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Review Article

Artificial intelligence in science education: A bibliometric review

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ABSTRACT

A descriptive bibliometric analysis of works on artificial intelligence (AI) in science education is provided in this article to help readers understand the state of the field's research at the time. This study's main objective is to give bibliometric data on publications regarding AI in science education printed in periodicals listed in the Scopus database between 2002 and 2023 end of May. The data gathered from publications scanned and published within the study's parameters was subjected to descriptive bibliometric analysis based on seven categories: number of articles and citations per year, countries with the most publications, most productive author, most significant affiliation, funding institutions, publication source and subject areas. Most of the papers were published between 2016 and 2022. The United States of America, United Kingdom, and China were the top-3 most productive nations, with the United States of America producing the most publications. The number of citations to the publications indexed in Scopus database increased in a progressive way and reached to maximum number in 2022 with 178 citations. Most productive author on this topic was Salles, P. with four publications. Moreover, Carnegie Mellon University, University of Memphis, and University of Southern California have the maximum number of publications as affiliations. The National Science Foundation was the leader funding institution in terms of number of publications produced. In addition, "Proceedings Frontiers in Education Conference Fie" have the highest number of publications by year as a publication source. Distribution of the publications by subject area was analyzed. The subject areas of the publications were computer sciences, social sciences, science education, technology and engineering education respectively. This study presents a vision for future research and provides a global perspective on AI in science education.

Keywords: artificial intelligence, science education, STEM, bibliometric review

INTRODUCTION

Science education might be significantly changed by artificial intelligence (AI), a fast-expanding field. It was gathered and examined research papers on the application of AI in science education for this overview of the literature.

Recent years have seen a rise in interest in the study of AI in science education. Science education is only one of the many domains, where AI has applications. For example, Zhai and Krajcik (2022) revealed that applying machine learning to automatically assess science models. AI is a constantly expanding and fascinating topic. The effectiveness of teaching and learning processes may be enhanced by the application of AI in science education (AlKanaan, 2022). Numerous studies have been conducted on the application of AI in science education, including teaching, learning, assessment, and curriculum development (Al Darayseh, 2023; AlKanaan, 2022; Good, 1987; Holmes & Tuomi, 2022; Kalogiannakis et al., 2021; Swiecki et al., 2022; Xu & Ouyang, 2022; Xu et al., 2021).

AI is becoming more and more of a standard in science education with much research investigating its applications and impacts. Wu and Tegmark (2019) explored using AI in coaching physics and determined that it advanced scholar engagement and conceptual know-how of the subject. Similarly, Mahroof et al. (2020) tested using a chatbot gadget powered by AI in coaching chemistry and determined that it was powerful in helping scholars get to know and improving instructional achievement. Likewise, Kim (2022) proposed that AI had the potential to enable personalized and adaptive learning experiences, which might assist college students in achieving greater educational outcomes in technology education. Moreover, Farahmand (2021) provided an overview of the integration of cybersecurity and AI research in cybersecurity education and the implementation of a module in an already-existing undergraduate cybersecurity engineering course. According to Yeo et al. (2022) AI and microbiomes, exposure to various types of humor produced varying degrees of laughter, and respondents' need for comedy mitigated the impact of humor on involvement intentions. Besides this, it was found that the chatbot application improved the experimental group students' online learning experience by a study conducted by Deveci et al. (2021).

The potential for addressing science education's challenges using AI has been acknowledged. According to Dimitriadou and Lanitis (2023), collaborative learning environments, personalized and adaptive learning systems, and virtual and augmented reality are among the AI-based innovations promoting scientific thinking skills, enhance student engagement, and improve learning outcomes. However, incorporating AI in science education poses challenges such as potential biases in AI algorithms and ethical considerations. Our bibliometric review seeks to offer insights into AI research in science education, highlighting major themes and gaps in research. In education, especially in science education, AI is a subject that is gaining popularity. AI has the potential to enhance instruction, motivate students more, and increase learning outcomes (Luan et al., 2020). Furthermore, Gonzales et al. (2017) described an interactive museum display teaching museum visitor about AI and Alan Turing's influential Turing test for machine intelligence to display features an avatar of Turing. In addition, it was found that the AI had a beneficial effect on the students' viewpoints of science and robotics by a study conducted by Acisli Celik and Ergin (2022). Likewise, the statistical studies conducted by Su (2022) showed that those students developed their scientific cognitive problem-solving abilities through quantitative analyses and demonstrated them through qualitative ones.

AI integration in science education has drawn a lot of attention recently. For instance, the findings showed that the experimental group of students' computational thinking abilities, learning motivation, and self-efficacy were all enhanced by the inclusion of science, technology, engineering, and mathematics (STEM) education in AI teaching according to Huang and Qiao (2022). Similarly, Huang (2022) stated that it was very important to deepen the evaluation of STEM learning in elementary schools, improved the effectiveness of STEM teaching, and promoted the healthy development of elementary pedagogical application. It has been demonstrated by a study conducted by Huang et al. (2023) that AI may have positive effects on instructional strategies, student motivation and engagement, and learning outcomes. Numerous important themes were identified by the analysis. The use of AI-based virtual and augmented reality technologies to increase student engagement is an important topic of research. Numerous studies have shown how virtual reality simulations in science instruction can help students better understand and retain difficult concepts. Similar results have been found for augmented reality, which has been shown to boost student engagement and motivation in

science instruction (FitzGerald et al., 2013). Moreover, Cooper (2023) stated that for teachers creating science lessons, rubrics, and tests, ChatGPT was probably a beneficial tool. Any AI-generated resource should be critically evaluated by teachers before being adapted for their unique teaching situations. In another study, Antonenko and Abramowitz (2022) explored in-service teachers' misconceptions of AI in K-12 science education. On the other hand, Ezquerra et al. (2022) developed a method for evaluating the dynamics of affective variables during an inquiry-based activity using an AI system detecting facial expressions. Similarly, Watters and Supalo (2021) created an AI tool for accessible science education called virtual lab assistant. It is essential to underscore that the primary objective of our study was to explore and assess the prevalence and impact of specific pedagogical techniques employed in science education research with a focus on AI applications.

Rationale and Significance of Study

A bibliometric analysis on AI in scientific education is not only important but also very pertinent and timely due to the fast-growing nature of both subjects. A thorough and methodical analysis of the existing literature is required because, as AI becomes more common in many educational contexts, it has the potential to revolutionize science teaching. This study uses bibliometric techniques to highlight areas for future growth and innovation, identify major research trends, and provide an objective and data-driven knowledge of the state of AI integration in science education today. Furthermore, a bibliometric approach is necessary to sort through the mass of data, draw up insightful conclusions, and identify the most significant studies that can guide educational practices and policy choices given the constantly growing volume of publications in this field.

METHOD

Data Collection Process

This study is an overview of the literature related to AI in science education and used Scopus database to identify research articles on AI in science education published between 2002 and 2023 end of May. The search keywords used were "artificial intelligence", "AI," "science education and "STEM education". 366 publications were found in the first scan. Educational context and journals were selected, and 254 publications remained. The search resulted in 202 publications after selecting peer-reviewed publications in English language and these publications were analyzed using descriptive bibliometric techniques. Preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines (Moher et al., 2015) were used for article selection procedure (**Figure 1**).

Data Analysis

Several bibliometric tools, including Excel and Scopus Analyzer in terms of year, source, author, affiliation, country/territory, document type, and subject area were utilized to evaluate the data and construct maps of significant variables. Statistical analysis was also performed in the study to find trends and patterns in the data. The distribution of publication output across yearly accounts, countries, publications, and publication years was examined using descriptive statistics. Additionally, inferential statistics were employed to examine whether there were any appreciable variations in publication output between various variables. The study was limited by the scope of the search, which only included publications indexed in the Scopus database. Additionally, the study was limited by the availability of data on citation counts and other bibliometric data. Despite these limitations, the study provided valuable insights into the trends and patterns in research related to AI in science education. Data validation and reliability of the findings were ensured by defining its inclusion and exclusion criteria, specifying the time frame, publication types, and relevant keywords. Comprehensive databases such as Scopus were utilized to access a diverse range of peer-reviewed publications, ensured the inclusion of high-quality and impactful research. Furthermore, inter-coder reliability tests were conducted, and multiple reviewers were employed to enhance accuracy of data extraction and minimize potential biases.

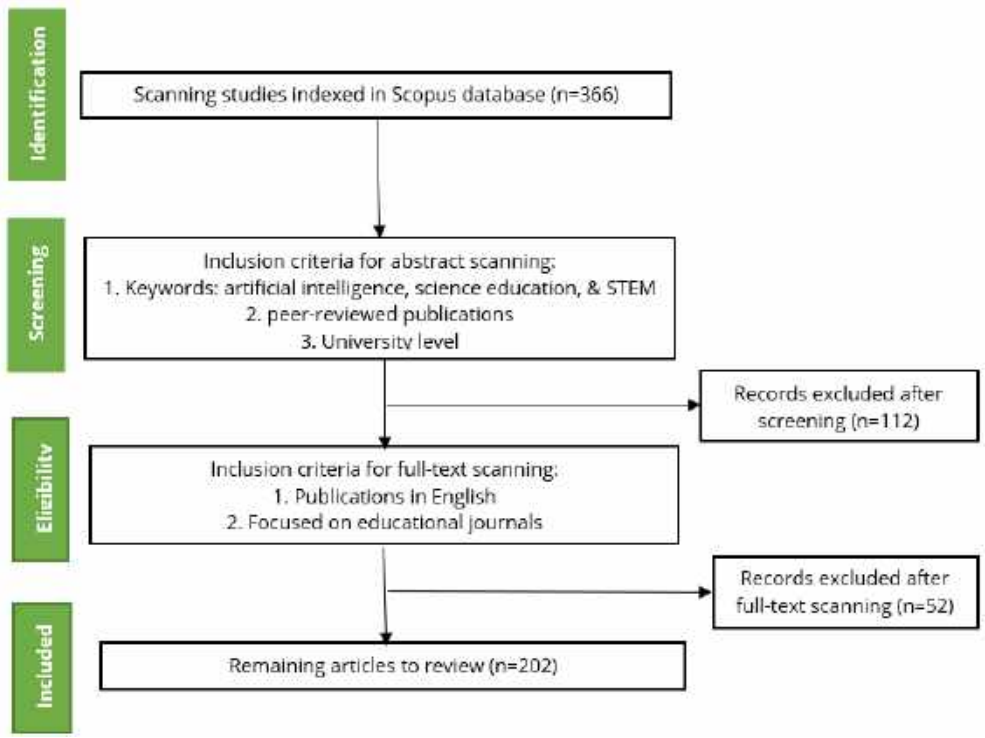

Figure 1. PRISMA flow diagram showing article selection process (Source: Authors)

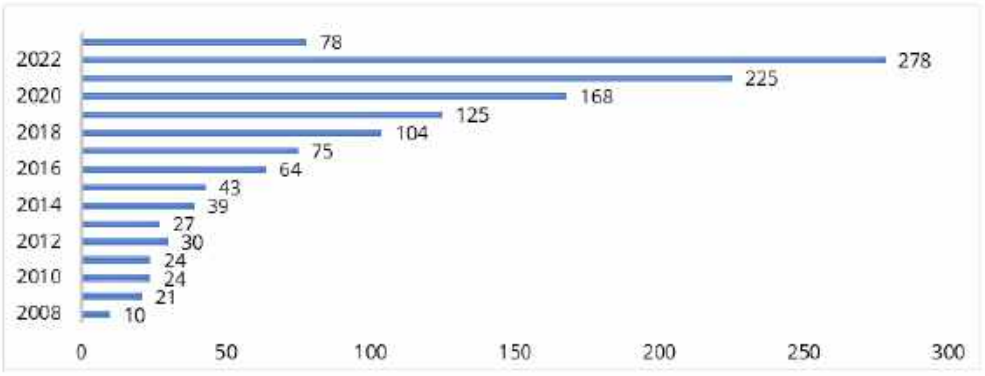

Figure 2. Number of citations by years from 2008 to 2022 (Source: Authors)

RESULTS

Number of Citations by Years

Figure 2 shows that the number of citations to the studies on AI in science education has increased steadily over the years. Since the year 2023 has not ended, it is an expected result that the number of citations in this year will be less than in 2022. In addition, it is seen that the number of citations to studies on AI in science education peaked in 2022. In a world, where technological developments are advancing at a dizzying pace, it is natural that the number of studies on AI in science education will increase linearly and will be at its highest level in 2022.

Distribution of Publications by Type, Years, and Country

Considering the types of publications analyzed, most of the studies (77.7%) were conference proceedings and 19.3% were articles. The remaining 3.0% consisted of reviews, book chapters and conference reviews. One of the reasons for this is that AI is a very current and popular topic in science education, and because of

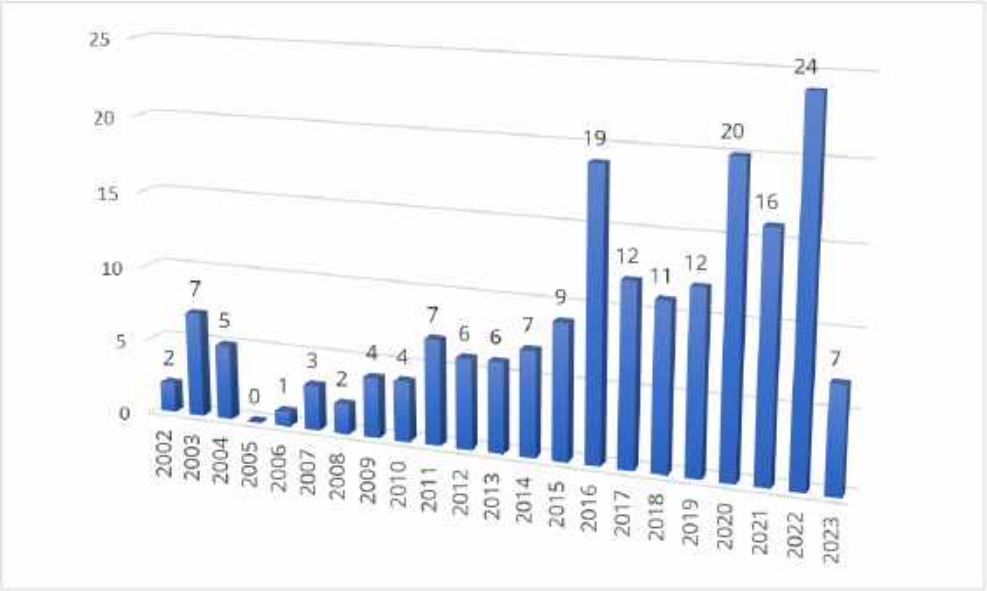

Figure 3. Distribution of publications by years from 2002 to 2023 end of May (Source: Authors)

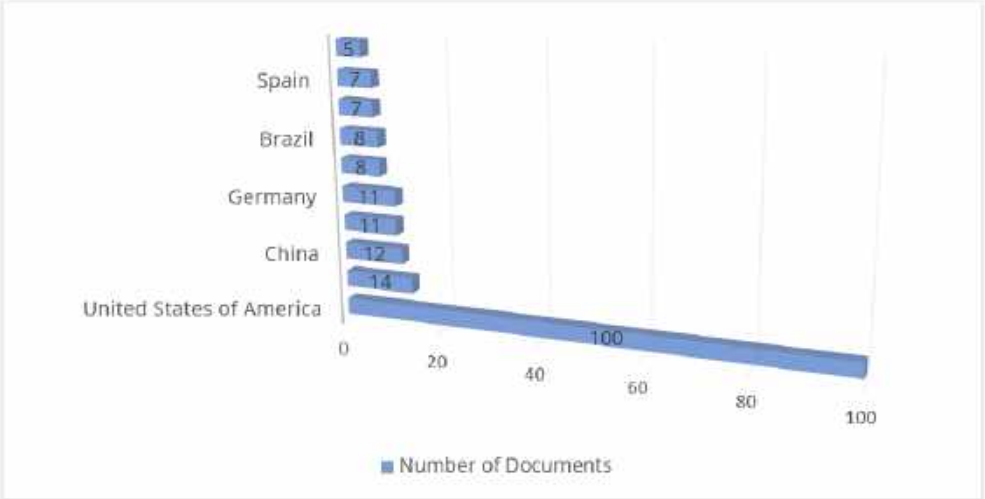

Figure 4. Distribution of publications by country from 2002 to 2023 end of May (Source: Authors)

the rapid concentration on this subject, this situation has naturally led to an increase in congress papers, which is the first step in the presentation of scientific studies.

The distribution of papers published in the journals indexed in Scopus database by year was analyzed first in the study. **Figure 3** shows the results of the study. Analysis of **Figure 3** revealed that there were few publications between 2002 and 2015 but that there was an increase in the number of publications in the latter years. Nevertheless, publications released after 2015 account for most of all articles. The most publications were produced in the years 2022 (f=24) and 2020 (f=20).

Distribution of Publications by Country

It was also looked at how the publications in the discipline were distributed by country. **Figure 4** lists the top-10 countries by number of publications. Most of the documents were conducted in the United States of America, according to **Figure 4** (f=100). Following the list were the United Kingdom (f=14), China (f=12), Canada (f=11), Germany (f=11), and others. It is an expected result that the countries with the highest number of publications on AI in science education are developed countries that are ahead in technology. In bibliometric analysis of AI in science education, analyzing the distribution of publications by country is a valuable approach to gain insights into the global landscape of research contributions. To determine the country-wise

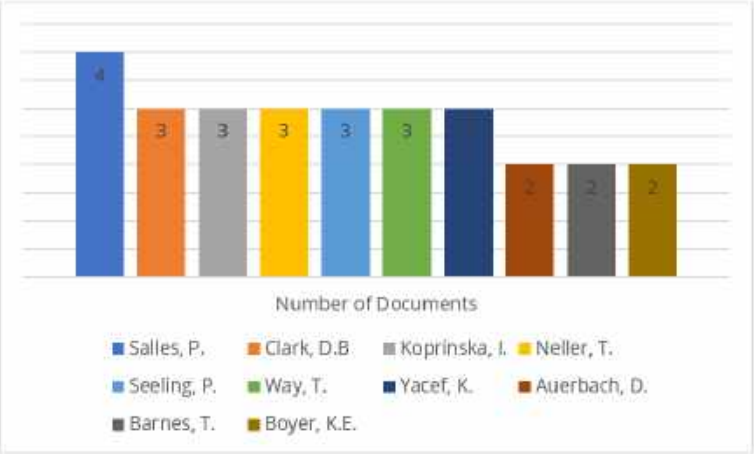

Figure 5. Number of publications by author (Source: Authors)

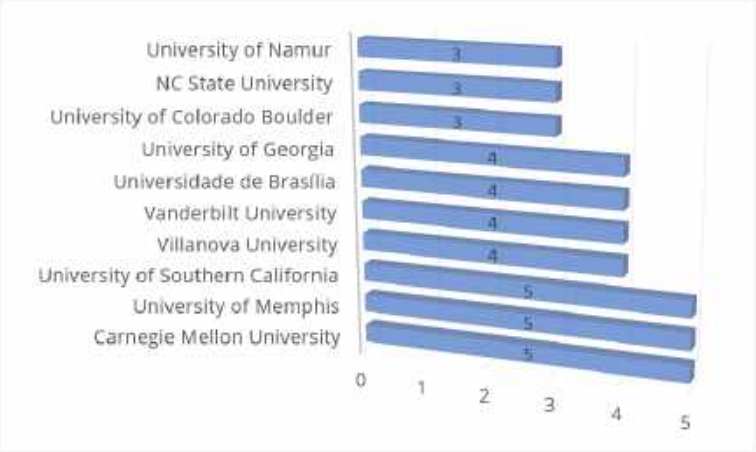

Figure 6. Number of publications by affiliation (Source: Authors)

distribution, the method commonly employed is based on attributing each publication to the country of affiliation of its first author. By considering the first author's country of origin, the analysis aims to capture the primary institutional affiliation and country-based research contributions accurately. This approach ensures a clear representation of the international collaboration and research activities in AI-related science education, providing valuable information on the geographic distribution of scientific output and potential trends in specific regions.

Distribution of Number of Publications by Author

When the authors conducting studies on AI in science education are examined, it is seen that author who published the most documents on this subject is Salles, P. with four publications (h-index: 37). Besides this, Clark, D. B. (h-index: 63), Koprinska, I. (h-index: 27), Neller, T. (h-index: 6), Seeling, P. (h-index: 16), Way, T. (h-index: 14), and Yacef, K. (h-index: 25) follow with three publications each. Finally, authors with two publications each are Auerbach, D. (h-index: 7), Barnes, T. (h-index: 22), and Boyer, K. E. (h-index: 19) (**Figure 5**).

Distribution of Number of Publications by Affiliation

In terms of the number of publications by affiliates, Carnegie Mellon University, University of Memphis, and University of Southern California institutions rank first with five publications each.

In addition, the second ranking is shared by Villanova University, Vanderbilt University, Universidade de Brasília and University of Georgia with four publications each. Finally, there are three different institutions, namely University of Colorado Boulder, NC State University and University of Namur with three studies each in the third ranking as can be seen from **Figure 6**.

Figure 7. Number of publications by funding sponsors (Source: Authors)

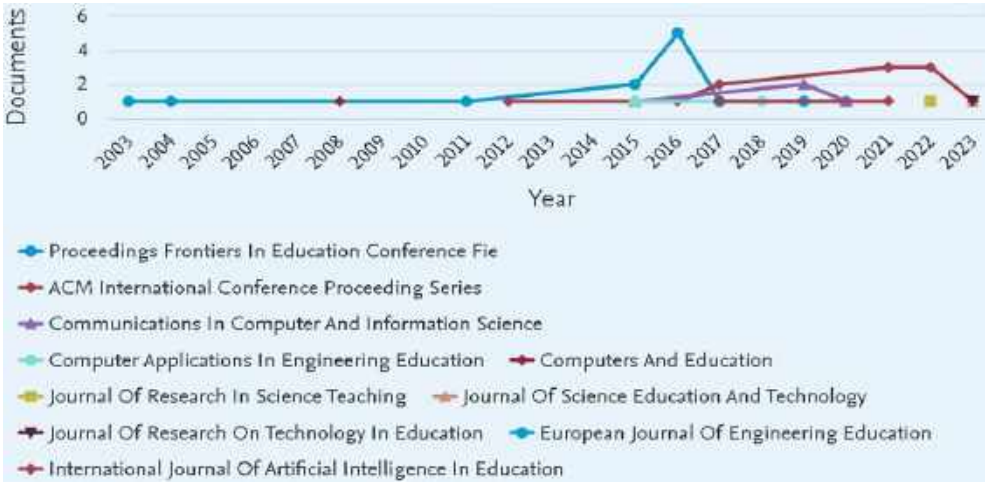

Figure 8. Publications per year by source (Source: Authors)

Distribution of Number of Publications by Funding Sponsor

The National Science Foundation, sponsoring such a popular research topic as AI in science education, shows leadership with its support for 24 publications. The European Commission and the Japan Society for the Promotion of Science are the second-ranked sponsors with their support for three publications each. After that, there are five sponsors with two publications each and two different sponsoring organizations with one publication each (**Figure 7**). It is a consistent result that The National Science Foundation, which supports research in a country with the most qualified and respected research organizations in the world, supports the most publications in this field.

Distribution of Publications per Year by Source

When the distribution of publications by years in terms of source names (**Figure 8**) is analyzed, it is seen that the sources with the highest number of publications by years are "Proceedings Frontiers In Education Conference Fie" and "ACM International Conference Proceeding Series, respectively, as can be seen from **Figure 8**. Among the sources, where the studies on AI in science education are mostly published, the first two places are the books in which papers and conferences are published. This can be explained by the fact that the topic is current and popular and attracts a lot of attention in congresses and symposiums.

Distribution of Publications by Subject Area

When the subject areas of the analyzed publications are taken into consideration, it can be seen from **Figure 9** that almost half of the studies (47.0%) are in computer sciences, 20.0% in social sciences, 19.0% in science education and the remaining 14.0% in technology and engineering education. The fact that the field of computer sciences is in forefront in the field ranking of the sources, where the most studies on AI in science education are published can be explained by the fact that subject title itself is related to computer technology.

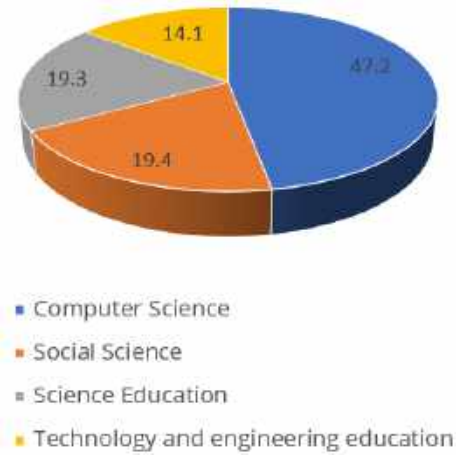

Figure 9. Distribution of publications by subject area (Source: Authors)

Thematic Analysis

The rising influence of AI in science education promises to redefine teaching and learning approaches. This thematic analysis explores three key themes that emerge from the literature on AI's impact in science education: "enhancing learning experiences," "advancing assessment methodologies," and "empowering educators."

Theme 1: Enhancing learning experiences

AI technologies have the capacity to revolutionize learning experiences by providing personalized and adaptive learning pathways for students (Anderson et al., 2014). AI-powered platforms analyze individual learning patterns and preferences, delivering tailored content that maximizes engagement and comprehension. The amalgamation of immersive simulations, virtual laboratories, and interactive visualizations facilitates students to delve into intricate scientific concepts in a dynamic and experiential manner (Haleem et al., 2022).

Theme 2: Advancing assessment methodologies

AI-driven assessment methods are reshaping how student progress is measured and understood (Basu et al., 2016). Automated evaluations, propelled by AI algorithms, furnish instantaneous response on scholars' accomplishments, thus facilitating prompt interventions and customized pedagogical tactics (Shute et al., 2013). These methodologies not only gauge students' grasp of scientific concepts but also track their cognitive processes, facilitating a deeper understanding of individual learning trajectories (Hattie & Timperley, 2007).

Theme 3: Empowering educators

AI technology empowers educators by providing data-driven insights that inform instructional decisions. Educational professionals have the capacity to employ analytics generated through AI to pinpoint areas of proficiency and deficiency among students, customize pedagogical approaches, and enhance scholastic achievements. AI-driven professional development programs equip teachers with the skills needed to effectively integrate AI tools into their teaching strategies, fostering a technologically adept and innovative teaching workforce (Harris & Hofer, 2011). This thematic analysis reveals the transformative impact of AI on science education through the themes of "enhancing learning experiences," "advancing assessment methodologies," and "empowering educators." As AI continues to shape the educational landscape, careful consideration of these themes will be crucial in maximizing the benefits of AI while addressing potential challenges and ethical considerations.

In conclusion, this thematic analysis sheds light on the multifaceted landscape of AI in science education, unveiling its transformative potential and identifying areas for further exploration. By synthesizing key trends and recurring themes, this article provides a valuable resource for researchers and practitioners alike, guiding

evidence-based decision-making and fostering the responsible integration of AI to cultivate the next generation of innovative and informed scientific minds.

DISCUSSION

202 publications were obtained on AI in science education in the Scopus database. With a notable rise in publishing starting in 2002, most of the papers were published between 2016 and 2022. This result is generally consistent with the studies conducted in previous years (Bircan & Salah, 2022; Prahani et al. 2022; Talan, 2021). The United States of America, United Kingdom, and China were the top three most productive nations, with the United States of America producing the most publications like Talan's (2021) study. The number of citations to the publications indexed in Scopus database increased in a progressive way and reached to maximum number in 2022 with 178 citations. This result is consistent with the study conducted by Jia et al. (2022). Most productive author on this topic was Salles, P. with four publications. Moreover, Carnegie Mellon University, University of Memphis, and University of Southern California have the maximum number of publications as affiliations. The National Science Foundation was the leader funding institution in terms of number of publications produced. In addition, "Proceedings Frontiers In Education Conference Fie" have the highest number of publications by year as a publication source. Distribution of publications by subject area was analyzed. The subject areas of the publications were computer sciences and social sciences, respectively.

This bibliometric evaluation gives an in-depth look at the research trends and prominent actors in the field of AI in science education. The findings emphasize the need to continue investing in this field to enhance the application of AI in science education and improve teaching and learning outcomes. This review's material may be utilized to guide future study and development in this subject. According to a bibliometric analysis of research on AI in science education conducted between 2002 and 2023, there is significant interest in using AI to promote student engagement and motivation, improve teaching methods, and improve learning results. Thoughts of ethics and the need to overcome potential biases in AI algorithms are also brought up when using AI in science education. The findings of this study show necessity for additional inv estimation into the efficacy and morality of using AI in science teaching, particularly when addressing issues of fairness and inclusivity.

From 2002 to 2023, a bibliometric analysis of AI use within science education indicates a surge of curiosity in AI to enhance the quality of teaching techniques and support students. However, the review also indicates gaps in research as well as ethical concerns linked to the utilization of AI in science education requiring further consideration in upcoming studies. Using only the Scopus database in this study may have disregarded some pertinent articles found in alternate databases, marking this as a study limitation. The review was solely restricted to publications in the English language, limiting its potential. A more all-encompassing analysis of AI in science education could be achieved by utilizing numerous databases and accounting for items published in other languages in future studies. The bibliometric examination performed on the domain of AI in the realm of science education furnishes an all-encompassing survey of the tendencies, configurations, and impacts within this swiftly progressing convergence. By incorporating comparative elements, such as contrasting different countries, authors, and subject areas, we can delve deeper into the findings and extract richer insights into the dynamics of this multidisciplinary field.

Examining publication trends across different countries highlights the varying levels of engagement with AI in science education. While countries like the United States, China, and the United Kingdom have shown high publication outputs, a comparative analysis can reveal unique regional emphases. For instance, publications from Asian countries might lean towards pedagogical applications, whereas Western countries might focus on AI-driven assessment methodologies. This comparison provides a nuanced understanding of how cultural, educational, and technological contexts influence research directions.

Comparing prolific authors and research groups sheds light on collaborative networks and individual contributions. Analyzing the publication output and impact of authors from diverse backgrounds allows us to identify thought leaders who shape the field. Comparing and contrasting the literary contributions of these authors may expose divergent methodologies and approaches, thereby augmenting the comprehensiveness of our understanding of the role of AI in science education. Conducting a comparative analysis of subject areas within the broader field of AI in science education uncovers interdisciplinary intersections. Mapping the distribution of publications across educational technology, computer science, pedagogy, and specific science

domains can highlight areas of cross-pollination. This comparative approach can lead to insights into how AI applications in different subject areas are influencing each other and facilitating innovative educational practices.

Contrasting the research focus and collaborative patterns across different regions can reveal localized challenges and opportunities. Comparing the prevalence of topics like ethics in AI education, personalized learning, or educational data mining across different continents might highlight differing priorities. Moreover, analyzing collaboration networks can unveil clusters of research institutions and their impact on shaping the field's direction. A temporal comparative analysis, spanning different time periods, showcases the evolution of AI's impact on science education. Contrasting earlier works with recent studies could reveal shifts from theoretical explorations to practical applications. This comparison allows us to track the progression of the field and anticipate potential future directions.

Drawing upon a comparative analysis of AI in science education from various global perspectives enriches the understanding of the field's dynamics. Comparing and contrasting research conducted in developed and developing nations can provide valuable insights into the democratization capabilities of AI in the domain of education and help in tackling concerns pertaining to digital fairness and inclusivity. Incorporating these comparative elements deepens our understanding of the bibliometric trends in AI in science education. By analyzing countries, authors, subject areas, regional collaborations, and temporal evolution, we can unearth intricate patterns and relationships that contribute to the multifaceted nature of this field. The knowledge derived from these observations is of utmost importance to scholars, instructors, decision-makers, and interested parties as they navigate the intricate terrain of AI assimilation in scientific pedagogy.

CONCLUSION AND IMPLICATIONS

Several conclusions can be reached after performing a bibliometric examination of AI in science education. First off, it is obvious that the field of AI in science education has expanded greatly in recent years. This is sometimes demonstrated by the rise in publications on the subject, especially after 2012 in citations and research collaborations. Additionally, the study revealed that most papers are centered on secondary and higher education, particularly in STEM professions suggesting that AI is playing a bigger role in these fields. This study demonstrated to educators how AI has the potential to revolutionize science instruction by offering fresh approaches to student engagement and improving learning outcomes. Teachers should think about integrating AI technology into their curricula, especially in the fields of STEM and higher education. The possible dangers and ethical questions that come with using AI in education must, however, be understood by educators. On the other hand, it is crucial for educators to be aware of the possible risk potential and ethical issues coming with using AI in the science classroom.

In conclusion, the bibliometric analysis of AI in science education revealed the technology's expanding significance in this area and underlined the need for more investigation into its potential to improve science education. This analysis highlighted the significance of considering the ethical and practical consequences of AI in education and offers significant insights for academics, educators, and policymakers.

The implications of those findings are crucial for each researcher and educators in science education. For researchers, this evaluation indicated that there was a need for continued research on AI in science education, particularly in K-12 education, where there is still a lack of research in this area. Furthermore, researchers need to discover the capacity of AI in enhancing science education and the demanding situations including its implementation.

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Data availability: Data generated or analyzed during this study are available from the authors on request.

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