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Investigating the Research Trends of Articles on Science Education and Artificial Intelligence

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Abstract

In the current era, the integration of artificial intelligence applications into education systems is inevitable. One of the fields that is expected to be in contact with the concept of artificial intelligence the most is science education. This study was carried out with the aim of revealing the research trends of articles on science education and artificial intelligence and bringing the bibliometric profile to the literature. Descriptive research design, one of the quantitative research models, was used in the study. In the analysis step, bibliometric analysis method was preferred. Web of Science Core Collection was used as the database and VOSviewer was used as the network analysis program. The findings of the study were obtained by analyzing 89 articles on science education and artificial intelligence. As a result of the research, the most productive author in the articles on the relevant subject area is Xiaoming Zhai, the journal is Frontiers in Education, the institution is University System of Georgia, and the country is the USA. In addition to these findings, it was determined that the most frequently used keyword in the articles in the related subject area was "artificial intelligence".

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Introduction

Traditional learning models are being reexamined and critically scrutinized in an era marked by rapid technology breakthroughs and a massive multiplication of information (Anderson & Rivera Vargas, 2020; Collins & Halverson, 2018). One theory that has emerged from this re-evaluation is connectivism. It emphasizes the importance of digital technologies and the interconnectedness of information in the modern world (Siemens, 2005). As a relatively recent learning theory, connectivism has become a significant framework for understanding the impact of technology on education. According to connectivism, learning is not just an individual process; it is heavily influenced by the connections and networks formed online (Downes, 2007). It means that the individual's learning process does not only occur with his or her knowledge and experiences but is also shaped by contributions from online environments and tools that technology has brought to our lives. This stands in contrast to traditional learning theories, which typically center on individual cognition or behavior. Therefore, in the digital age, connectivism acknowledges that knowledge is widely dispersed and continually evolving, necessitating learners to adeptly navigate and utilize these networks. This paradigm shift calls for a departure from the conventional, instructor-centric classroom towards more learner-centered, collaborative, and technology-enhanced approaches. Blended learning, which integrates both face-to-face and online elements, exemplifies this evolution by enabling learners to interact with content, peers, and educators through diverse modalities (Hrastinski, 2019; Kaur, 2013). Moreover, connectivism's emphasis on the role of technology in learning aligns with the potential applications of artificial intelligence (AI) in education. Both highlight the transformative impact of digital tools on educational practices and the improvement of learning outcomes (Spiess et al., 2021). This intersection signifies ongoing progress towards more dynamic and responsive educational environments. AI has the potential to revolutionize education by providing personalized and adaptive learning experiences for students. AI-supported systems can identify learning patterns and adapt teaching content to meet individual needs (Chen et al., 2015; Roll & Wylie, 2016). Accordingly, the utilization of artificial intelligence in education aligns with the fundamental principles of the connectivist approach, influencing students' control over their learning processes and enabling them to make various connections between different sources of information (Roll & Wylie, 2016).

AI has the capacity to transform various aspects of education, from personalized learning to intelligent tutoring systems (Pratama et al., 2023) and has the potential to change traditional patterns of learning and teaching. The intersection of connectivism and AI in education carries promising implications for science education. By eliminating the difficulty of teaching lessons in a real classroom environment using traditional methods and taking into account each student's individual differences, AI can provide personalized learning experiences by adapting content to individual students' needs and learning pace, making complex scientific concepts more accessible. It provides data-driven feedback to teachers and curriculum developers by identifying areas where

students struggle and providing targeted support. However, AI can overcome the barrier of perceiving science and mathematics courses as difficult subjects (Leyva et al., 2022), improving accessibility and inclusiveness, and enabling students with different learning needs to benefit from science education (Tapalova & Zhiyenbayeva, 2022). Innovative tools like virtual labs and simulations can allow students to engage with scientific experiments in a practical and hands-on manner. Furthermore, AI can support teachers by automating routine tasks, giving them more time to focus on facilitating deeper understanding and critical thinking in science subjects. This integration of AI into science education can not only improve learning outcomes but also can prepare students for a future where technology plays a central role. With all this awareness, the application of AI in education has garnered increasing attention in recent years. Even a simple search on Google Scholar with the search code "artificial intelligence" between 2020 and 2024 yields 1,290,000 results. If we add "education" to this code, we encounter 490,000 results between these years. In every field, even in different branches of education, studies using AI are undoubtedly important in understanding its nature and effects. One of these branches is science education, which we can view as a steppingstone for AI and other technological advancements. Understanding the landscape of AI research in science education is crucial for identifying trends, gaps, and future directions. Bibliometric analysis provides a systematic method to analyze the vast body of literature, offering insights into the development and impact of AI in science education. That's why this study aims to conduct a bibliometric analysis of research on artificial intelligence in science education. By examining publication patterns, influential authors, and key research topics, the study seeks to map the evolution of AI research in science education and highlight emerging trends and areas for future investigation.

Theoretical Framework

The History of Artificial Intelligence

Alan Turing's 1950 paper, "Computing Machinery and Intelligence," laid the foundations for artificial intelligence and questioned whether machines could think. In this paper, although the current accessibility and wide applicability of artificial intelligence might seem like just a theory, Turing proposed the "Turing Test" to determine whether a machine could exhibit human-level intelligence (Turing, 1950). Following this notable work, research in the field of artificial intelligence and its development progressed rapidly. Specifically, the concept of AI was first introduced in 1955 by John McCarthy, a mathematician who is also known for organizing a conference on AI the following year (Brynolfsson & McAfee, 2017). Shortly thereafter, a platform was established to discuss the capacity of machines to exhibit human-like intelligence. One of the discussions, led by economist Herbert Simon in 1997, was quite bold. According to him, computers would surpass human chess abilities within a decade (Frantz, 2003). Similarly, in 1974, cognitive scientist Marvin Minsky believed that artificial intelligence would be largely solved within a generation (Minsky, 1974). Since 1975, AI has progressed from expert systems to artificial neural networks, big data, and deep learning breakthroughs

(Rumelhart et al., 1985); became widespread in various fields like autonomous vehicles and healthcare in the 2010s (Hengstler et al., 2016); and rapidly advanced in the 2020s with a focus on chatbots and ethical regulations (Larsson, 2020; Shin et al., 2021). To summarize, AI, a topic of discussion for nearly 70 years, has reached the stage where it is realizing some of the predictions made in the past. However, debates about what more lies ahead continue.

The Transformative Role of Artificial Intelligence in Science Education

As can be seen, AI has emerged as a transformative force in various domains, and its impact on science education is particularly profound. Even before AI had reached its current level of development and widespread use, researchers in the 1980s, such as Good (1987) and Hurd (1988), discussed its potential effects and the role of science education in leveraging this technology. These early studies underscored the importance of using AI in science education and highlighted the need to train individuals through science education to advance AI technology. They argued that integrating AI into science education not only enhances the learning experience but also prepares students to contribute to the development of AI technologies. The importance of combining science education with AI can also be clearly seen when we compare it with the goals of integrated STEM (Science, Technology, Engineering and Mathematics) education over the last two decades. In today's increasingly technological world, it is no longer sufficient to know science and mathematics in isolation. Instead, the integration of technology and engineering with science and mathematics is essential for keeping pace with technological advancements (Hamal et al., 2022; Miller, 2017). AI, as a product of this technological evolution, plays a crucial role in this integration. Therefore, science education, which we believe is important in integrating rapid technological progress into education and understanding technological developments, should not be left behind.

Through simulations, virtual labs, and intelligent tutoring systems, AI can create interactive and immersive learning environments that make complex scientific ideas more accessible and engaging for students. Therefore, AI's impact on science education extends beyond personalized learning; it also equips students with the skills necessary to thrive in a technology-driven future. According to a study, AI has the potential to revolutionize STEM higher education by transforming teaching and learning methodologies, curriculum design, student engagement, assessment practices, and institutional strategies (Nagaraj et al., 2023) AI-based systems can analyze student data, identify individual strengths and weaknesses, and tailor learning materials to cater to each student's unique needs (Mavroudi et al., 2017).Moreover, this entegration can significantly enhance student engagement, improve learning outcomes, and reduce dropout rates. AI-based tools can provide instant feedback, allowing students to receive real-time guidance and identify areas for improvement (Kamalov et al., 2023). This can lead to more efficient and effective learning, as students can receive immediate support

and guidance to address their learning gaps. Additionally, AI-powered educational robots have garnered attention in the field of science education (Yang et al., 2023). Although research on artificial intelligence is in its early stages, it has been suggested that chatbots in science education can enhance learning experiences, improve learning outcomes, and increase student engagement and interest in the course (Deveci Topal et al., 2021).

In summary, the application of AI to education is seen as a technology with high potential that will increase the quality of education and learning in many respects.The motivation behind this study stems from the observation that, despite the transformative potential of AI, there remains significant uncertainty about how best to integrate it into education. As Brynjolfsson and McAfee (2017) aptly put it, "*You've been told it will transform everything. You've been told you need to invest in it. But you haven't been told how. Start here.*" AI is still a nascent topic in the field of education, with many attempting to integrate it but lacking clear guidelines and methodologies. Therefore, this study aims to examine the research trends in articles focusing on science education and AI by analyzing the bibliometric profile of publications in this area. By investigating these trends, this study seeks to provide valuable insights into the current state of research in this emerging field, helping educators, researchers, and policymakers make informed decisions on effectively integrating AI into science education. This can lead to more effective educational practices and better prepare students for a technologically advanced future. The central research question guiding this study is: What are the research trends in articles on science education and AI?

The sub-problems examined in the study in the context of the research question are:

- How is the publication trend in the fields of science education and artificial intelligence distributed over the years?
- In which languages are publications on science education and artificial intelligence available?
- In which research areas are publications on science education and artificial intelligence being studied?
- Which journals are the most productive for publications on science education and artificial intelligence?
- Which countries are the most productive in publishing articles on science education and artificial intelligence?
- Which countries have the highest level of collaboration in publications on science education and artificial intelligence?
- Which institutions are the most productive in publications on science education and artificial intelligence?
- Who are the most productive authors studying on science education and artificial intelligence?

- Which documents have the highest number of citations in research on science education and artificial intelligence?
- Who are the authors with the highest number of citations in articles on science education and artificial intelligence?
- Which journals have the most citations for articles on science education and artificial intelligence?
- What are the keywords used in articles on science education and artificial intelligence?

Method

Research Model

The aim of the study is to reveal the research trends of articles on science education and artificial intelligence. In line with the research purpose, descriptive research model, one of the quantitative research methods, was preferred in this study. Descriptive research is research that aims to describe the characteristics of the study sample or the relationship between situations and events observed by the researcher (Siedlecki, 2020; Vaismoradi et al., 2013). In the study in which descriptive research model was used, bibliometric analysis method was preferred as the analysis method. Bibliometric analysis method is a quantitative analysis method that presents the bibliographic characteristics of the literature on the relevant subject with numerical data in the historical process (Hawkins, 2001). Bibliometric analysis method is an analysis method that offers the opportunity to reveal and examine the research trend and bibliometric profile on the relevant subject at a global level based on the outputs obtained through analysis programs of scientific publications published in various databases. With the bibliometric analysis method, it is possible to examine the research trend of a certain concept or a journal from past to present. In this context, it has been a frequently preferred method especially in recent years in studies aimed at examining the research profile or research trend (Donthu et al., 2021; Ellegaard, 2018).

Research Data

Web of Science Core Collection (WoS) was preferred as the database to collect data in order to reveal the research profile and examine the trend of articles on Science Education and Artificial Intelligence. VOSviewer program was used as a network program for the analysis of bibliometric data. In order to create the research data, the researchers searched the Web of Science Core Collection database with the keywords "science educat*" and "artific* intelligen*". In the study, the scientific studies on artificial intelligence were focused on those related to science education. The researchers were interested in the research tendency of the articles related to artificial intelligence and science education. Therefore, the keywords "science educat*" and "artific* intelligen*" were used in the search. The researchers carried out the first search in the database with keywords in the topic heading. When topic is preferred as the search heading, the title, abstract, keyword plus, and author keywords of the publications registered in the database are searched. This heading was preferred to narrow the area to be searched and to reach highly relevant publications with the selected keywords. In the research,

articles were analyzed among scientific publications. Scientific articles were preferred in the study because they are considered to be the most representative type of academic publications as they have the most frequent publication intervals and they provide original, comparable data suitable for bibliometric method analysis (Prahani et al., 2024). The data set of this study consists of 89 articles obtained after the studies eliminated with appropriate filtering selected by the researchers in the search made with the selected key concepts in the WoS database.

Data Collection Process

The data for this study were created in June 2024. The study data consists of articles published in the Web of Science (Web of Science Core Collection provided by Clarivate Analytics) database on the relevant subject. The Web of Science database is one of the most popular and widely used databases that publishes studies from many different disciplines, is sensitive to the reliability of the scientific studies it publishes, publishes scientific studies with high impact power, has a wide coverage network, and has high popularity (Goodman, 2007; Zyoud et al., 2017). For these reasons, Web of Science was preferred as the database in this study. At the beginning of the data collection process, the researchers searched the WoS database with the keywords "science educat*" and "artific* intelligen*" in the topic heading. The first search resulted in 179 scientific publications. Among 179 scientific publications, articles were filtered. As a result of the filtering, 111 articles were found. It was determined that 22 of the 111 articles were published in 2024. Since the aim of the study was to reveal the research trends of scientific articles on science education and artificial intelligence, the data for 2024 were not included in the study. Since interpreting the data of a year that has not yet been completed may make the bibliometric profile and trend of the relevant subject open to misinterpretations, the data of 2024 were not included in the study. With the exclusion of 2024 data, the remaining 89 articles constitute the data of the study. The data collection and filtering process is presented in Figure 1.

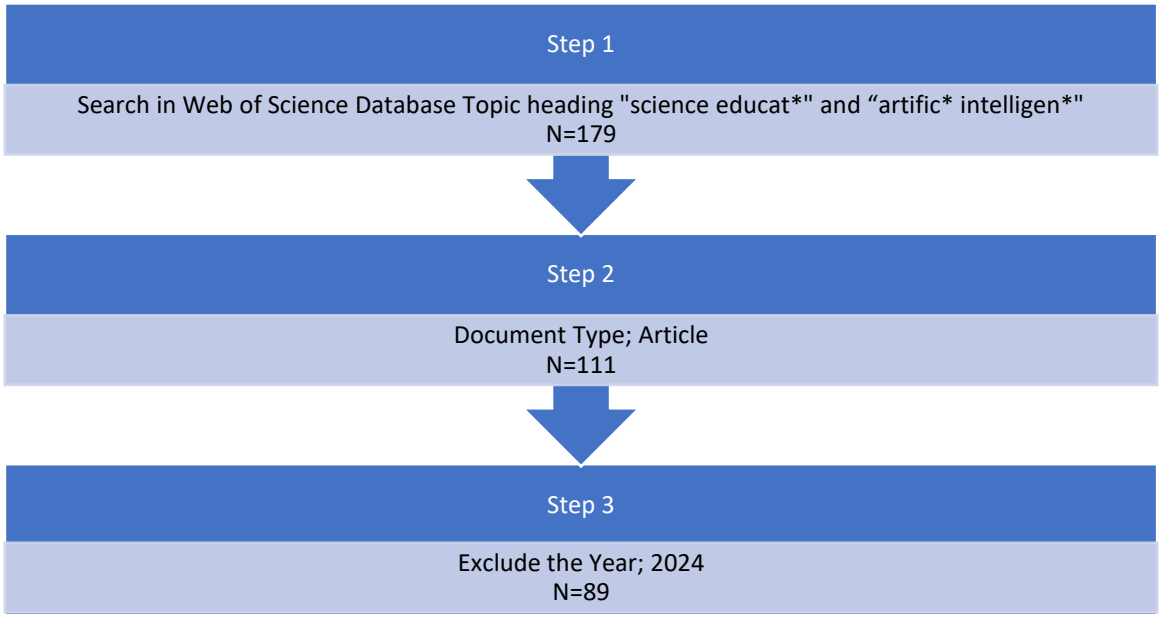

Figure 1. Data Selection Process

Data Analysis

With the completion of the data collection process, the data analysis step was started. The study is a descriptive study. Bibliometric analysis was preferred as the analysis method. In this context, VOSviewer, one of the network programs, was used to analyze the bibliometric data that constitute the data set of this study. VOSviewer is a network program that can visualize data and uses the Visualization of Similarities (VoS) algorithm for this visualization process. The VOSviewer network analysis program creates high-quality visual materials, making large-scale scientific network graphs easier to understand (Sinkovics, 2016; Van Eck & Waltman, 2009; Van Eck & Waltman, 2017). For these reasons, VOSviewer program was preferred in the study. As a result of the analysis made with the VOSviewer program, information such as authors, journals, countries with the most documents in the literature on the relevant subject, as well as information on the number of citations, relationship strengths and keywords can be presented. The VOSviewer program can make visualization with co-occurrence maps in the presentation of this information. Co-occurrence maps match the size of the circle or the shape it uses with features such as the number of publications in the literature, the number of citations, and can show the links and relationships between the shapes. Likewise, the larger and more central the shape used in the co-occurrence maps presented in the analysis of keywords, the more frequently the keyword is used. The larger the shape, the more popular the keyword is. The stronger the relationship between two key concepts in the keyword co-occurrence map, the more frequently the two key concepts are used together (Pei et al., 2021; Van Eck & Waltman, 2014).

Results

Year Distribution of Scientific Articles on Science Education and Artificial Intelligence

Articles on science education and artificial intelligence are analyzed, it is seen that the first article was published in 1985. The first publication published in 1985 was an article titled "Artificial intelligence and expert systems research and their possible impact on information science education" written by Harold Borko. The study was published in the journal "Education for Information". The study focuses on expert systems and artificial intelligence and investigates their impact on information systems. The distribution of the number of publications by years is presented in Chart 1.

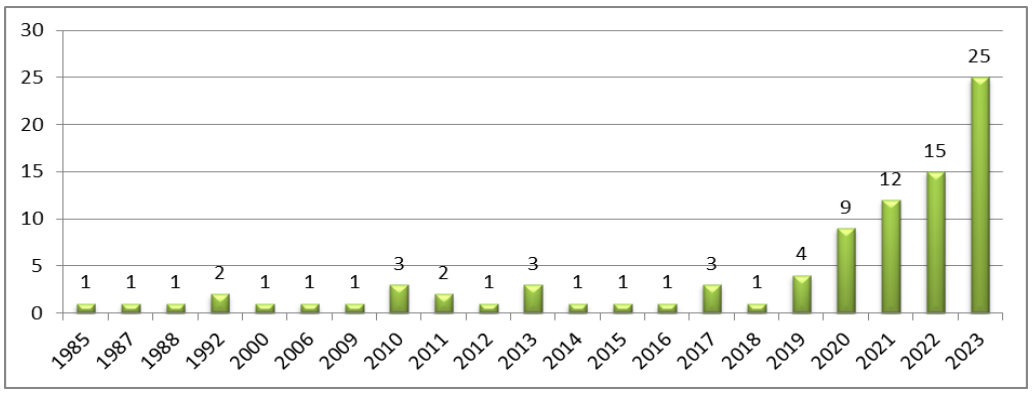

Chart 1. Annual Distribution of Publications on Science Education and Artificial Intelligence

When the years and numbers of publications are analyzed, it is seen that in some years no publications were published, while in some years (1985, 1987, 1988, 2000, 2006, 2009, 2012, 2014, 2016 and 2018) only one publication was published. When the year distribution data of the articles are analyzed, the trend in the number of articles on the relevant subject for the last 39 years, except for the year 2024, emerges. When the 39-year research trend is analyzed, it is seen that the year with the highest number of publications is 2023. When the data are analyzed, it is possible to say that the interest in studies on science education and artificial intelligence started in the mid-1980s, but this interest disappeared in the 1990s. In the 1990s, only two articles were published in the preferred database in 1992. When the graph is analyzed, while there is a variable number trend before 2018, a steady increase in publications is observed after 2018. After 2020, the number of publications increased significantly compared to previous years. This situation can be interpreted as the main popularity in the relevant subject gained in 2020 and after.

Distribution of Languages in which Scientific Articles on Science Education and Artificial Intelligence are Published

Language of publication of the articles on science education and artificial intelligence is analyzed, it is seen that the majority of the articles are published in English (Chart 2).

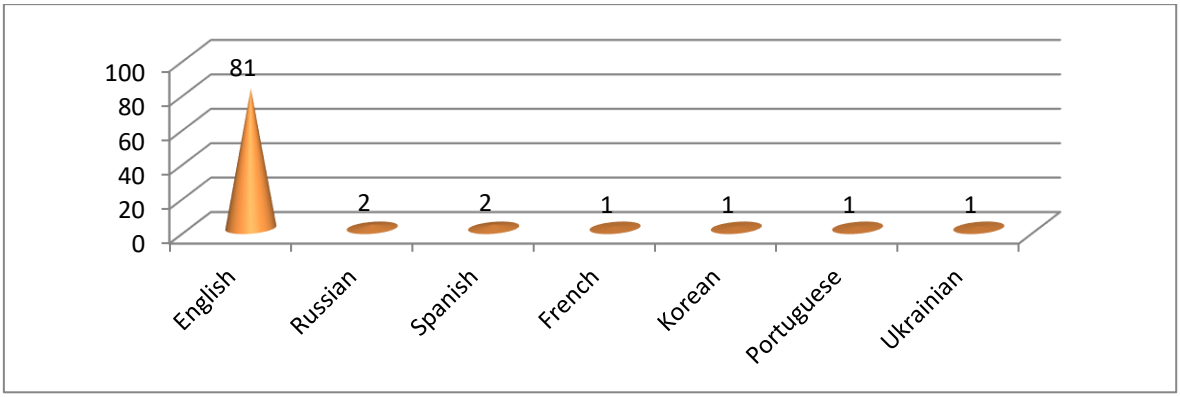

Chart 2. Language Distribution of Publications on Science Education and Artificial Intelligence

When the data are analyzed, it is seen that articles on science education and artificial intelligence are published in 7 different languages in the WoS database. In the 39-year period from 1985 to 2024, 91.01% of the articles (81 articles) were published in English. Of the remaining 8 articles, 2 were published in Russian and 2 in Spanish. The remaining 4 articles were published in French, Korean, Portuguese and Ukrainian. Since English is the most widely used language in academic and spoken language, it is an expected result that the majority of the articles are in English.

Distribution of Scientific Articles on Science Education and Artificial Intelligence by Research Areas

Scientific articles on science education and artificial intelligence cover 23 distinct research fields in the WoS database (Chart 3).

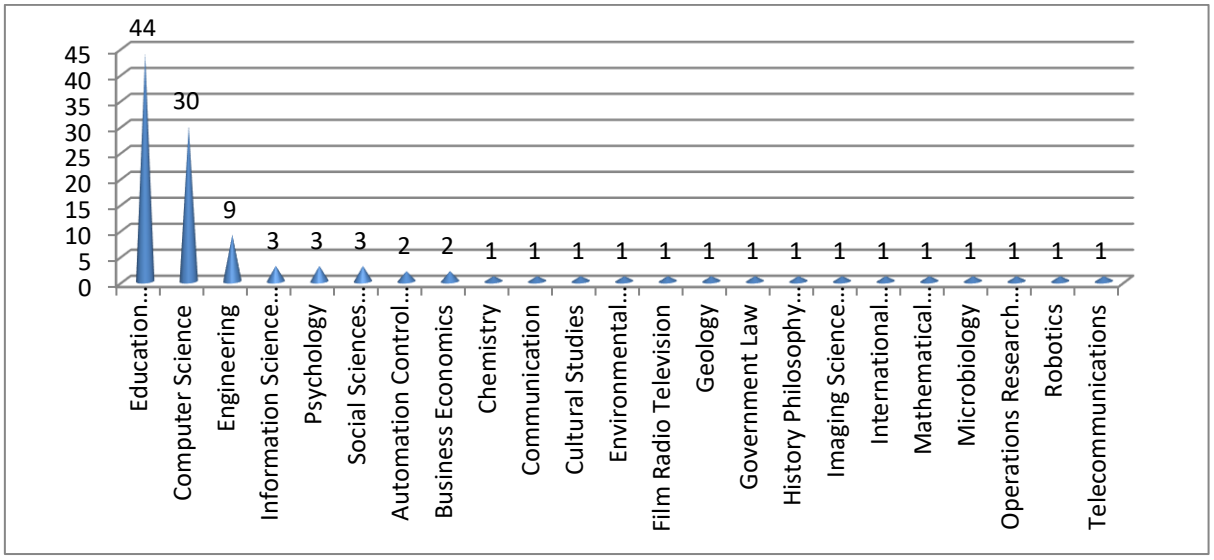

Chart 3. Distribution of Research Fields in Scientific Articles on Science Education and Artificial Intelligence

When the data are analyzed, it is seen that the articles on science education and artificial intelligence are mostly (49.43%) studied in the field of educational research. In the field of educational research, 44 articles on science education and artificial intelligence were studied. Educational research is followed by Computer Science (30 articles), Engineering (9 articles), Information Science Library Science (3 articles), Psychology (3 articles) and Social Sciences Other Topics (3 articles).

Distribution of Productive Journals for Scientific Articles on Science Education and Artificial Intelligence

Data on the journals publishing articles related to science education and artificial intelligence reveal a total of 71 journals in the database. To enhance data readability, the top 20 journals and their publication counts are presented in Chart 4.

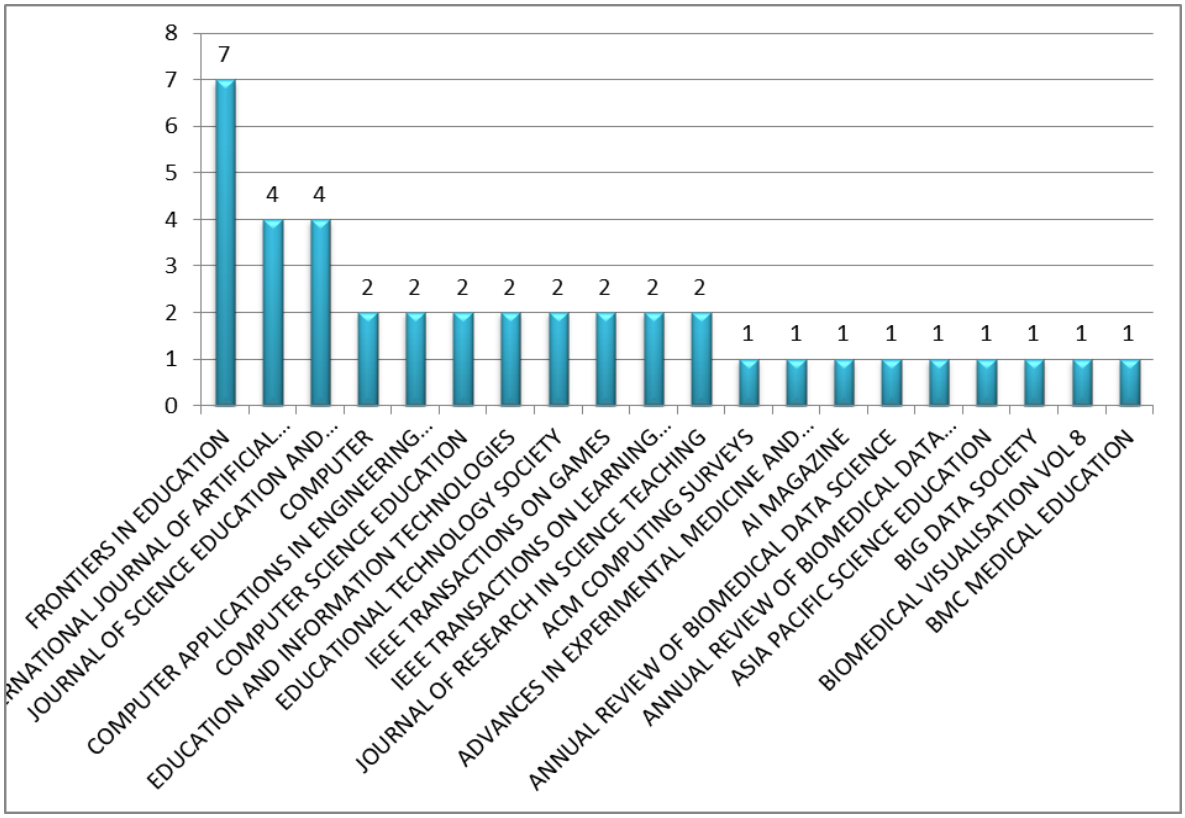

Chart 4. Distribution of Most Productive Journals in Science Education and Artificial Intelligence Research

The most productive journal in the field of science education and artificial intelligence is "Frontiers in Education." This journal focuses on topics such as digital learning innovations and STEM education, publishing a total of 7 articles in the area. Next in productivity are the journals "International Journal of Artificial Intelligence in Education" and "Journal of Science Education and Technology," each publishing 4 articles. The list of the most productive journals continues with "Computer," "Computer Applications in Engineering Education," "Computer Science Education," "Education and Information Technologies," "Educational Technology Society," "IEEE Transactions on Games," "IEEE Transactions on Learning Technologies," and "Journal of Research in Science Teaching," each contributing 2 articles.

Distribution of Productive Countries for Scientific Articles on Science Education and Artificial Intelligence

The analysis of the most productive countries for scientific articles on science education and artificial intelligence reveals 42 countries listed in the WoS database. For clarity, the top 20 most productive countries in this field are presented in Chart 5.

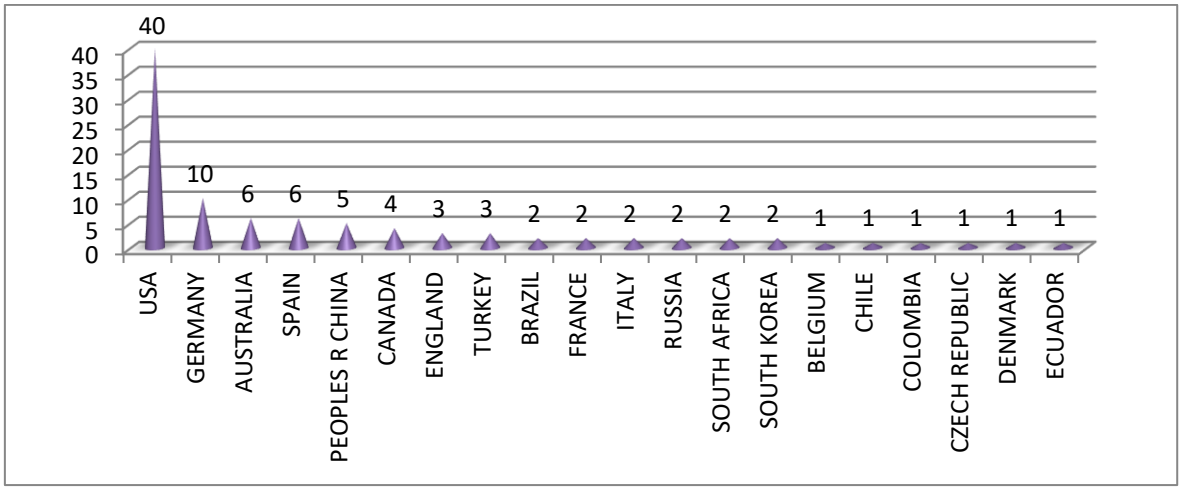

Chart 5. Distribution of Most Productive Countries for Scientific Articles on Science Education and Artificial Intelligence

The United States is the most prolific country in publishing articles on science education and artificial intelligence, with a total of 40 articles (44.94%) in this field. The integration of technological systems into science education began in the USA, which is recognized as a pioneer in this integration. This prominence reflects the significant emphasis placed on technology-supported structures within the U.S. education system. Germany follows as the second most productive country with 10 articles. Australia (6), Spain (6), and China (5) are ranked third, fourth, and fifth, respectively.

International Collaboration (Country) Distribution in Scientific Articles on Science Education and Artificial Intelligence

International collaboration in scientific articles on science education and artificial intelligence involves 42 different countries. The top 20 countries with the highest collaboration strength are shown in Chart 6.

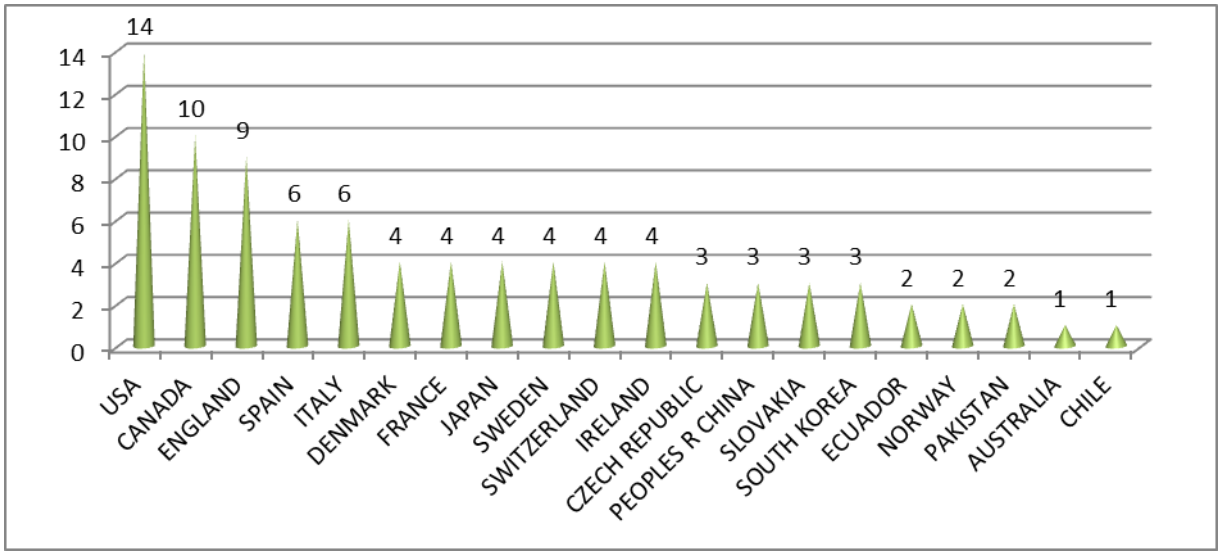

Chart 6. Collaboration Strength among Countries in Science Education and Artificial Intelligence Research

When the data are analyzed, it is seen that among the countries with publications on the relevant subject, the USA is the country that collaborates the most and has the highest strength of relationship. This is an expected result since the USA has the highest number of publications. The USA is followed by Canada (10), England (9), Spain (6) and Italy (6). Twenty-three of the countries with publications on the related subject maintain a collaborative relationship with each other. The co-occurrence map of the cooperation between countries is presented in Figure 2.

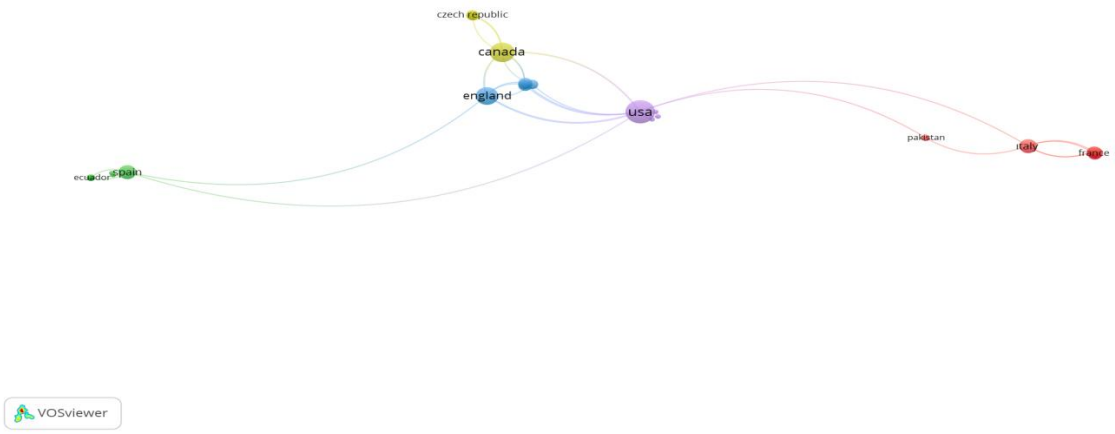

Figure 2. Co-occurrence Map of International Publication Collaborations

Distribution of the Most Productive Institutions in Scientific Publications on Science Education and Artificial Intelligence

Analysis of productive institutions in science education and artificial intelligence research reveals 173 institutions listed in the WoS database. The top 20 most productive institutions are presented in Chart 7.

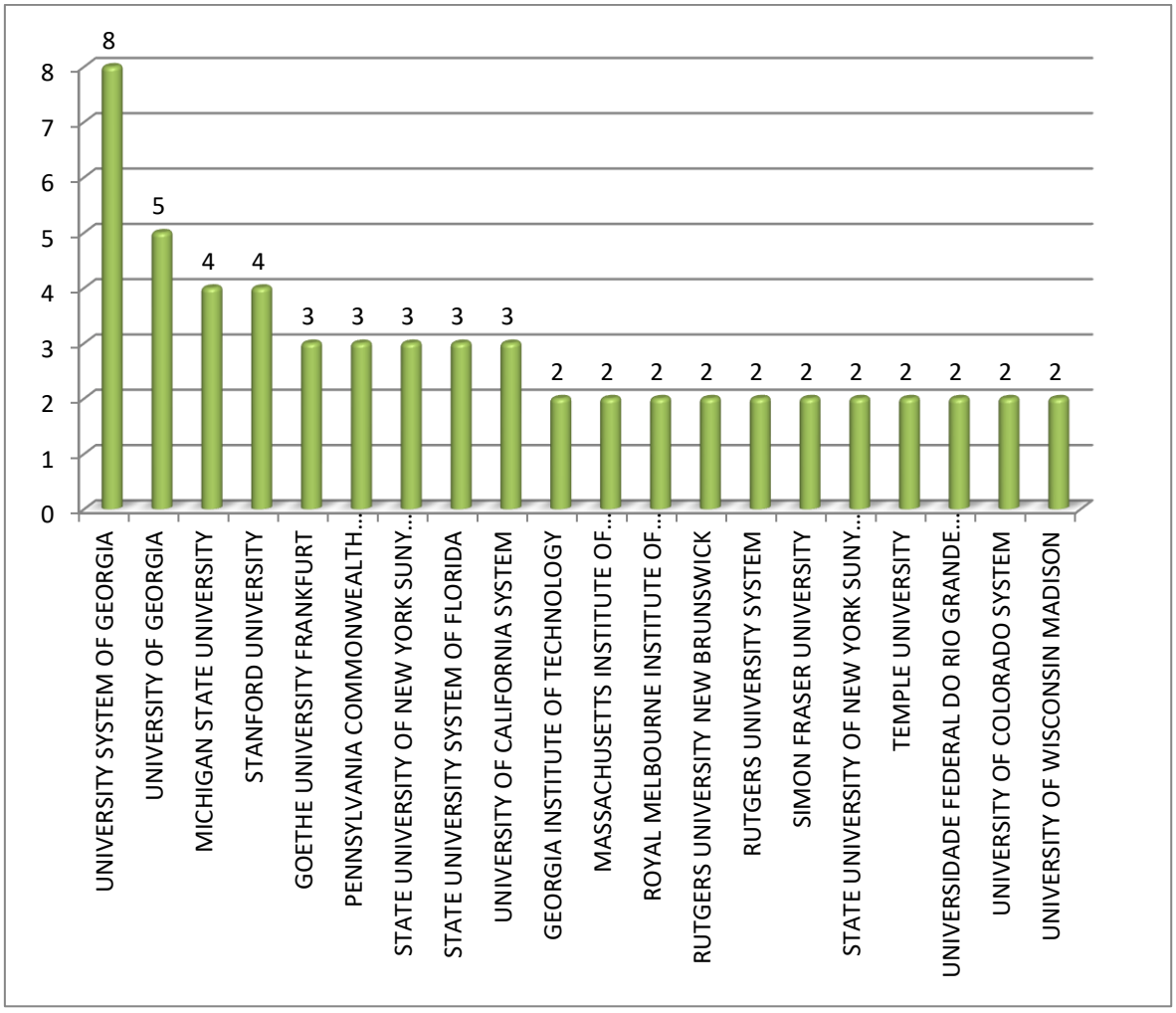

Chart 7. Leading Institutions with Publications on Science Education and Artificial Intelligence

The analysis of institutions publishing articles on science education and artificial intelligence reveals that the University System of Georgia is the most prolific, contributing to 8 publications in this field. The second most productive institution is the University of Georgia, with 5 publications. Other notable contributors include Michigan State University and Stanford University, each with 4 articles, and Goethe University Frankfurt, Pennsylvania Commonwealth System of Higher Education, State University of New York SUNY System, State University System of Florida, and University of California System, each with 3 articles. Among the institutions with at least 3 publications, 8 out of 9 are located in the United States. The sole institution outside the U.S. is Goethe University Frankfurt in Germany. This distribution underscores the prominence of U.S. institutions both in terms of publication volume and collaborative efforts in this field.

Distribution of the Most Prolific Authors in Science Education and Artificial Intelligence Research

Analysis of the most prolific authors in science education and artificial intelligence research reveals 315 researchers in the Web of Science database. To enhance readability, the top 20 authors are presented in Chart 8.

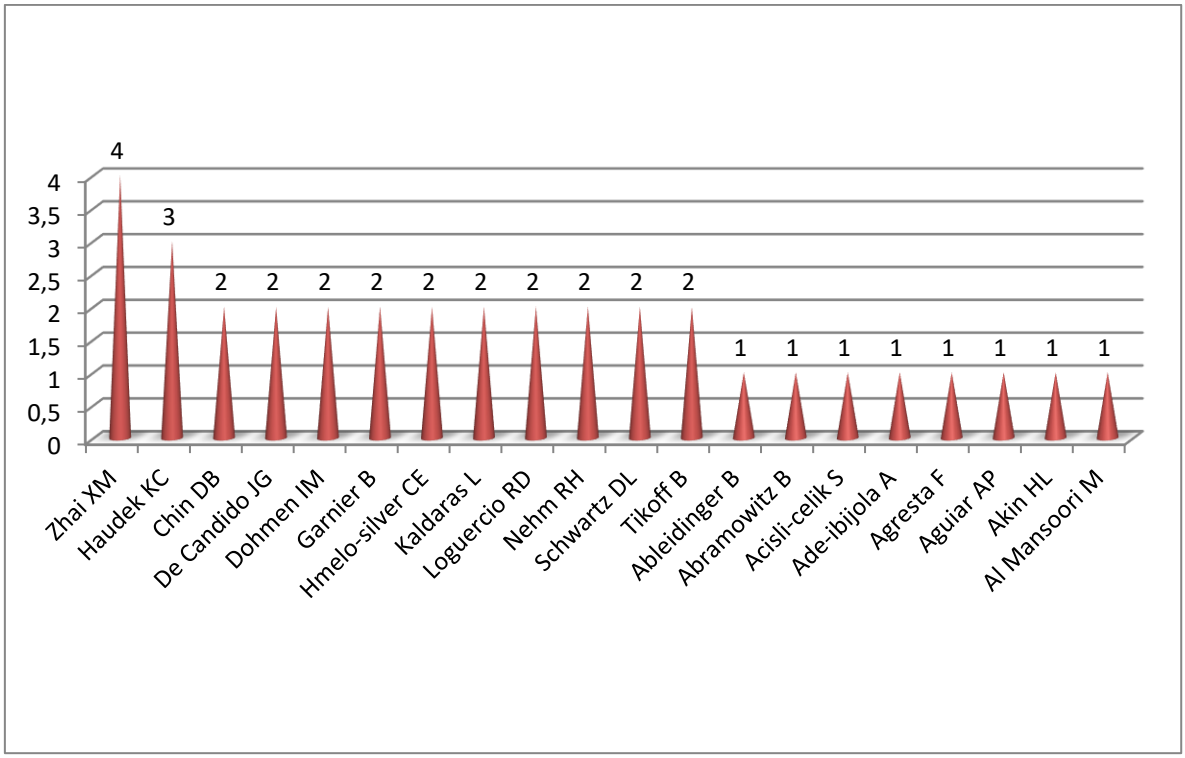

Chart 8. Prolific Authors and Their Number of Publications in Science Education and Artificial Intelligence

The most prolific author in the field of science education and artificial intelligence is Xiaoming Zhai, who has published four articles on this topic. Zhai is affiliated with the University of Georgia, which ranks as the second most productive institution in this field. The second most prolific author is Kevin C. Haudek, with three articles. Haudek is affiliated with Michigan State University, the most productive institution in this domain.

Findings Related to Citation Information of Scientific Articles on Science Education and Artificial Intelligence

The citation information for articles on science education and artificial intelligence was initially examined on a document basis. According to the analysis results, the document with the most citations is the study titled "Examining Science Education in ChatGPT: An Exploratory Study of Generative Artificial Intelligence," written by Grant Cooper and published in the Journal of Science Education and Technology in 2023. This study has 149 citations. The top 20 most cited documents are presented in Chart 9.

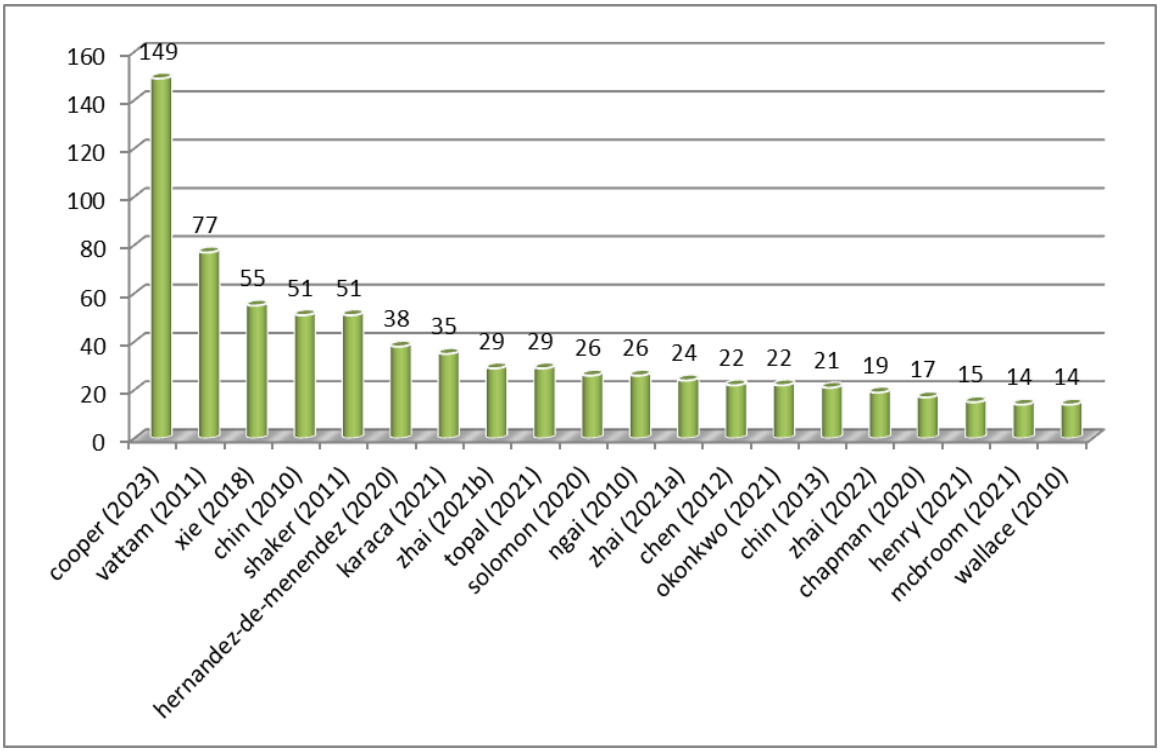

Chart 9. Distribution of Publication Citations on Science Education and Artificial Intelligence

The publication with the highest number of citations in this field focuses on science education and ChatGPT. Developed by OpenAI, ChatGPT has recently become one of the most frequently used applications among AI trends due to its potential educational applications. One of the major advantages of the ChatGPT application is its high capability to adapt to educational contexts. Researchers suggest that appropriate use of this application could lead to significant advancements in distance or online education systems (Bozkurt & Sharma, 2023; Zhai, 2023). This emphasis on the alignment of ChatGPT with educational systems may explain why a publication on ChatGPT receives a high number of citations or references in our current technological era. The second most cited publication is "Understanding Complex Natural Systems by Articulating Structure-Behavior-Function Models," published by Vattam et al. in 2011 in the *Journal of Educational Technology & Society*. This publication investigates the effectiveness of an AI-based interactive learning environment for understanding the structure-behavior-function models of complex systems. The third most referenced publication is "Learning and Teaching Engineering Design through Modeling and Simulation on a CAD Platform," published by Xie et al. in 2018 in *Computer Applications in Engineering Education*. This publication offers a theoretical perspective on the use of modeling and simulation applications on a CAD platform to teach science concepts.

After examining publication-level citations, an analysis of the most cited authors was conducted. The data reveal that the most cited author in this field is Grant Cooper, who is also the author of the publication with the highest number of citations. The author has a total of 149 citations. The top 20 most cited authors are presented in Chart 10.

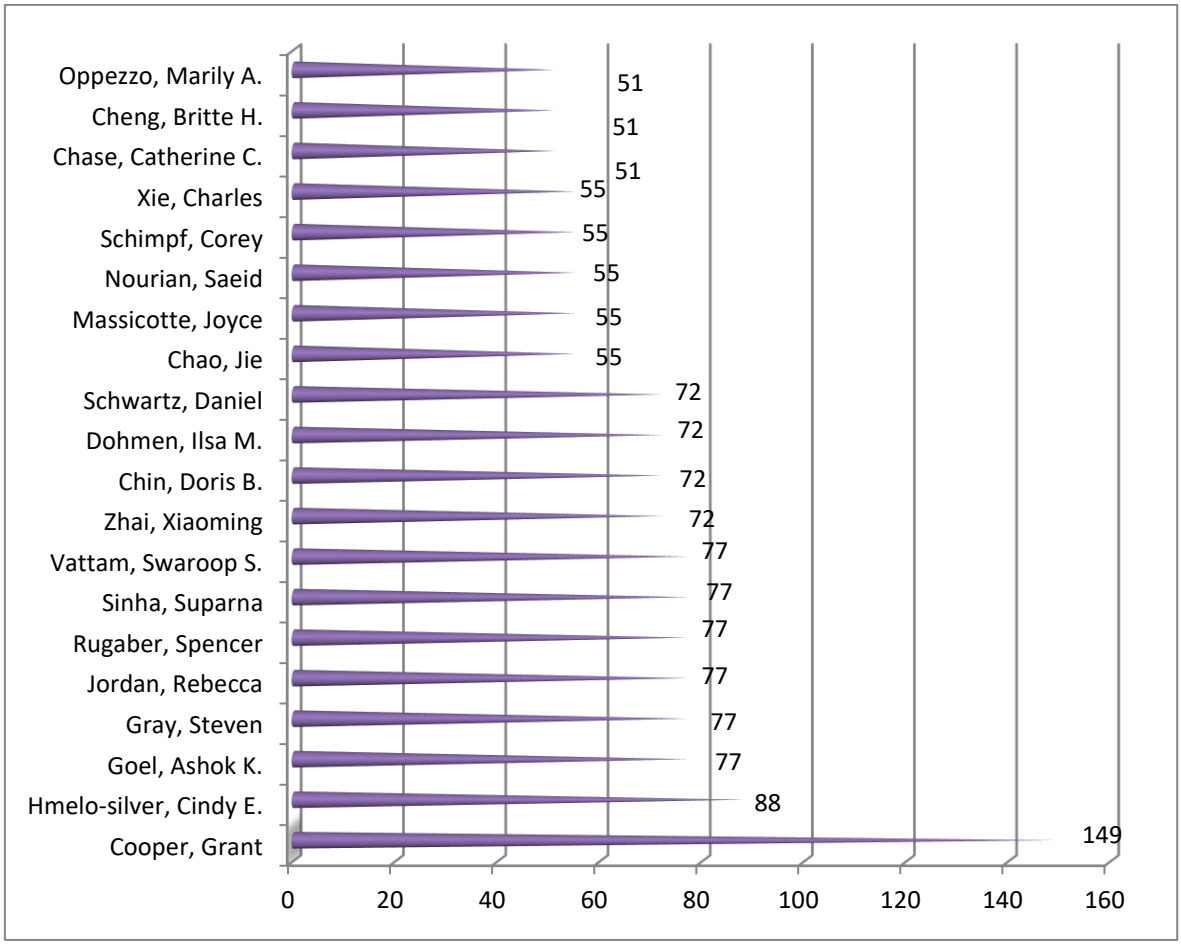

Chart 10. Author Citation Distribution in Science Education and Artificial Intelligence

Analysis of the data reveals that the second most cited author is Cindy E. Hmelo-Silver. Hmelo-Silver is listed among the authors of the second most cited document in the field. She has authored two publications related to science education and artificial intelligence and has a total of 88 citations. She is affiliated with Indiana University Bloomington. Additionally, six researchers with 77 citations each, as shown in Chart 10, are among the authors of the second most cited document. Following the examination of the most cited authors, an analysis of the most cited journals in the field has been conducted. The top 20 most cited journals are presented in Chart 11.

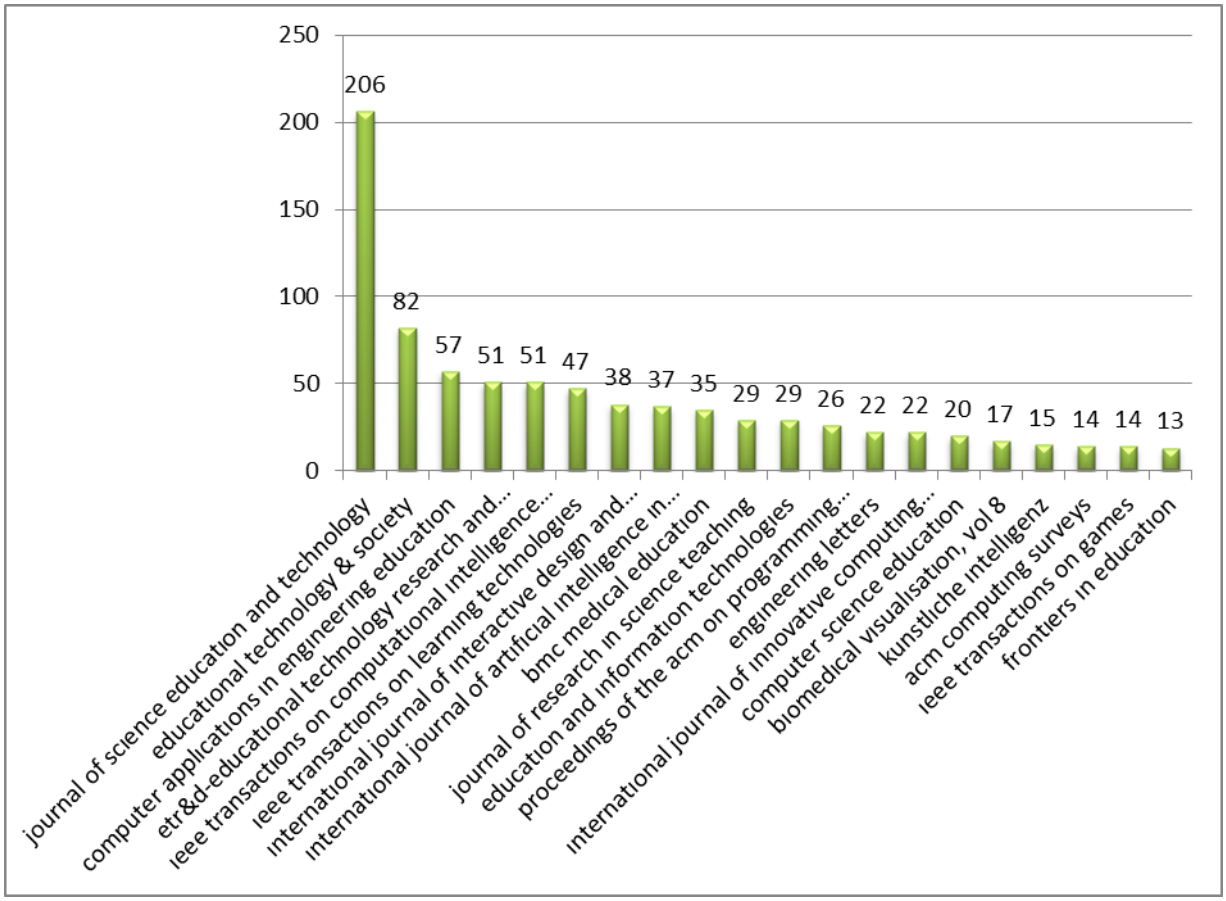

Chart 11. Most Cited Journals and Number of Citations in Science Education and Artificial Intelligence Research

Analysis of citation data reveals that the most cited journal in the field of science education and artificial intelligence is the "Journal of Science Education and Technology," with a total of 206 citations. This journal is also where the most cited article is published and ranks among the top three journals in terms of publication volume in this field. The journal focuses on themes related to science education and technology. The second most cited journal is "Educational Technology & Society," with 82 citations, and it is the publication source for the second most cited article. The third journal in terms of citations is "Computer Applications in Engineering Education," which is the publication source for the third most cited article.

Findings Related to the Distribution of Keywords Used in Scientific Articles on Science Education and Artificial Intelligence

Another data analyzed in the study in order to reveal the bibliometric profile of articles on science education and artificial intelligence are keywords. The analysis identified a total of 364 keywords, each appearing at least once. Among these, 34 keywords appeared two or more times, 12 keywords appeared three or more times, and 7 keywords appeared four or more times. Additionally, 6 keywords appeared five or more times. The top 20 most frequently occurring keywords are presented in Chart 12.

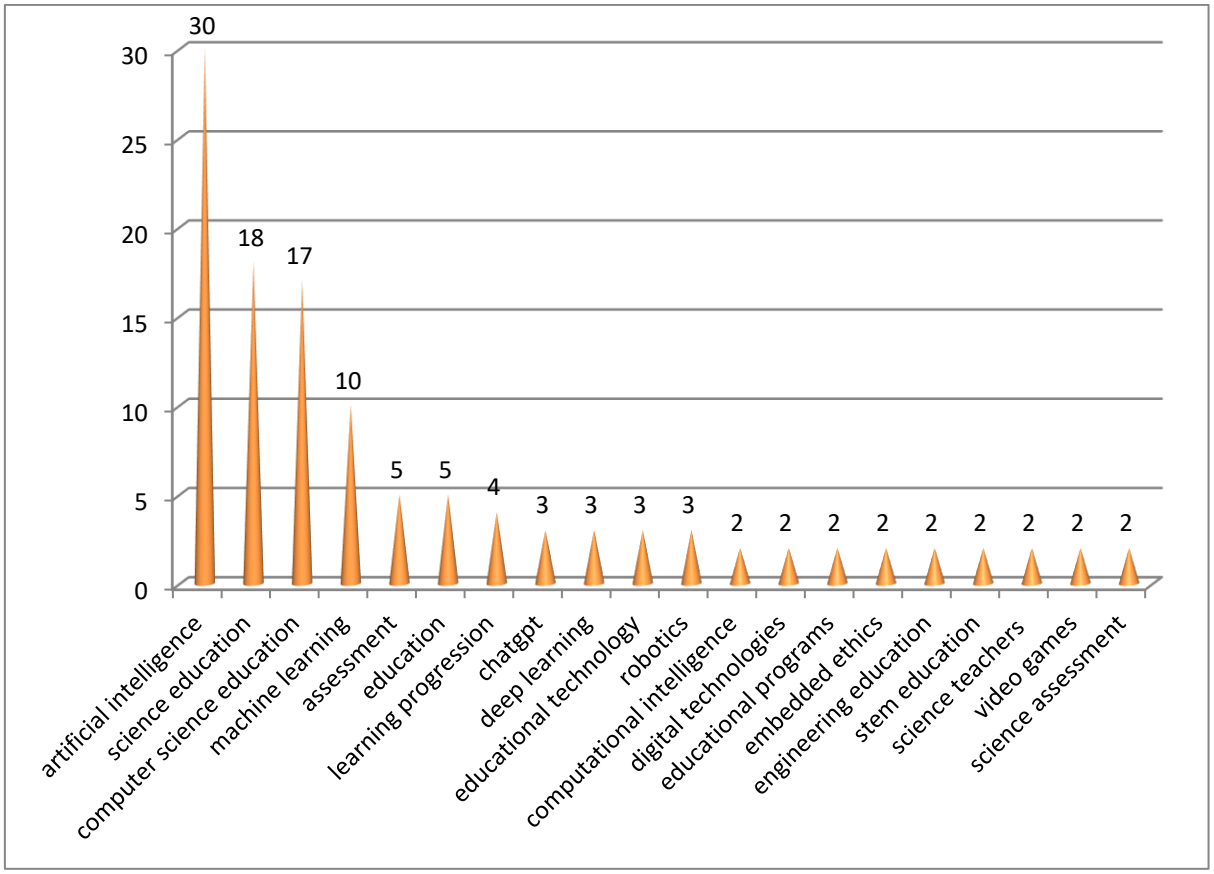

Chart 12. Keywords & Occurrences

The analysis of data reveals that the most frequently used keyword in the 89 articles on artificial intelligence and science education is "artificial intelligence," which appears 30 times. The second most frequently used keyword is "science education," occurring 18 times. The sequence continues with "computer science education" (17 occurrences), "machine learning" (10 occurrences), "assessment" (5 occurrences), and "education" (5 occurrences). Given the focus of this study on articles related to science education and artificial intelligence, it is expected that "artificial intelligence" and "science education" would be the most frequently repeated keywords. Examining the top 20 keywords reveals that references to artificial intelligence in science education are not limited to the concept of technology but also include interdisciplinary approaches such as computer science education, machine learning, engineering education, robotics, video games, digital technologies, and STEM education. The prominence of ChatGPT as a keyword suggests that it is a preferred artificial intelligence application in educational programs and environments. The presence of keywords such as "education," "learning processes," "educational technologies," "educational programs," "science assessment," "evaluation," "computational intelligence," and "deep learning" indicates an examination of the contributions of AI applications to science education.

Another notable keyword is "embedded ethics." The inclusion of this term as a keyword in articles on artificial intelligence and science education may reflect concerns and discussions about integrating ethical considerations into AI applications. The appearance of "embedded ethics" suggests that ethical processes are

considered in AI and science education research. The co-occurrence map of keywords used in articles on artificial intelligence and science education is presented in Figure 3.

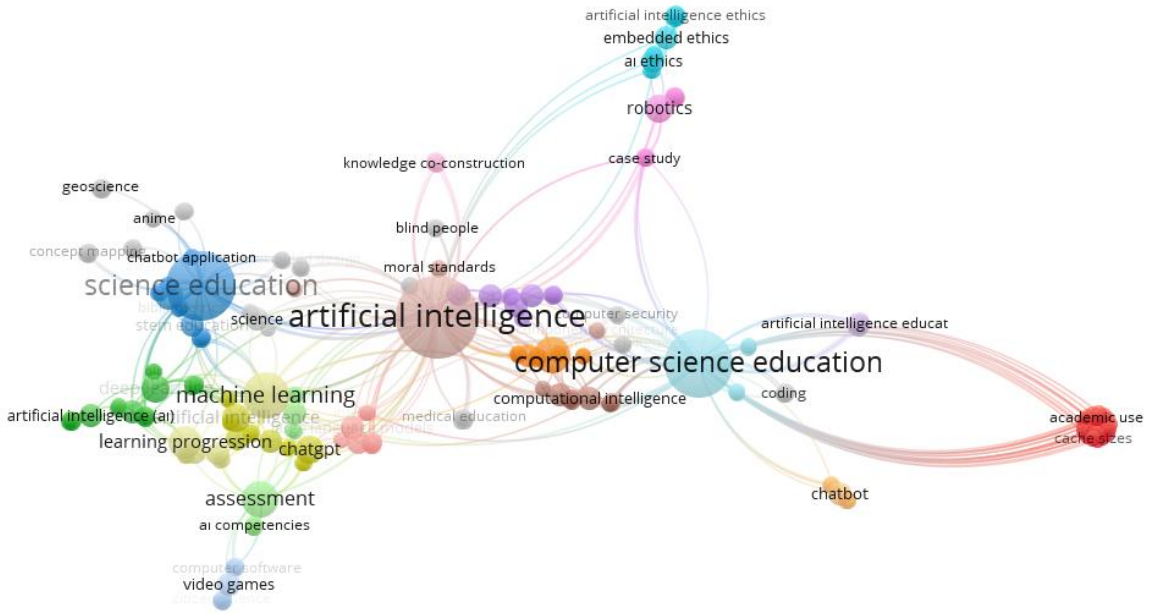

Figure 3. Co-occurrence Map of Keywords in Artificial Intelligence and Science Education Articles

Discussion and Conclusion

This study provides a detailed overview of research trends at the intersection of science education and AI. It examines publication tendencies, language distribution, and major research areas. The study also highlights the most productive journals, institutions, and authors, as well as the most highly cited documents. Additionally, it explores collaboration tendencies, identifying key countries and institutions involved in joint research. These findings offer a comprehensive view of the current research landscape and trends in these fields.

The analysis reveals that the first publication on science education and AI appeared in 1985. Subsequent publication activity was inconsistent, with notable gaps in the 1990s. However, in the early 2000s, research on Technological Pedagogical Content Knowledge (TPACK) gained momentum, sparking significant discussions on integrating technology into education (Lin et al., 2013; Schmid et al., 2024). This period saw an increased emphasis on connectivism and the rapid pace of technological advancements, setting the stage for incorporating AI in educational settings. A marked increase in the number of publications began in 2018, peaking in 2023. The data suggest a renewed interest in the field post-2018, with a sharp rise in publications from 2020 onwards, likely driven by the development and accessibility of AI technologies, particularly chatbots, which have facilitated more research and applications in education (Roll & Wylie, 2016). The surge in publications from 2020 onward highlights the growing interest in AI's role in science education, supported by expanding digital networks and increased collaborative research. The COVID-19 pandemic, which began in late 2019, made it necessary for individuals to become deeply engaged with technology and to accept it, thereby accelerating

technological development and accessibility. During this period, the use of AI technology, especially in the medical field, increased AI research efforts (Alhasan & Hasaneen, 2021).

The analysis indicates that the vast majority of publications in science education and AI are in English, accounting for 91.01% of the total. This trend reflects the dominance of English as the lingua franca in academic publishing, facilitating international collaboration and dissemination of research findings (Swales, 1990). The dominance of English, which is seen as the language of science, is also evident in the results of other bibliometric studies (Mongeon & Paul-Hus, 2015). While English predominates, valuable research is also being conducted and published in other languages such as Russian, Spanish, French, Korean, Portuguese, and Ukrainian. This linguistic diversity, though limited, underscores the global interest in the intersection of science education and AI, while also highlighting potential barriers for non-English-speaking researchers in accessing and contributing to the broader academic discourse.

Research areas within publications on science education and AI span 23 different fields, with the majority (49.43%) concentrated in educational research. Educational researchers are continuously exploring new instructional methods and tools to improve teaching practices and enhance student learning outcomes. This pursuit of innovation arises from the understanding that traditional teaching methods may not fully engage students or effectively foster learning. The increasing interest in AI applications in educational research can be attributed to this recognition. This focus on integrating AI into educational practices and studying its impact on learning and teaching is understandable, given the growing interest in leveraging AI technologies to enhance educational outcomes, personalize learning experiences, and improve instructional methods. AI's potential to revolutionize education through adaptive learning systems, intelligent tutoring, and data-driven insights has made it a prominent topic within educational research (Rammer et al., 2022). The recent accessibility and novelty of AI technology have spurred researchers' interest, leading to increased exploration of its applications in education.

Another finding of the research indicates that studies on science education and artificial intelligence are primarily published in educational research and AI application journals. "Frontiers in Education" stands out as the most productive journal in this field, particularly noted for its research-based approaches. This multidisciplinary journal focuses on education for human development, addressing global educational challenges and opportunities. Its high CiteScore, open access and relevance to AI and science education topics make it a popular choice among researchers, explaining its prominent position in our study. The "International Journal of Artificial Intelligence in Education" and the "Journal of Science Education and Technology" are also leading journals in this area. The "International Journal of Artificial Intelligence in Education" has a CiteScore of 11.1, while the "Journal of Science Education and Technology" has a CiteScore of 9.4. Given their focus on technology and AI, it is expected that research in these fields would be published in these journals. They play a crucial role in promoting applied research in AI and educational technologies.

The distribution of productive countries in the field underscores the significant role of the United States, which accounts for 44.94% of the publications. The USA's pioneering role in integrating technological systems with

science education, reflected in concepts like "Science-Technology-Society" (STS) and STEM education, reinforces its leading position (Layton, 1971; Ramaley, 2017). Germany ranks second, with 10 publications, due to its strong research infrastructure and focus on STEM education (OECD, 2022). Other notable contributors include Australia, Spain, China, and search in these regions. Leading researchers such as Xiaoming Zhai from the University of Georgia and Kevin C. Haudek from Michigan State University reflect their institutions' prominent roles. The concentration of significant research activity in these regions and institutions underscores their advanced capabilities and collaborative networks.

Grant Cooper's 2023 paper on ChatGPT, with its high citation count, underscores the significant interest in AI tools for educational purposes. This document's prominence highlights the growing importance of ChatGPT in advancing remote and online education. Similarly, Vattam et al.'s (2011) work on AI-based interactive learning environments and Xie et al.'s (2018) study on CAD-based modeling are highly cited. Cindy E. Hmelo-Silver, a notable contributor with 88 citations, and the institutions linked to her research, such as Indiana University Bloomington, demonstrate the substantial impact of specific researchers and their affiliations. The most cited journals, including the Journal of Science Education and Technology, Educational Technology & Society, and Computer Applications in Engineering Education, play crucial roles in disseminating influential research in this field. The analysis of citations reveals that the most cited document is Grant Cooper's 2023 paper in the Journal of Science Education and Technology, with 149 citations. This journal leads in citations with a total of 206 and a 2023 CiteScore of 9.4, indicating its significant impact and relevance. Educational Technology & Society, the second most cited journal, with 82 citations, boasts a CiteScore of 9.1, reflecting its influential role. The third journal, Computer Applications in Engineering Education, where the third most cited document was published, has a CiteScore of 7.2, underscoring its importance in integrating technology into science education. The prominence of these journals, all with high CiteScores, highlights the critical role of educational technology in AI and science education research. This situation can be attributed to the tendency of researchers focusing on AI to first review and cite studies published in these leading journals. Because the journals' strong focus on integrating AI into educational practices aligns with current trends and demands for innovative teaching and learning methods.

Lastly, the bibliometric analysis of keywords from articles on science education and AI reveals several significant insights. The prevalence of "artificial intelligence" and "ChatGPT" underscores the increasing integration and transformative potential of AI technologies in education. The frequent occurrence of interdisciplinary terms such as "computer science education," "machine learning," and "STEM education" indicates a holistic approach to incorporating technological advancements to enhance learning experiences. Ethical considerations, highlighted by the keyword "embedded ethics," emphasize the growing awareness of the need for ethical frameworks in AI applications in education. Ethics in artificial intelligence (AI) is seen as a critical area of focus due to the significant ethical and socio-political challenges that AI presents. That's why, it is said that integrating ethical considerations into AI development is essential to address these challenges and ensure that AI systems align with ethical principles (Coeckelbergh, 2020). The focus on keywords related to learning processes, and educational technologies that emphasise integrated teaching methods such as STEM (Ramaley, 2017), and assessment also underscores AI's potential to improve educational outcomes. These

findings suggest future research should further explore ethical implications, interdisciplinary methods, and the role of AI in enhancing assessment processes to maximize its benefits in science education.

To sum up, this comprehensive bibliometric analysis reveals how the fusion of science education and AI mirrors the principles of connectivism, emphasizing the interconnected nature of contemporary learning and technology. The study illustrates how advancements in AI and collaborative research efforts enrich our understanding of science education, reflecting the connectivist idea that learning thrives through the interconnections between various fields and knowledge domains.

Recommendations

This study provides valuable insights into the current research landscape at the intersection of science education and AI. The high impact and academic influence of the leading journals, as indicated by their CiteScores, reflect the growing importance and relevance of AI and educational technology in science education research. Future research should continue to explore the potential of AI to transform educational practices, addressing the challenges and opportunities it presents. By fostering collaboration and leveraging technological advancements, researchers can contribute to the development of innovative, effective educational strategies that meet the needs of learners in an increasingly digital world.

Limitations

This bibliometric analysis has several limitations. Firstly, the study was conducted exclusively using the Web of Science (WoS) database, which means relevant studies from other databases such as Scopus, IEEE Xplore, and Google Scholar were not included, potentially affecting the comprehensiveness of the results. Secondly, the search was performed using the specific keywords “science educat*” and “artific* intelligen*” in the topic title, which might have excluded relevant studies that use different terminologies. Additionally, the analysis only covers studies published up to 2024, excluding 22 relevant studies that were identified but not included in the final dataset.

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