynamics of the field and updating the accumulation of knowledge. This study, which is conducted both to determine the current state of the field and to verify or compare previous findings, plays a critical role in the continuity of scientific progress. Hence, the current study aims to holistically investigate the current trends, patterns, and future directions of AIEd. The purpose of this research is to offer insights to field experts to discover diverse research subjects and mitigate redundancies among studies. In line with these aims, the research questions of the current study address the following:

1. What is the overview of the publications in the AIEd field?
2. What are the leading authors, countries, and publication outlets in the AIEd field?
3. How do collaborations among the relevant authors and countries manifest in the AIEd field?
4. What are the trends and patterns in the AIEd field?

2. Methods

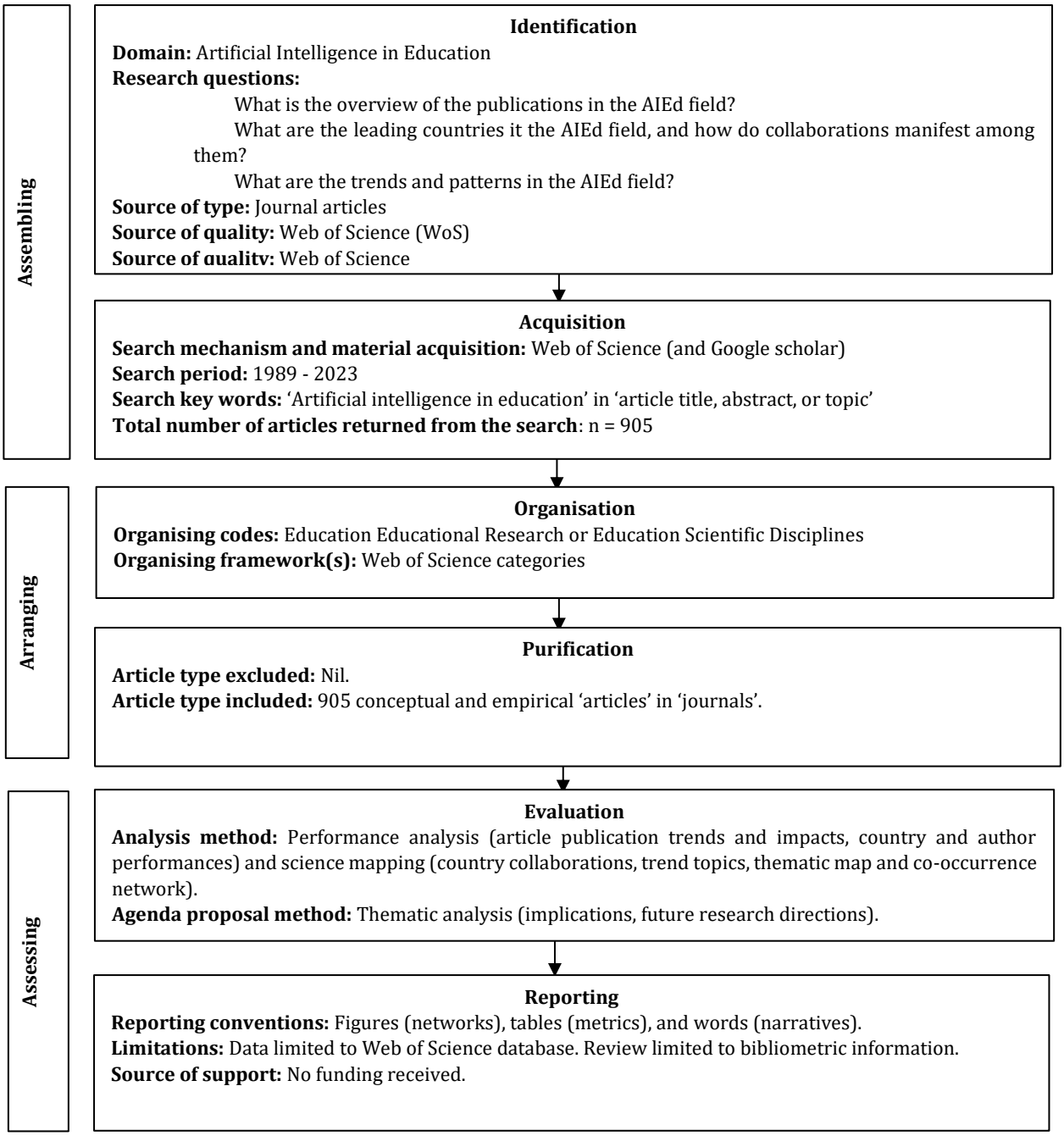
The current study adapts the scientific mapping analysis method. The methodology for the current study involves two main phases: the selection of document sources and the conduct of bibliometric analysis. The following sections explain these stages.

2.1. Selection of document sources

The Scientific Procedures and Rationales for Systematic Literature Reviews (SPAR-4-SLR) protocol was followed to maintain clarity and transparency (Paul et al., 2021). Figure 1 below describes the work flow for the current study.

Figure 1

SPAR-4-SLR protocol



As can be seen in Figure 1, the Web of Science (WoS) was selected for the data query because it is a sophisticated research repository and offers extensive bibliographic data, including authors, their affiliations, and cited works. The search query for the current study included 'Artificial Intelligence in Education'. All the documents that incorporated the search query within their abstracts, titles, or topics were included. As the current study aimed to trace the past, present, and future of AI within the educational field, the filters were applied to include the documents that were only listed under the categories of Education Educational Research or Education Scientific Disciplines. To obtain a holistic view, all document types, including book chapters and proceedings papers, as well as articles and early access were screened. All WoS indices were also included. The time limit was not applied to observe the progress of the term since its emergence. This means that publications between 1989, the date of the

first publication indexed in WoS, and 2023, the date of the last analyses of this study, were examined. Consequently, 905 documents were screened.

2.2. Bibliometric analysis

With the aim of conducting a quantitative evaluation of the documents, bibliometric methods were employed. Bibliometric studies, also referred to as scientific mapping, are useful methods for visually mapping the body of scientific literature in relation to a specific research area (Huang, Yang, Wang, Wu, Su & Liang, 2019; Song, Chen, Hao, Liu & Lan, 2019). Bibliometric studies involve evaluating a particular term by analysing and evaluating the impact of the relevant researchers and tracking the evolving patterns or changes in that specific concept over time (Hallinger & Kovačević, 2019). Bibliometric studies offer a comprehensive understanding of the field by categorising research according to publications, authors, and journals (Merigó & Yang, 2017; Sreenivasan & Suresh, 2023). Studies employing bibliometric methods provide insights into citation impact, establishing a correlation between author productivity, the influence of the scientific community, and publication success (Yu & Shi, 2015). For this study, Bibliometrix Software in the RStudio statistical analysis program was used. To visually present the data, the Biblioshiny Software package was used. The Biblioshiny package allowed several statistical analyses, such as conceptual and intellectual structure analyses, to be performed.

3. Results

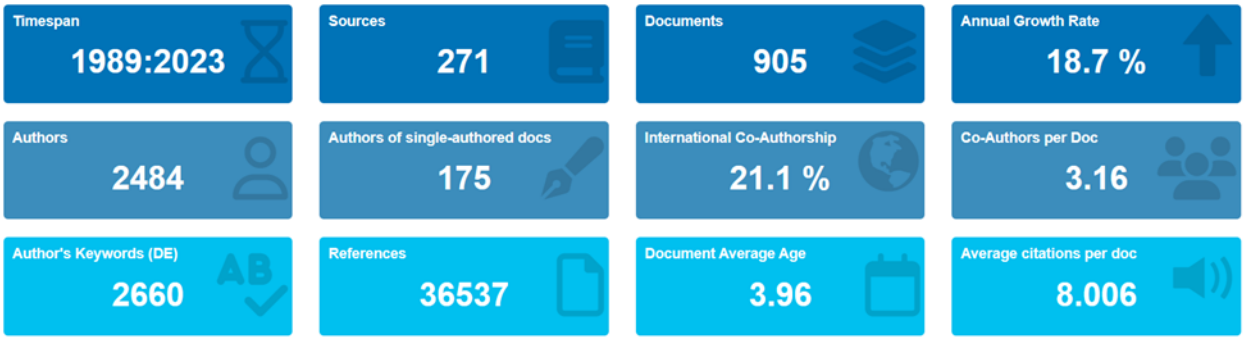
3.1. Overview of the publications in the AIEd field

3.1.1. Overview of the main information

The aim of the study was to investigate the historical progression, current status, and anticipated future developments within the field of AIEd studies. With this in mind, 905 records published between 1989 and 2023 in 271 journals with contributions from 2,484 authors were screened, as shown in Figure 2 below.

Figure 2

Overview of the Main Information



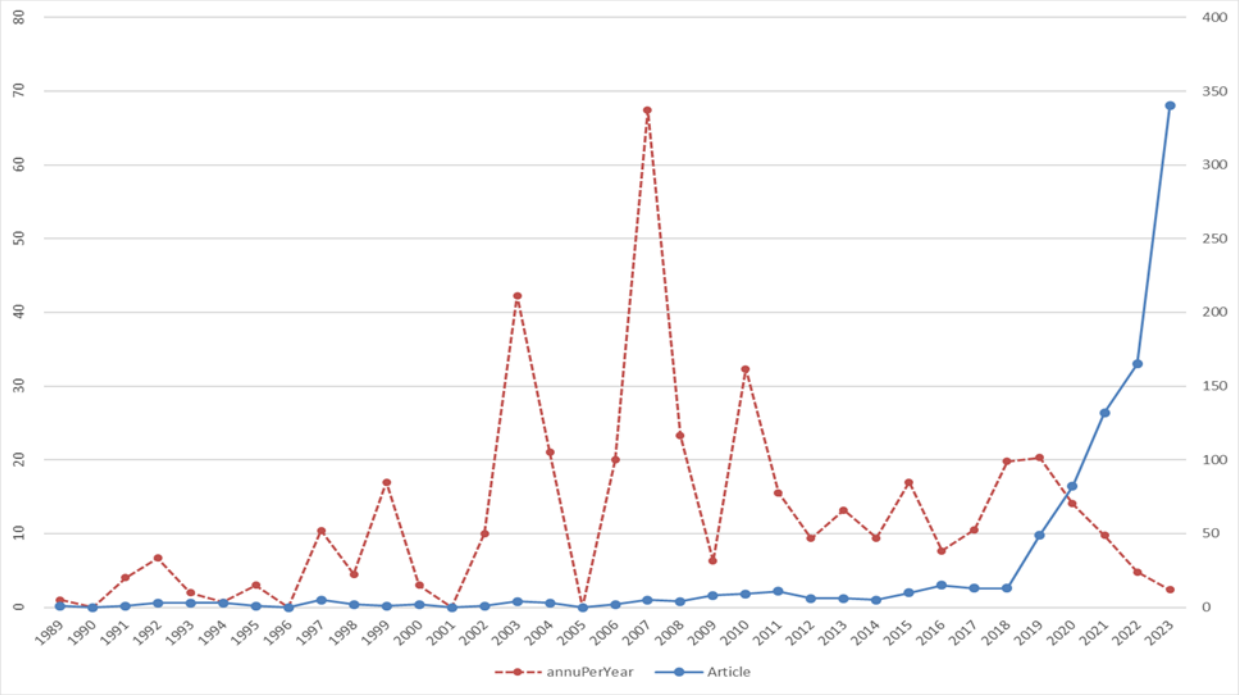
The analysis yielded 2,484 authors and 175 published single-authored documents. The review encompassed 36,537 references and approximately 8 citations per document. The yearly growth rate was calculated as 18.7%.

3.1.2. Distribution of annual publications and average citations per year

Biblioshiny analysed data regarding yearly scientific output and average citation counts. A graphical representation was employed to encapsulate the corpus of works and associated citations within a given year below.

Figure 3

Annual Scientific Production and Average Citations per Year



As can be inferred from Figure 3, an analysis of the yearly production of documents on AIEd revealed that the concept gained momentum after 2019. The number of studies published before 2018 was calculated as 137. While there were only a few publications for almost three decades since the emergence of the concept, 637 publications were produced during the last three years. The figure above demonstrates that no publications produced in 1990, 1996, or 2001 included AIEd in their abstracts, titles, or topics. It can also be seen that only a single document was detected for the years 1989, 1991, 1995, 1999, and 2002. Three documents were produced annually in the years 1992, 1993, 1994, and 2004. Figure 3 suggests that there has been a sudden increase in interest and, subsequently, the number of publications in recent years. A total of 132, 165, and 340 documents were produced in 2021, 2022, and 2023, respectively.

For the yearly average citations, 2019 and 2007 had the highest average citations per year, 4.1 and 4, respectively. Additionally, fluctuations can be observed between those years. A sudden decrease was observed in 2008, with an average of 1.4 citations per year. Although the average citations per year increased to 2.3 in 2010, this number decreased to 1.2 in 2011 and 0.8 in 2012. A steady decrease was also observed after 2019.

3.2. Leading authors, countries, and publication outlets in the AIEd field

3.2.1. Authors and their contributions

Examining publications through the lens of authorship reveals insights about notable contributors to the field of AIEd. These authors are classified by their productivity, quantified by the number of papers they have published in their field. Table 1 presents the five authors who contributed the most to the field.

Table 1

The Five Most Relevant Authors and Number of Publications

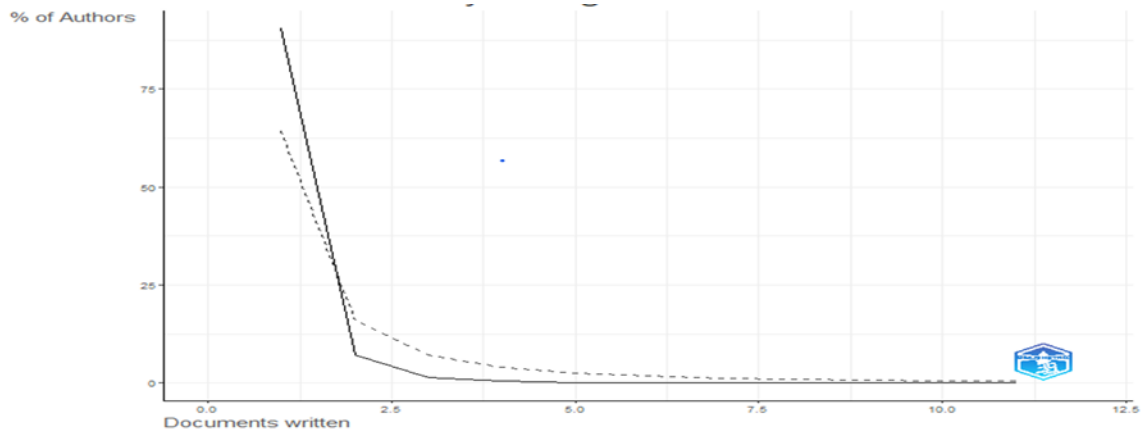
Authors	Publications
CHIU TKF	11
HWANG GJ	10
CHAI CS	9
WANG Y	8
XIE H	8

As can be seen in Table 1, Chiu TKF (n=11), Hwang GJ (n=10), Chai CS (n=9), Wang Y (n=8), and Xie H (n=8) were the authors who contributed the most to the field.

Author productivity was also analysed based on Lotka's Law (Lotka, 1926) distribution. Lotka's Law demonstrates the frequency distribution of scientific productivity among authors. This law suggests that the number of authors with a specified number of publications follows an inverse square distribution. Essentially, it states that a small number of authors publish the majority of publications, and a large number of authors publish fewer publications. Authors who have published more than five documents can be considered experts in the field and core authors (Metli, 2023). Figure 4 illustrates the relevance of the authors in the AIEd field.

Figure 4

Author Productivity by Lotka's Law



As Figure 4 suggests, author relevance in the AIEd field mostly aligns with the actual Lotka curve. The analysis showed that 2,246 authors published only one document. This number consists of nearly 90% of the authors. The results also showed that while 176 authors contributed to the field in association with only two articles, 33 authors published three documents. The percentage of authors who contributed to the field with five or more publications appeared to be only 0.64.

3.2.2. Most cited documents

The most cited document has the potential to represent the core body of knowledge in a relevant field and can, therefore, be considered an indispensable primary source for understanding or contextualizing the field. Hence, examining the most cited documents is important for comprehending the production and diffusion of knowledge within the discipline. With this in mind, the top ten most cited documents in this field are presented in Figure 5.

Figure 5

Most cited documents

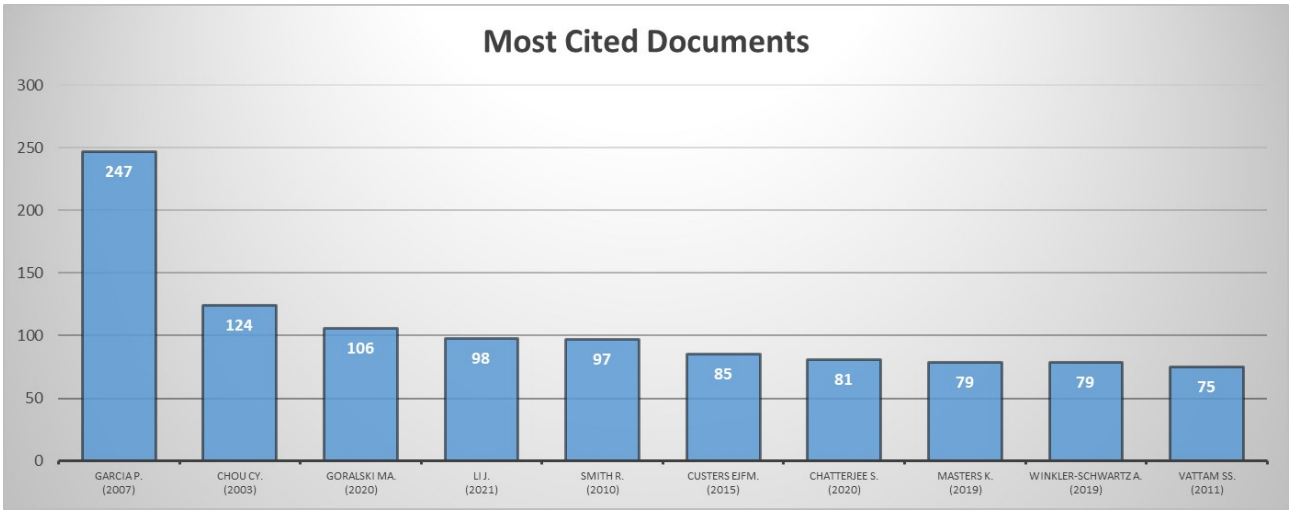


Figure 5 demonstrates that Garcia P. (2007) is the study with the highest number of citations in this field, with a total of 247 citations, followed by Chuo CY (2003) with 124 citations and Goralski MA (2020) with 106 citations. In addition, it was noted that Li J. (2021) and Smith R. (2010) were very close to each other in the top five with 98 and 94 citations, respectively.

3.2.3. Leading countries in the field

Within Bibliometrix's analysis of country-specific production, a distinct pattern emerges, delineating the five countries that exhibit the highest frequency in generating documents within the AIEd research field. Figure 6 visually illustrates the trajectory of each country's output.

Figure 6

Country Scientific Production

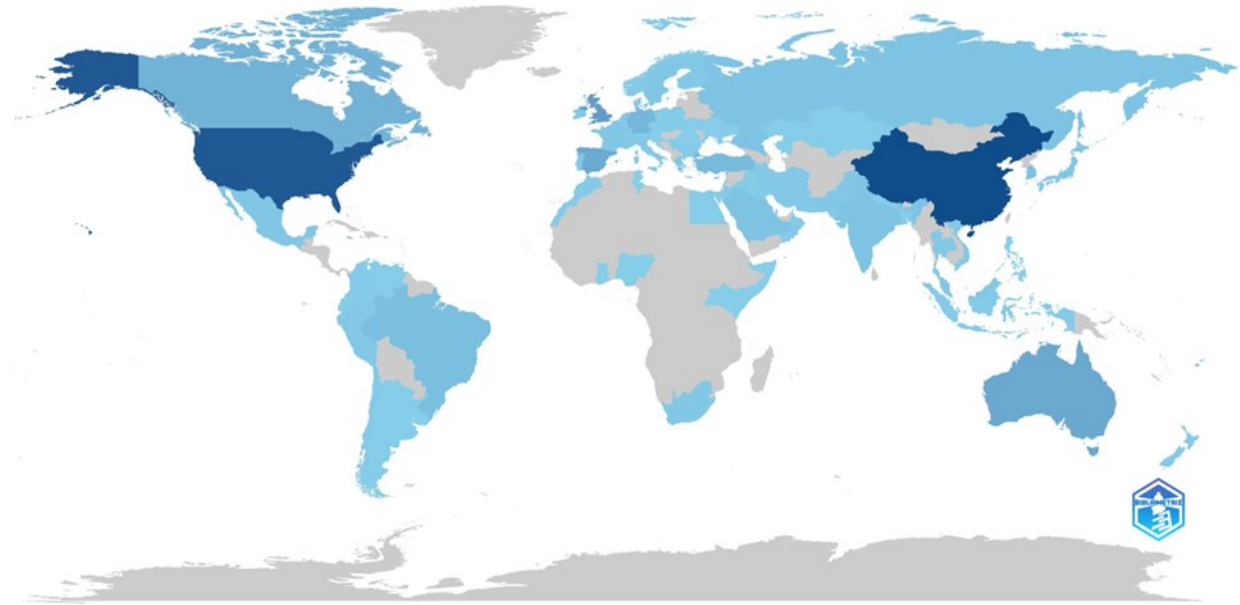


Figure 6 demonstrates the top five leading countries in the field of AIEd based on their production. In the figure, as the shade of blue increases, there is a positive correlation with the country's productivity. Based on the data obtained from Bibliometrix, China (n=624), the USA (n=565), the UK (n=226),

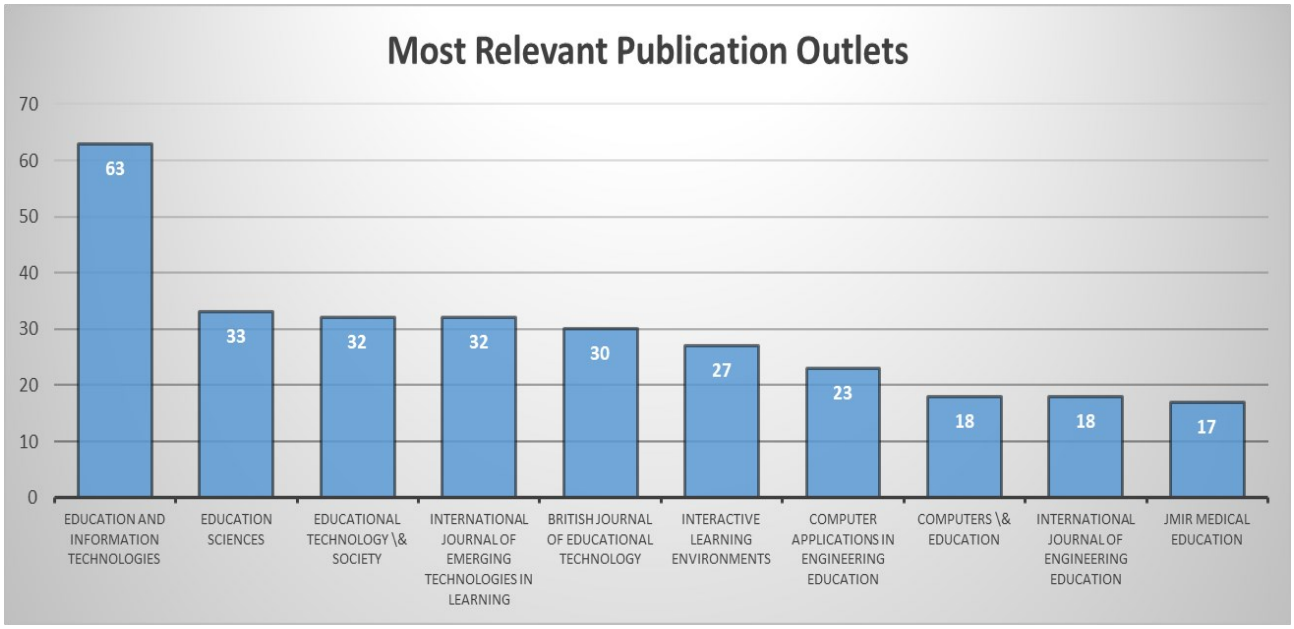
Australia (n=169), and Spain (n=164) are among the top five countries. The collaboration maps of these countries are visualised below. Increasing shades of red indicate increasing levels of cooperation between the entities represented. This darker shade suggests the frequency and strength of collaboration observed in the dataset.

3.2.4. Most relevant publication outlets

Identifying the best journals in a field is valuable as it provides a specific resource for those interested in that field. Hence, the most relevant publication outlets are presented below.

Figure 7

Most Relevant Publication Outlets



Upon the analysis of Figure 7, it can be seen that the Journal of Education and Information Technologies (n=63) is the main source of coverage in this area. This is followed by Educational Sciences (n=33), Educational Technology & Society (n=32), International Journal of Emerging Technologies in Learning (n=32), and British Journal of Educational Technology (n=30) with almost half the number of publications.

3.3. Collaborative links among the authors and countries

Identifying the most collaborating authors and countries in a field is crucial for researchers. This data is used to identify countries and institutions operating in similar fields. This helps researchers identify opportunities for collaboration and shape their career goals. At the same time, knowing the global development of a field and its leading authors and countries allows researchers to follow trends in their field and identify potential partners for international cooperation. As a result, analysis based on this data enables researchers to be effective and efficient in the international arena. Therefore, the data of the most collaborating authors and countries in the field are presented below.

Figure 8

Collaboration Among the Authors in the Field

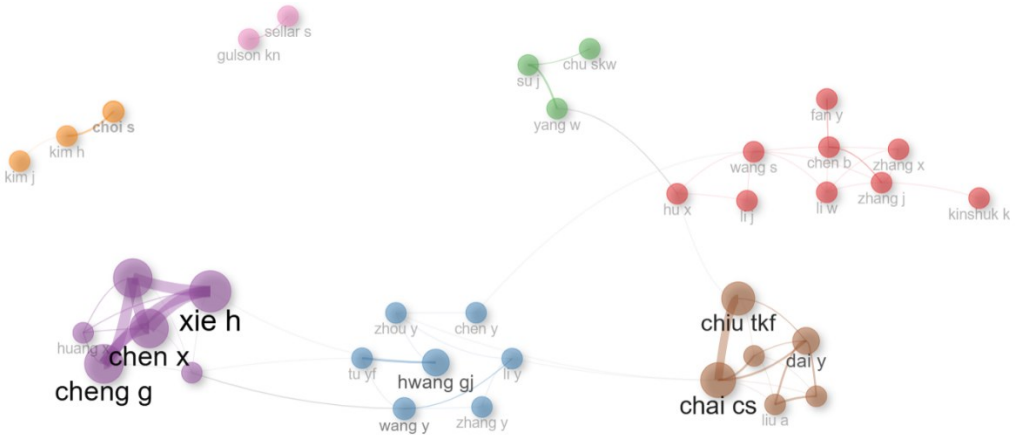
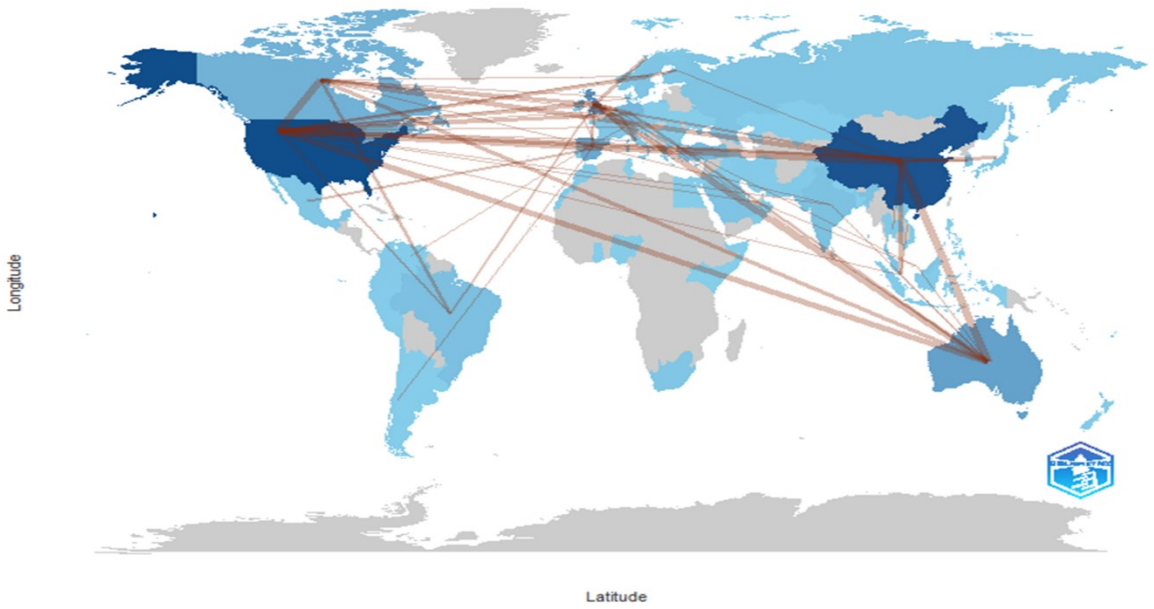


Figure 8 demonstrates that authors collaborating in this field are grouped into seven clusters. Although collaborations are predominantly within clusters, some authors also collaborate across clusters. For example, there are links between Yang W and Hu X, Hu X and Chiu TKF, and Chai CS and Li Y in different clusters. In particular, the presence of collaboration links between specific authors across different cluster groups suggests that these authors are active in a broad network and could potentially converge on different research areas or projects. This suggests that the field values collaboration and knowledge sharing and that such collaboration can enhance research results and knowledge production.

When the collaborations among countries were analysed, the results of the network analysis presented in the figure below were obtained. The network structure shown in the figure visually represents the cooperation links between various countries and the intensity of these links.

Figure 9

Collaboration World Map



Upon the analysis of Figure 9, it appeared that China and the USA had a very strong collaboration network (f=15). This frequency of network collaboration is followed by the UK and Australia (f=9) and

the USA and Canada (f=9). A strong collaboration network between China and Australia (n=8) and between China and Canada (f=7) is also observed upon the analysis of Figure 9.

3.4. Thematic analysis

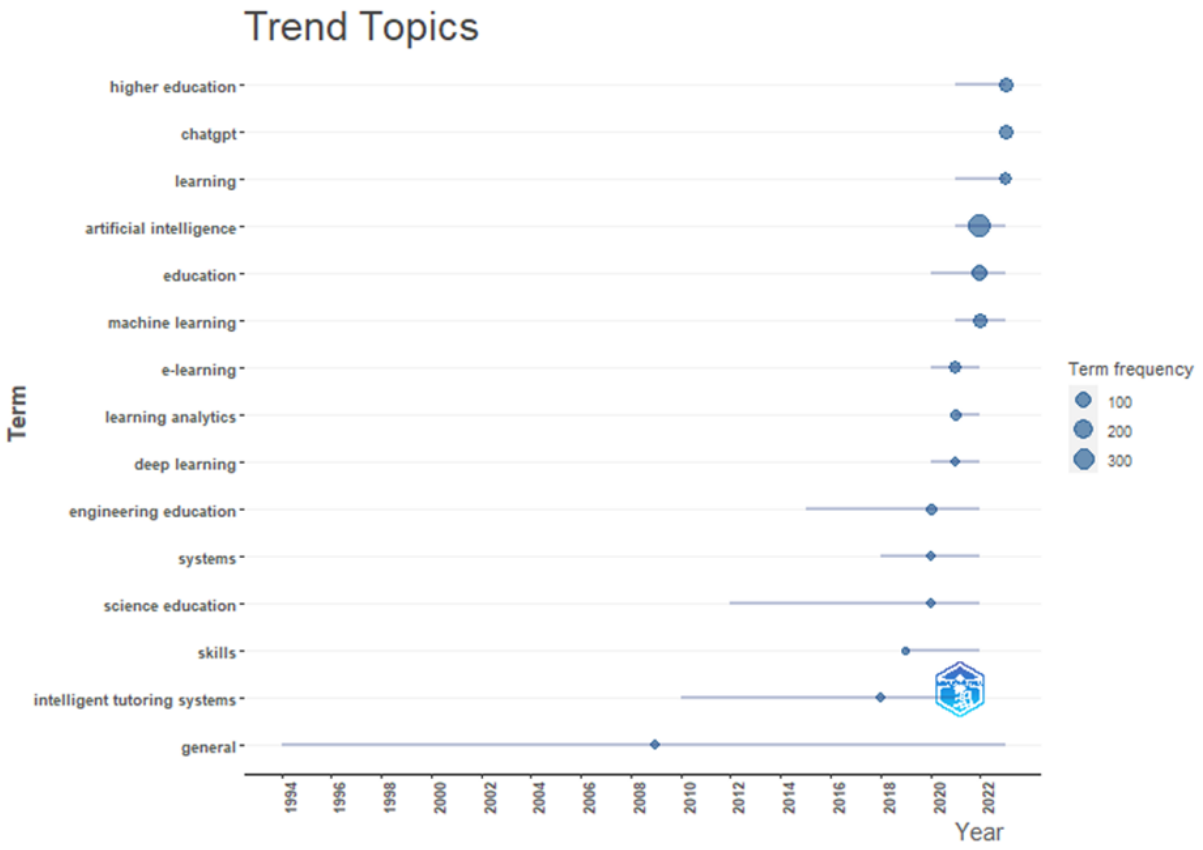
A set of thematic analyses, such as trend topic, thematic map, and co-occurrence network analyses, were also performed. Through these thematic analyses, the recurring themes, clusters, and interconnectedness of various research areas were illustrated.

3.4.1. Trend topics

Figure 10 graphically illustrates the temporal popularity of certain keywords identified by authors over different years. This visualisation focuses on the top three keywords used at least five times per year.

Figure 10

Trend Topics by Author Keywords



The figure above illustrates the trend topics according to author keywords. Until the second decade of the 21st century, the focus was more general, and the publications mostly revolved around intelligent tutoring systems and skills. The analysis suggested that more recently, the authors have narrowed their foci and studied engineering education, science education, systems, e-learning, learning analytics, and deep learning. It is not surprising that during the last three years, artificial intelligence has appeared to be a trending topic. However, interestingly, the focus has shifted from deep learning to machine learning, and studies have specifically concentrated on the context of higher education rather than education in general.

3.4.2. Thematic map

Figure 11 shows a strategic diagram of AIEd research. A strategic diagram shows the interactions of elements of a particular research topic over time. This diagram is a fixed depiction of the network

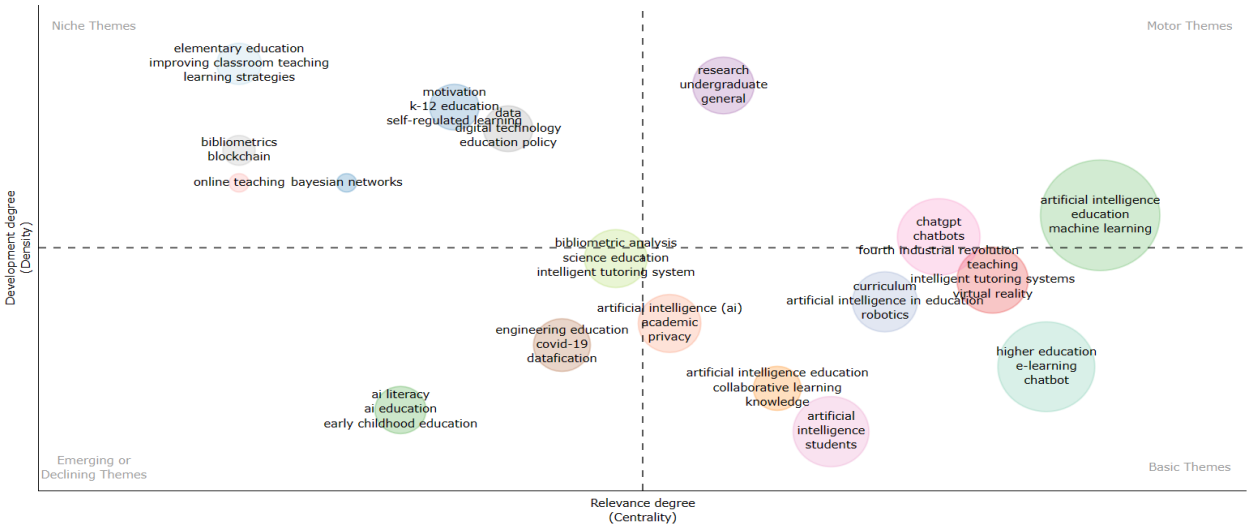
structure of a field. The diagram was created using Bibliometrix by focusing on the top 250 author keywords that appeared at least three to five times. The most common keywords are grouped into themes, each represented by the top three words. The size of each circle in the diagram corresponds to how often that keyword is used.

The strategic diagram was divided into four slices, and each slice was analysed within itself. With this purpose in mind, two metrics, centrality and density, were established. The y-axis represents the intensity parameter, while the x-axis represents the centrality parameter as a thematic map. The greater the centrality of the chosen theme is, the more important it is considered to be; similarly, the higher its intensity is, the more it is regarded as developed (Metli, 2023; Nasir et al., 2020).

In the interpretation of the strategic diagram, Cobo et al. (2011) use the terms Motor, Niche, Emerging or Declining, and Basic Themes. The Motor Themes are characterised by high density and centrality. They indicate significant development in the field of study and are shown in the first quadrant theme, positioned in the upper-right section of the thematic map. The niche themes, denoting highly developed yet isolated areas with high density and relatively lower centrality, align with the second quadrant theme, which is situated in the upper-left part of the thematic map. The emerging or declining themes, which display emerging or declining trends with low centrality and density, correspond to the third quadrant themes located in the lower-left segment of the thematic map. The Basic Themes, extensively researched with well-established internal connections demonstrating low intensity but high centrality, represent the fourth quadrant themes positioned in the lower-right portion of the thematic map. Figure 8 below visualises the interactions of themes related to AIEd over time.

Figure 11

Thematic Map



It becomes evident that within the field of education, artificial intelligence has attracted the interest of researchers across various subjects or areas. The largest bubble is observed in the motor theme quadrant, which consists of artificial intelligence, education, and machine learning. These findings suggest that these are the most commonly used author keywords and highly developed themes. In addition, research, undergraduate, and general themes encompass another cluster with high density within the motor themes. Although the ChatGPT, chatbot, and fourth Industrial Revolution clusters are situated mostly within the motor themes quadrant, a small part of these clusters fall into the basic themes quadrant. This observation might indicate that this cluster of ChatGPT, chatbots, and the fourth industrial revolution likely began to receive substantial attention and scrutiny within the field of study. Another basic theme appears to consist of artificial intelligence, academics, and privacy based on the

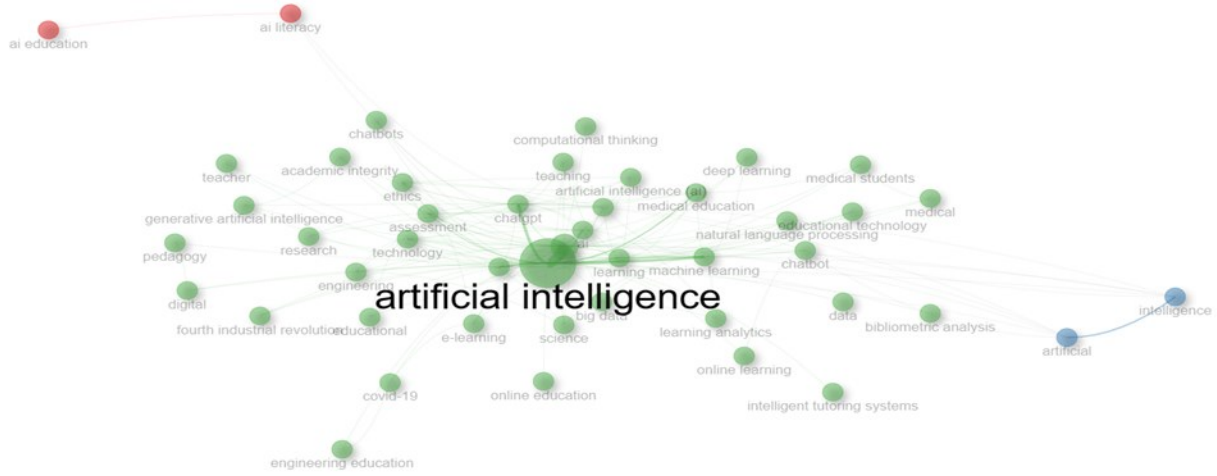
authors' keywords. However, this cluster positions itself on the verge of the basic theme quadrant, indicating that it has a tendency to fall into the emerging and declining themes. Among the emerging or declining themes, the cluster of "engineering education", "COVID-19", and "datafication" was detected, which suggested that although these themes were once well researched, they have started to lose popularity. When the niche themes are analysed, bibliometrics and blockchain; motivation, K-12 education, and self-regulated learning; elementary education; improving classroom teaching; and learning strategies form different clusters.

3.4.3. Co-occurrence network

Co-occurrence network analysis denotes how often two keywords co-occur within an article. This approach helps identify relationships and patterns within the field. Figure 12 shows the results of the co-occurrence network analysis based on author keywords.

Figure 12

Co-Occurrence Network



Upon analysing Figure 12, it can be inferred that the term artificial intelligence dominates the field. It can also be suggested that the term artificial intelligence developed strong links with several other themes, such as machine learning, deep learning, and computational thinking. In addition to the dominating theme, small clusters can be observed. Among those small groups, AI education and AI literacy appeared to be connected, and artificial and intelligence terms were observed to form a different network.

4. Discussion

The current study aimed to gain insight into and graphically represent the body of literature concerning AIEd through the use of the scientific mapping method. The timeframe of the review spans from 1989 to 2023. The last search was conducted in November 2023. The Bibliometrix program in R Software was used to analyse the data. The analysis included the basic structure encapsulating the authors involved in the field, the numbers of publications and references, the annual growth rate, and the average citations per year. The leading countries in the field, their collaborations with other countries, the most influential authors, and their contributions were also analysed. Finally, thematic analysis, including trend topic, cluster, and interconnectedness, of various research areas was also performed.

The main data analysis revealed that 905 documents were published in 271 publication outlets and indexed in the WoS database between 1989 and 2023. A cumulative count of 2,660 different author keywords was recorded. Moreover, the bibliographies included a total of 36,537 articles. The calculated

annual article growth rate is 18.7%, indicating a significant and swift increase in article production over the years. This rapid increase in publications in the field of AIEd is in line with the findings of the current literature (Metli, 2023; Prahani et al., 2022). This swift increase in AIEd publications can be attributed to several reasons. It can be suggested that advancements in technology constitute a main catalyst for the proliferation of publications. Technological developments, specifically in machine learning, deep learning, and natural language processing, paved the way for researchers to explore the field in depth (Song & Wang, 2020).

This study revealed that China, the USA, the UK, Australia, and Spain are the most productive and influential countries in the field of AIEd. Compared to previous studies, it is interesting to observe some variations in the rankings. For example, in Talan's (2021) study, the sequence followed the order of the USA, the UK, China, Australia, and Spain. In turn, Metli's (2023) study portrayed India, rather than Spain, as among the most active countries in the field, although the top four countries were the same in all three studies. When the collaboration world map is analysed, a robust network among the leading countries is observed. While the presence of this strong network is not entirely unexpected, the notable inclusion of Canada, as opposed to Spain, within the scope of collaborative connections is intriguing. The existence of Canada within this network link resonates with the current body of literature. In their relatively narrow-scope study, Baek and Doleck (2020) analysed 135 documents that were published in one journal, namely, the Journal of Artificial Intelligence in Education, between 2015 and 2019. Their findings revealed a robust collaborative linkage between the USA and Canada. Furthermore, the findings also revealed the five most influential authors in the field, one of whom appeared to be Hwang GJ. Although Hwang GJ was found to be the second most relevant author in the present study, in Metli's (2023) analysis, he was the most relevant author. This relatively small discrepancy between the current study and that of Metli (2023) might have occurred due to differences in the parameters used during the analysis. Despite this small difference in ranking, it can be concluded that Hwang GJ contributed enormously to the field and is one of the most, if not the most, influential authors in the AIEd field. The analysis of author productivity revealed that the results align with Lotka's Law. This means that although the AIEd has garnered researchers' interest substantially, the majority of them published only one article. The percentage of prolific authors, defined in this study as those who contributed to at least five publications, was calculated as 0.64. These results suggest that although the field has been explored by many researchers, only a few have specialised in this topic. However, while interpreting this finding, it is important to acknowledge the implications for funding allocation, research collaboration, and the challenges in ensuring equity and recognising contributions among researchers in a field.

The most cited works in the field of AiEd are Garcia's (2007) "Evaluating Bayesian networks' precision for detecting students' learning styles", Chuo's (2003) "Redefining the learning companion: the past, present, and future of educational agents", and Goralski's (2020) "Artificial intelligence and sustainable development". These studies suggest that AI in education enhances personalised learning, improves educational outcomes, and supports sustainable and inclusive educational practices. Assessing the role and impact of AI in education, these studies show that AI promotes personalised learning in educational processes, which can better respond to the individual needs of students. This contributes to a more effective and engaging learning experience for students (Liu et al., 2022; Seo et al., 2021). In addition, there is a large body of research supporting that AI-supported educational applications improve educational outcomes and increase students' achievement levels (Chen et al., 2020; García-Martínez et al., 2023). Finally, AI is also frequently researched to support sustainable and inclusive educational practices (Holmes, 2021; Lee & Lee, 2021). Studies on these topics point to the potential to increase equality of opportunity in education and meet the needs of diverse student groups. Hence, it can be inferred that these studies on the importance and impact of AI-supported educational practices shed light on the future development of educational systems. They also provide insights into the versatility and potential of AI in education in general.

Another interesting finding was that The Journal of Education and Information Technologies is the journal that publishes the most documents in this field. Moreover, the seven journals in the top ten have technology coverage, emphasizing the impact of educational technologies and digital transformation.

On the other hand, Educational Sciences stands out as the second journal with the second highest number of studies, indicating that educational sciences are addressed in a wide range. However, what is more striking is that medical education and engineering education themed journals are also in the top ten. This reveals that AI has become a growing research topic not only in general educational technologies but also in specific teaching fields. In particular, it shows how AI is transforming educational processes in technical and applied fields such as medicine and engineering and contributing to the development of innovative teaching methods in these fields.

For the thematic analyses, the recurring themes, clusters, and interconnectedness of several research areas were analysed. An analysis of the trend topics based on author keywords revealed that, at the beginning of the 21st century, the forefront of scholarly attention was on general skills and smart education systems. However, more recently, researchers have shifted their interest noticeably toward a more diverse range of subjects. This shift can be explained by several factors, including but not limited to the swift progress in educational technologies, the advancements in data analytics methodologies, and, consequently, the increase in AI applications. Notably, the dominance of fields such as science education, engineering education, learning analytics, e-learning, and deep learning potentially highlights the increasing significance of scholarly inquiries in these fields. The scholarly focus on advanced technology domains such as AI and deep learning emphasises their transformational potential in education. Furthermore, the growing amount of study on higher education, as opposed to general education, shows how scholarly interests in this field are evolving. These changes indicate a crucial evolution in educational research and reveal potential areas that could significantly influence future educational approaches.

The current study also investigated the evolution of keyword popularity throughout different time periods. The results revealed the evaluation of several themes over time, which became more or less important in different years. The analysis indicated that while the field was affected by current topics such as COVID-19, which once was popular and then lost popularity, certain themes such as machine learning, ChatGPT, and chatbots maintained their popularity. Based on the results, it can also be inferred that despite the existence of a few studies, there is a research gap in the themes of self-regulated learning, K-12 education, improving classroom teaching, and learning strategies. Hence, additional studies need to be conducted in these areas.

Finally, the analysis of co-occurrence networks revealed that AI has developed strong connections with machine learning, deep learning, and computational thinking. These findings align well with the literature (Metli, 2023; Prahani et al., 2022; Talan, 2021). This emphasises the importance of the strong links between these topics in the field of AI and suggests that future research could focus on examining these relationships in more detail.

4.1. Implications, further research, and limitations

This study has multifaceted implications. Among these implications, several key facets merit elaboration. Primarily, the current study refines the research focus by identifying the most influential authors, leading countries, and trend topics and themes in the field. This enables a more focused approach for researchers and practitioners. Gaining insight into the most common and impactful study types and methodologies helps in narrowing the research focus, facilitating more focused studies, and consequently fostering in-depth understandings within the AIEd field. Another facet of this study is that it offers insights for educational policy and practice. The current study revealed the most relevant issues within the AIEd field. Understanding the key concerns and priorities in the field helps in informing educational policies and practices. Insights gained from this study can assist policymakers, educators,

and curriculum developers in effectively integrating AI technologies into education, which in turn enhances learning experiences and outcomes. Anticipation and preparation for future trends can be listed as another facet of this study. This bibliometric study aimed to map researchers' main lines of focus and identify evolving trends. Hence, this study serves as a tool for anticipating and preparing for future developments within the AIEd field. This study provides a proactive perspective, helping stakeholders predict and adapt to emerging trends, thus maintaining a competitive edge in the ever-changing landscape of AI in education. Finally, this study can be considered a guide for future research. This study offers a guiding framework for future research within the AIEd field. By outlining motor, basic, emerging, and niche themes, this bibliometric study provides valuable guidance to researchers seeking to investigate niches and new avenues within the field.

Although this study offers several valuable insights, it is important to acknowledge its limitations. One of the main limitations of this bibliometric study is the use of a database. The search was limited to the documents that are listed on the Web of Science (WoS). Despite housing a wide range of publications, employing only the WoS database may have constrained the number of potentially relevant publications. Additional research might include the use of other databases. Another limitation is that the current study restricted the documents to be reviewed to Education Educational Research or Education Scientific Disciplines. Some other categories might include studies relevant to the AIEd. Hence, additional categories can be included in further research. However, in this case, a careful screening to exclude and include the publications is suggested.

5. Conclusion

Technological developments, specifically in artificial intelligence, have led to dramatic transformations in conventional education. Hence, it is imperative to explore the integration of AI into educational fields. With this aim in mind, the current study meticulously conducted a comprehensive bibliometric analysis in AIEd and investigated the patterns, trends, and further directions of AI in education. This study carefully examined the publication outputs, collaboration patterns, cluster formations, and evolutionary trends within the field. By leveraging these detailed and multifaceted analyses, this bibliometric study aimed to offer valuable insights into diverse facets of the AIEd field. Moreover, this study sought to underscore future possibilities and directions for this field.

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