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Artificial Intelligence in Physics Education Research in Two Decades: A Bibliometric Study from Scopus Database

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Abstract – *There has been a substantial rise in research on utilizing Artificial Intelligence (AI) technology in physics education. This study conducts a comprehensive bibliometric analysis of this emerging field, aiming to discern trends, patterns, and future research areas. Using the PRISMA methodology, data were extracted from the Google Scholar and Scopus databases and analyzed with Biblioshiny and VOSviewer. We identified 12 main topic clusters, including chatbot applications and 3D virtual simulations, with significant growth in publications from 2020 to 2023. Key findings focused on pre-trained language models like ChatGPT, revealing strong connections between ChatGPT and topics such as linguistic quality and student perception. Future research areas can include thorough evaluations of AI models' accuracy and quality across various physics topics and educational levels, developing fair and transparent AI-driven assessment systems, and exploring blended learning approaches integrating AI-powered simulations. Encouraging interdisciplinary collaborations and conducting longitudinal studies to assess the long-term impact of AI on learning outcomes are also crucial. The use of Google Scholar and Scopus databases limits our research. Future research could benefit from incorporating other databases, such as Web of Science (WoS), and conducting a systematic literature review for a more nuanced understanding.*

Keywords: *artificial intelligence; bibliometric analysis; physics education; scopus*

I. INTRODUCTION

During the Fourth Industrial Revolution, there has been a significant increase in digital technology, particularly Artificial Intelligence (AI) (Ibrahim & Hassan, 2019; Popkova & Sergi, 2020; Ribeiro et al., 2021; Selvarani et al., 2023). According to the definition provided by Yang et al. (2021), AI is the replication of human intelligence in machines, achieved through computer programming to mimic human thinking. This technology has enabled humans to improve efficiency, precision, and invention. AI has been crucial in advancing technologies, including robots, big data, self-driving cars, and the internet (Ghosh et al., 2018; Liao et al., 2021; Mantelero, 2018; Ribeiro et al., 2021).

Moreover, the prospective uses of AI have broadened across several fields, encompassing technology, industry, medicine, business, and education (Prahani et al., 2022). The advancement of AI leads to more potential for optimizing processes and achieving breakthrough discoveries in various domains, such as physics (Datcu et al., 2023).

Integrating artificial intelligence (AI) in education, specifically in physics, can generate substantial effects by offering possibilities and resolving prevalent issues in physics education. These issues often arise from the use of traditional teaching methods commonly employed in physics instruction (Amiruddin et al., 2023; Mahligawati et al., 2023; Nguyen et al., 2023; Ronsumbre et al., 2023; Roshanaei et al., 2023). Artificial intelligence (AI) and physics are essential in supporting research, as demonstrated by the studies carried out by Nguyen et al. (2023) and Roshanaei et al. (2023). However, AI in educational settings is not devoid of its difficulties.

Excessive reliance on AI is a significant educational obstacle (Zhai et al., 2024). Educators must guarantee that students persist in cultivating their critical thinking and problem-solving abilities. Another obstacle arises from the possibility of prejudice inside AI systems (Salazar et al., 2024). It is crucial to ensure that AI systems are designed in a fair and non-discriminatory manner. Notable obstacles encompass ethical questions about the utilization of AI, the need for resilient technological infrastructure, and the imperative to teach educators to employ these tools effectively. In addition, the rapid advancement of AI requires continuous adaptation of educational research to keep up with the latest developments. Conducting ongoing research to examine these dynamics and proposing a plan for future implementation is paramount (Baharuddin et al., 2020; Tupan et al., 2018; Bitzenbauer, 2021; Rahim & Widodo, 2024; Campbell, 2024). Thorough examinations are required to gain a complete understanding of the progress of AI research in physics education, taking into account the diverse perspectives on its promise and challenges.

Extensive research has been conducted for a significant time on integrating artificial intelligence and physics education. Integrating these two disciplines leads to a thorough investigation that propels the progress of teaching and research in several countries. The research on the quantum world was carried out by Dunjko & Briegel (2018); Faroughi et al. (2024); Zhang & Kim, (2017), natural science research (Ali et al., 2024; Ghalambaz et al., 2024; Siddique & Adeli, 2015), and learning media development (Dong & Chen, 2024; Z. Zhang et al., 2024). Unfortunately, there is now a dearth of research that investigates the expansion of research about these two issues. An instance of extant bibliometric research is an investigation by Ghalambaz et al., (2024). This study specifically examines the utilization of artificial intelligence (AI) in fluid flow and heat transfer (AIFH). The researchers utilized a database from the Web of Science to scrutinize works pertaining to Artificial Intelligence for Healthcare (AIFH) throughout 40 years, specifically from 1982 to 2022. This research is essential due to the significant influence and potential of AI and physics education research. There is a requirement for a thorough investigation of this issue to fill the knowledge gap that previous research still needs to address.

The research question for this study is: What are the patterns and trends in research within the field of physics education, as explained earlier? This study uses a bibliometric study to present a comprehensive analysis of the trends and patterns in research about using artificial intelligence (AI) in physics education. This study aims to motivate academics to improve the effectiveness and attractiveness of physics teaching practices (Zebua et al., 2023). The inquiry utilized the Scopus database, encompassing a publication span of 20 years (2004 - 2024).

This research holds great importance in the field of education, namely in the realm of physics education, for multiple reasons. AI can revolutionize the methods and outcomes of physics education (Mahligawati et al., 2023). Artificial intelligence can deliver customized learning experiences that cater to learners' specific requirements and abilities. It can also provide prompt feedback and create opportunities for students to explore their learning strategies. These advantages can significantly enhance students' learning results. In addition, this study offers insights into forthcoming approaches to physics teaching (Mahligawati et al., 2023). This study provides educators with valuable insights into the efficient utilization of AI to boost physics teaching and learning. Furthermore, a bibliometric review can thoroughly represent the research environment and pinpoint areas of knowledge deficiency that require attention, namely in physics education (Donthu et al., 2021). This review is a significant resource for guiding future research, particularly in the application of artificial intelligence (AI) in physics education. It offers valuable insights that can inform and benefit future researchers.

II. METHODS

This study uses a quantitative approach utilizing the bibliometric analysis technique. *Bibliometrics is* a quantitative method used to study and assess large amounts of written publications (Ellegaard & Wallin, 2015; Hsieh & Yeh, 2024).

Database

The Google Scholar database was selected due to its comprehensive coverage. It is well-suited for a relatively new topic, such as artificial intelligence in physics education, which has garnered limited research attention thus far.

Data selection

Using the PRISMA framework (Page et al., 2021), we employed logical operators and keywords to refine and evaluate the search results in the Google Scholar database. Figure 1 displays a comprehensive visual depiction and description of the methodical approach employed to search the literature and select the publications that were finally incorporated into the review process. This graphic depicts the sequential methodology, offering a thorough analysis of the various stages, such as the initial investigation, filtering, evaluation of articles' appropriateness, and the final selection of studies that met the stated criteria for inclusion.

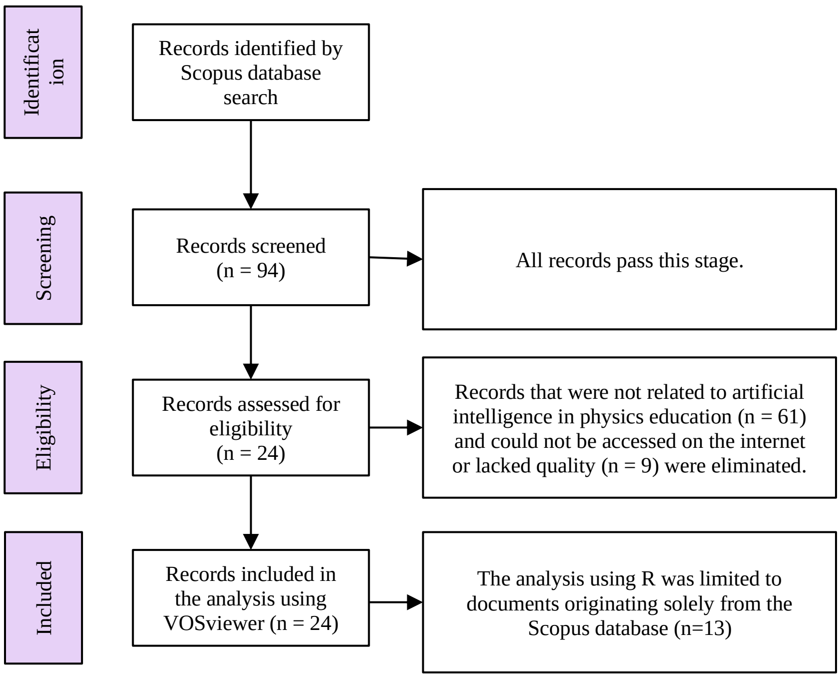

Figure 1. Selection of the publications included in the research by PRISMA method

A comprehensive search was carried out on April 27, 2024, using the Publish or Perish tool on the Google Scholar database to find relevant studies for the current research. The initial phase of the PRISMA process, known as identification, involved utilizing a combination of precise phrases and logical operators within the Publish or Perish feature to search. We input the keyword "Artificial Intelligence Physics" in the "title word" box to guarantee that the filtered papers specifically address the intersection of AI and physics. In the keywords field, we included terms like "school," "student," and "education." The logical operator "OR" operates by necessitating the presence of at least one keyword in a publication. Utilizing these keywords ensured that the AI applications mentioned in the filtered papers were specifically related to the field of education. We selected this combination of keywords to refine our search results and include only pertinent papers, specifically those focused on the application of artificial intelligence in physics education. Currently, we have not implemented any filtration process on the publications that have been detected. As a result, there were a total of 94 items initially.

Every record was preserved during the screening stage of the PRISMA approach. The third phase of the PRISMA methodology meticulously examined the titles and quality of the data. Excluded from consideration were records that lacked a direct correlation to artificial intelligence in physics education and either had quality problems or were inaccessible. We assessed the relevance of each document to our research question by analyzing the title and abstract. In addition, we conducted a thorough examination by reading the articles. This measure guaranteed that the selected documents accurately reflected our study goals. Afterward, we thoroughly examined the quality of the publications by looking for them individually on the internet. We excluded publications that were unavailable online, had missing content, or consisted of only concise text. Consequently, 68 records that did not satisfy the criterion were removed. Currently, we have excluded a substantial amount of papers. Throughout the search process, we saw that data searching utilizing Publish or Perish with the Google Scholar database has a drawback. This weakness lies in the less strict publication identification and restricted filtering capabilities, unlike Scopus. However, we addressed this vulnerability by thoroughly examining the highlighted publications.

During the eligibility stage, the study incorporated the 24 papers that were still accessible and considered highly relevant to the research issue. These publications specifically investigated the application of artificial intelligence in physics education. The ultimate publication data was stored in two formats: .csv and .ris. The data in .csv format was obtained from Scopus. The data was examined using the R program. The .ris data, however, included all the data from Google Scholar. The data was evaluated using the VOSviewer software. The separation was essential because of the disparity in data granularity between Scopus and other databases, rendering them incompatible for analysis using Biblioshiny. Subsequently, we employed an alternative methodology by subjecting it to analysis using VOSviewer.

Analysis of data

The utilization of the Biblioshiny and VOSviewer software tools facilitated the accessibility of data analysis and visualization from the articles in the study. Biblioshiny is a web-based application that is included with the bibliometric package of the R programming language. The software conducts bibliometric research and produces data matrices, enabling users to investigate co-citation networks, collaboration patterns, and co-word analyses. The system utilized data from reviewed papers to provide significant outcomes, encompassing graphics, keyword analysis, authorship analyses, and document analytics. This data facilitated the comprehensive analysis of bibliometric characteristics (Aria & Cuccurullo, 2017). The analysis conducted with Biblioshiny was restricted to records exclusively from the Scopus database (n=13) due to data structure incompatibilities with records from sources outside Scopus (n=11).

The bibliometric analysis of Scopus data was performed using the R program, utilizing the Biblioshiny package. We installed the Biblioshiny package by executing the command "install.packages("bibliometrix")". Installing this package allows us to conduct bibliometric analysis within our R program. Afterward, we initiated the package by entering the syntax "biblioshiny()." Subsequently, a Biblioshiny window interface materialized. This interface provided various bibliometric analysis elements, including significant information, authors, cooperation, and more.

Subsequently, imported the analysis data acquired from the data selection process in .csv format. Additional examination of the choice of bibliometric analysis outputs was specifically customized to meet the study analysis needs. This methodology showcases a methodical approach to bibliometric analysis with specialist software tools. Utilizing R and the Biblioshiny package enables a thorough analysis of bibliometric data, offering valuable insights into several facets of the literature, including authorship patterns, collaboration networks, and primary research issues.

To analyze the entire data of 24 entries retrieved from the Google Scholar database, we employed VOSviewer. VOSviewer is a powerful tool for generating bibliometric maps, network visualizations, overlays, and density visualizations. This tool allows for examining subjects related to particular keywords and visualizing how often keywords appear together, offering significant insights into relationships and patterns (Van Eck & Waltman, 2010). Integrating Biblioshiny and VOSviewer facilitated a comprehensive examination of citations, distribution, and textual content in the selected publications, directly aligned with the research objectives guiding the study.

Before entering the data into the VOSviewer software for analysis, we ensured the integrity of our. ris data by utilizing the Mendeley tool. At this point, we verified and incorporated any missing data from the current .ris file. Afterward, we imported this data into VOSviewer and performed the analysis. Before presenting the study results, we selected specific terms to be displayed in the network visualization. Keywords that lacked relevance to the research aims or had the potential to be biased or erroneous were excluded.

This technique exemplifies a methodical approach to data preparation and analysis. Utilizing Mendeley for data verification guarantees the integrity and comprehensiveness of the bibliographic information. The subsequent meticulous choice of keywords for the network visualization in VOSviewer aids in concentrating the analysis on the most pertinent phrases, hence minimizing interference and potential partiality in the outcomes. This approach enables a focused and significant representation of the study field, emphasizing the essential topics and relationships within the body of literature on the application of artificial intelligence in physics education

III. RESULTS AND DISCUSSION

This study analyzes the data using output results and visuals from Biblioshiny and VOSviewer. The analysis for Biblioshiny covers various aspects, including general information such as document counts by year, primary sources, affiliations, and countries. It also includes the most cited countries and sources. Additionally, the analysis focuses on keywords to highlight trending topics. Furthermore, it provides information on authors, specifically the most relevant authors, based on their fractionalized frequency. It includes the ten most globally cited documents and explores collaboration networks among authors based on their institution and country. VOSviewer's analysis encompasses network visualizations and keyword clusters about the integration of artificial intelligence (AI) in physics education. It also incorporates overlay visualizations to demonstrate the chronological progression of topics and engages in discussions on issues associated with ChatGPT.

General information

Figure 2 shows a consistent increase in published publications from 2020 to 2023. The graph illustrates a steady and continuous paper growth from 2014 to 2020. However, there was a decline in 2020, succeeded by a substantial surge in 2022. The maximum number of records throughout this period is approximately 12. In 2022, articles have risen significantly, constituting more than 12% of all publications. The graph illustrates a decline in 2024 during its beginning phase, followed by a forecasted increase towards the end of the year. After a thorough analysis of the entire period, it is clear that there is a substantial rise in the number of publications from 2020 to 2024. Specifically, in 2023, the quantity is almost multiplied by five.

Integrating artificial intelligence (AI) in education can significantly revolutionize the instructional methods employed in physics education. Although there has been a demand for additional investigation into the application of Artificial Intelligence (AI) in Physics education during the last decade, the graph depicting the number of publications each year demonstrates a significant increase from 2022 to 2023.

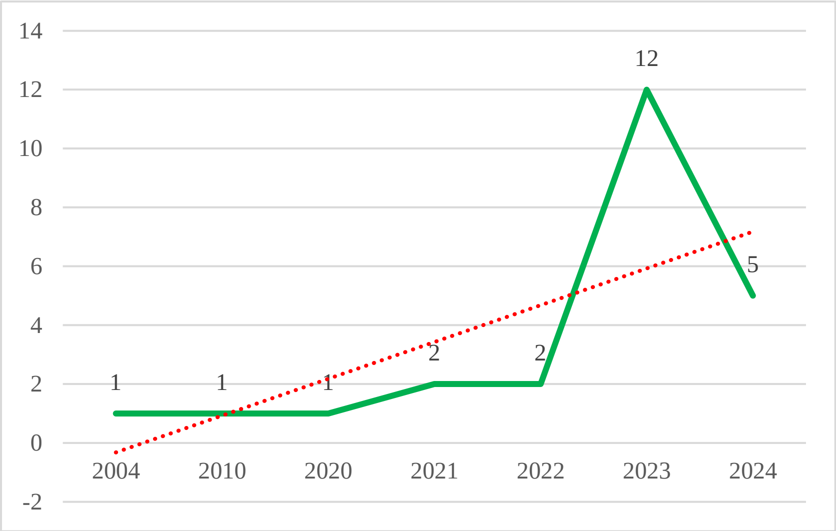

Figure 2. Documents by year (n = 24)

Figure 3 illustrates the primary data from the database entered into the bibliometric software. The paucity of publications (13) from 8 sources indicates that this topic is in its nascent stage of development, with restricted yet expanding attention from the scientific community (Bornmann & Mutz, 2015). Another metric is the yearly growth rate, which provides data on the expansion of several papers in the last year and is recorded at 8.5%. The authors' information reveals that 34 writers were involved in this topic, with just three authors contributing to multiple articles. The result illustrates the comprehensive set of scholars active in the subject (Glanzel & Schubert, 2005). However, the relatively small percentage of international/country collaborations (30.77%) indicates a requirement for enhanced worldwide cooperation and knowledge exchange to expedite advancements in this interdisciplinary field (Adams, 2013).

The citation rate of six citations per manuscript indicates moderate impact and recognition among the broader scientific community. The field of physics education about Artificial Intelligence (AI) encompasses 20 distinct keywords/themes. Additional information that can be determined includes the average number of citations for each document, which stands at six citations for the document. This parameter measures the likelihood that the research findings will be shared and accepted and serves as a platform for future studies to expand upon and enhance the current knowledge base (Newman, 2001). The bibliometric findings emphasize the importance of prioritizing international partnerships, enlarging the research community, and improving the visibility and influence of scholarly work on this topic.

In the first phases of a research field, such as applying artificial intelligence in physics education, developing a solid knowledge base and cultivating a cooperative atmosphere to encourage additional research and advancements is imperative. The topic is experiencing a surge in interest, as seen by its rapid growth rate and relatively low number of publications. The latter shows that more scholars are investigating its possible uses and benefits. International collaboration plays a crucial role in improving the quality and breadth of research by facilitating the sharing of ideas and procedures among diverse cultural and academic settings.

The involvement of a heterogeneous group of authors indicates that the subject matter is of interest to a broad spectrum of scholars. However, the scarcity of repeated contributions from specific authors implies that further focused research endeavors are necessary to enhance the comprehension and utilization of artificial intelligence in physics education (Glänzel & Schubert, 2006). Expanding the number of publications and citations can enhance the prominence of this research and its legitimacy and impact within the scientific community (Garfield, 2006). In order to accomplish these objectives, it is crucial to prioritize specific measures such as organizing international conferences, facilitating joint research projects, and providing financing possibilities for multidisciplinary studies. These endeavors can expedite the exchange of exemplary methodologies, groundbreaking concepts, and novel discoveries, thus hastening the progress and implementation of AI technologies in physics education.

Figure 3. Main information

The bibliometric analysis of the source data yielded numerous noteworthy findings about the study of Artificial Intelligence (AI) in physics education. The paucity of publications (13) from 8 sources indicates that this topic is in its nascent stage of development, with restricted yet expanding attention from the scientific community. The annual growth rate of 8.5% signifies a consistent and moderate rise in academic activity, implying the possibility of more study and advancements in this field. The participation of 34 writers, with just three authors contributing to multiple pieces, underscores the heterogeneous range of experts involved in this subject matter. Nevertheless, the relatively small percentage of international/country collaborations (30.77%) indicates a requirement for enhanced worldwide cooperation and knowledge exchange to expedite advancements in this interdisciplinary field. A 6 citations per manuscript citation rate suggests moderate impact and recognition among the broader scientific community. This statistic can measure the likelihood that the research findings will be shared and accepted and serve as a platform for future studies to expand and enhance the current knowledge base. The bibliometric findings emphasize the need to prioritize international cooperation, broaden the research community, and improve the visibility and influence of scholarly production on this topic.

The data in the fourth result from SCOPUS was classified based on the association, as shown in Figure 4. Sixteen universities have collaboratively generated a significant quantity of papers. Istanbul University-Cerrahpaşa holds the top position in the ranking, supported by two research publications. The University of Applied Arts Vienna achieved the second rank with two publications. Conversely, all other colleges possess precisely one paper.

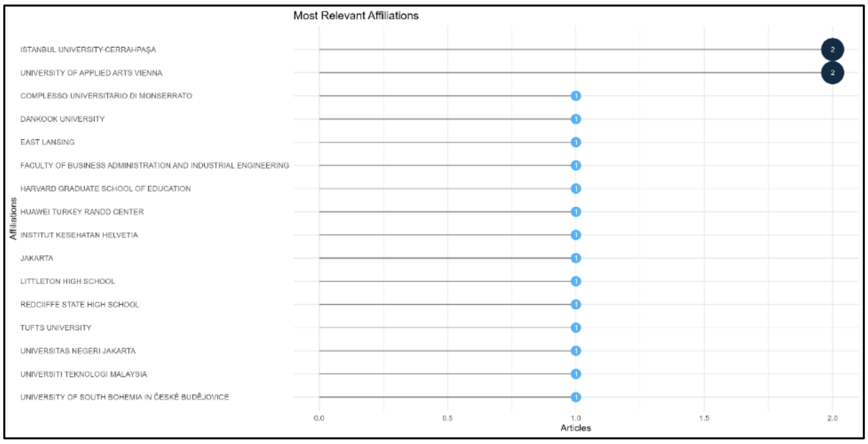

Figure 4. Documents by affiliation

Figure 5 shows the data arranged based on the studied country or region. The disparity between the initial and final positions is highly conspicuous. This graph displays the seven countries that own a substantial quantity of documents, as indicated by the analysis conducted in this study. Scientific publications sometimes necessitate author collaboration, as the analysis findings demonstrate cooperation between writers from comparable and diverse countries.

A collaborative study uncovers complex patterns of authorship collaborations in the domain of Artificial Intelligence (AI) within physics education research. Authors from Austria, the Czech Republic, Korea, and Switzerland have primarily focused on collaborating with fellow researchers within their nations. German and Indonesian authors actively collaborate internationally, cultivating relationships with professionals from many countries. This discovery emphasizes the simultaneous existence of domestic and international collaboration efforts in this study field. While several nations have emphasized enhancing domestic research networks and exchanging information, others have actively sought opportunities for collaboration that extend beyond geographical limits (Glänzel & Schubert, 2006).

The ever-changing character of the landscape highlights the possibility of exchanging ideas, approaches, and viewpoints, which could speed up the progress of AI applications in physics education. Ultimately, these cooperative tendencies emphasize the necessity for a holistic strategy that promotes local research capacities and fosters international collaboration. Enabling knowledge transfer and fostering collaboration among scholars from other fields helps accelerate innovation, tackle common obstacles, and reveal new possibilities in utilizing AI to improve physics education worldwide.

A comprehensive investigation was carried out on the impact and scope of collaboration in information technology. Studies on semantic digital libraries (SDL) show significant collaboration, with an average collaboration index of 0.898, showing that publications involving several authors are collaborative (Pandey & Sahoo, 2020). In addition, a scientometric examination of biotechnology research in IBSA countries reveals a significant prevalence of articles with many authors, suggesting a considerable degree of collaborative research in this field (Singh, 2017).

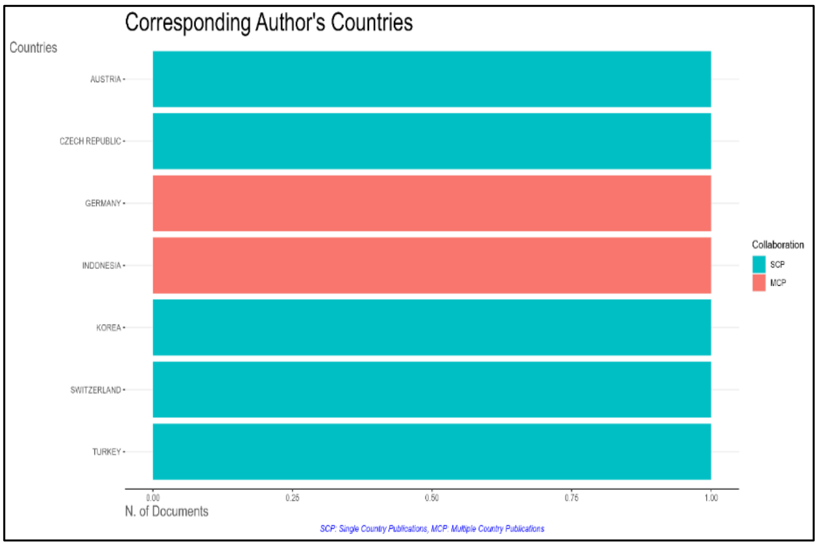

Figure 5. Documents by country

The following figure, labeled as Figure 6, displays data categorized by the countries with the highest number of citations. The graph illustrates the seven countries with the highest citation counts, as determined by the analysis undertaken for this study. The United States is the dominant global leader in citations, with thirty. Switzerland ranks second, having accumulated a total of 22 citations. Korea is positioned in third place, having obtained three citations. Indonesia ranks fourth with a solitary citation. Germany, Austria, the Czech Republic, and Turkey do not have accompanying citations.

The study investigates the utilization of intelligence-based learning (IA) in physics. It focuses on the authors of publications on this topic, their level of knowledge, and the quantity of articles they have authored. The United States of America ranks first in the report's assessment of countries with the highest number of citations. The following aligns with the nation's robust focus on research and development in educational technology (Susilo et al., 2023).

The yearly citation impact of an article is directly proportional to the number of citations it receives. The number of citations a research work receives is often a reliable indicator of its importance and impact within the academic community (Bornmann & Daniel, 2008). The citation value of an article can utilize to underline and emphasize its importance and impact.

Furthermore, this study identifies specific areas that need further investigation and suggests potential directions for future research. Indonesia's limited citation count implies the existence of obstacles to disseminating research findings, which require attention and resolution (Shafie et al., 2021). Researchers can influence future scientific publications by identifying limitations in current research and drawing links between key concepts. By identifying these gaps, researchers can focus their efforts more precisely and better understand how to use IA in various educational settings effectively.

Moreover, this study identifies specific areas that necessitate further examination and suggests potential paths for future investigation. Researchers can influence future scientific publications by identifying deficiencies in current research and developing associations between pertinent phrases (Luhgiatno et al., 2024).

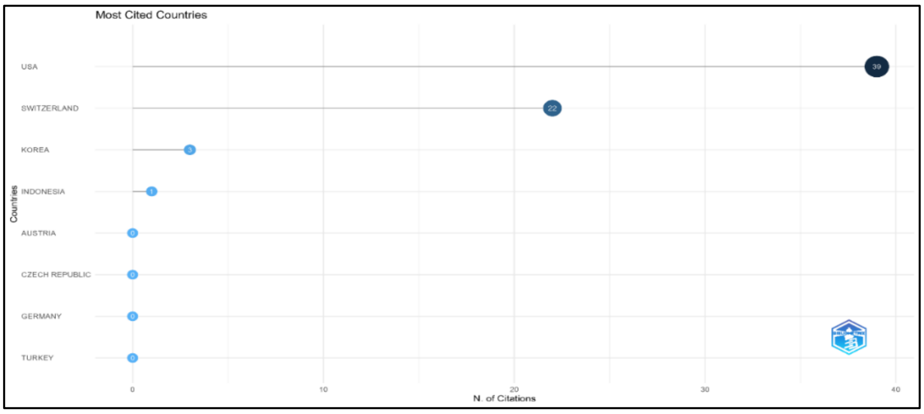

Figure 6. Most cited countries

Figure 7 illustrates the material classified according to its origins. According to the analysis, the publication source with the most articles on the topic is Physical Review Physics Education Research, with four publications. The magazine is acknowledged for its emphasis on research in physics education and its dedication to improving the discipline through rigorous scholarly contributions (Hidayatullah et al., 2021).

Numerous studies explore the application of artificial intelligence (AI) in physics education, indicating an increasing desire to include sophisticated technologies in teaching methods. The discourse and investigation of AI applications in this domain commenced in 2020 and have since progressed, underscoring the growing significance of AI as a means to improve educational results (Eden et al., 2024). Integrating artificial intelligence (AI) into physics education seeks to enhance learning experiences individualized training and offer novel opportunities for student participation and comprehension.

The continuous discourse on AI's role in physics education underscores the transformative potential of technology in academic settings. As these discussions evolve, they shape future research agendas and educational practices (Chiu et al., 2023).

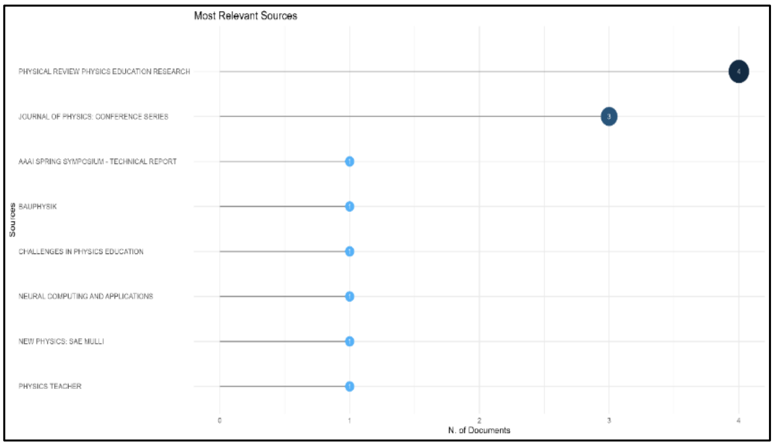

Figure 7. Documents by sources

Keywords

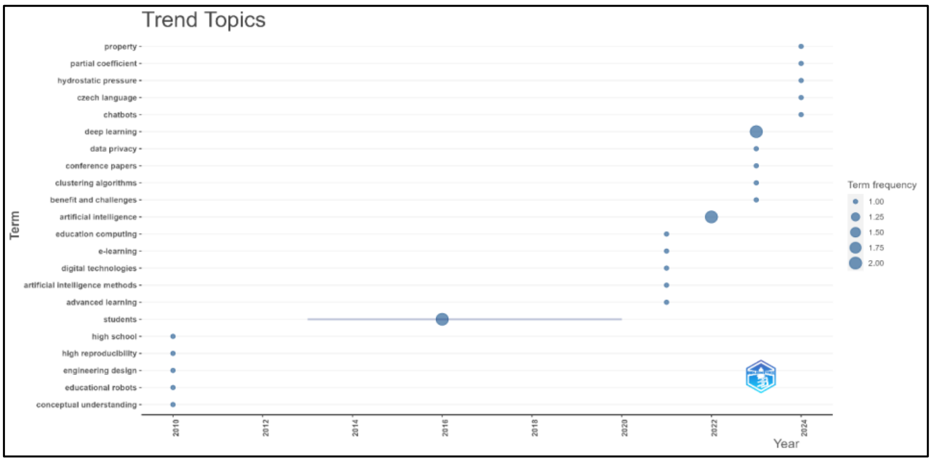

Figure 8. Trend topics

The data provided pertains to the patterns of concerns occurring between 2010 and 2024, emphasizing noteworthy developments in educational research themes. Deep learning gained prominence in 2023 and quickly attracted much attention as an intriguing subject, with a phrase frequency 2.00. The recent increase in interest is related to the progress made in neural network topologies and their utilization in diverse fields, including education (Janiesch et al., 2021).

The subject of artificial intelligence (AI) is both captivating and first documented around 2022, with a phrase frequency of 2.00. The increasing significance of AI is apparent in its increased involvement in educational technology, where it provides inventive solutions for individualized instruction and automated evaluations (Russell & Norivg, 2021).

An analysis was conducted on pupils from 2013 to 2020, yielding a word frequency of 2.00. During this period, there was a notable emphasis on student-centered learning methods and the influence of educational technology on student involvement and results. In contrast, conversations regarding high school education were solely documented and only gained significant recognition in 2010. There has been a noticeable increase in interest in research on secondary education and its changing difficulties and possibilities.

In 2021, discussions on the use of computational tools in education rose, highlighting their growing presence in educational environments and their impact on teaching and learning (Siemens, 2013). However, chatbots first piqued interest in literary conversations in 2024. The delay indicates that although chatbots have been examined in many contexts, their precise function and potential in education are still being investigated and advanced (Winkler & Soellner, 2018).

Authors

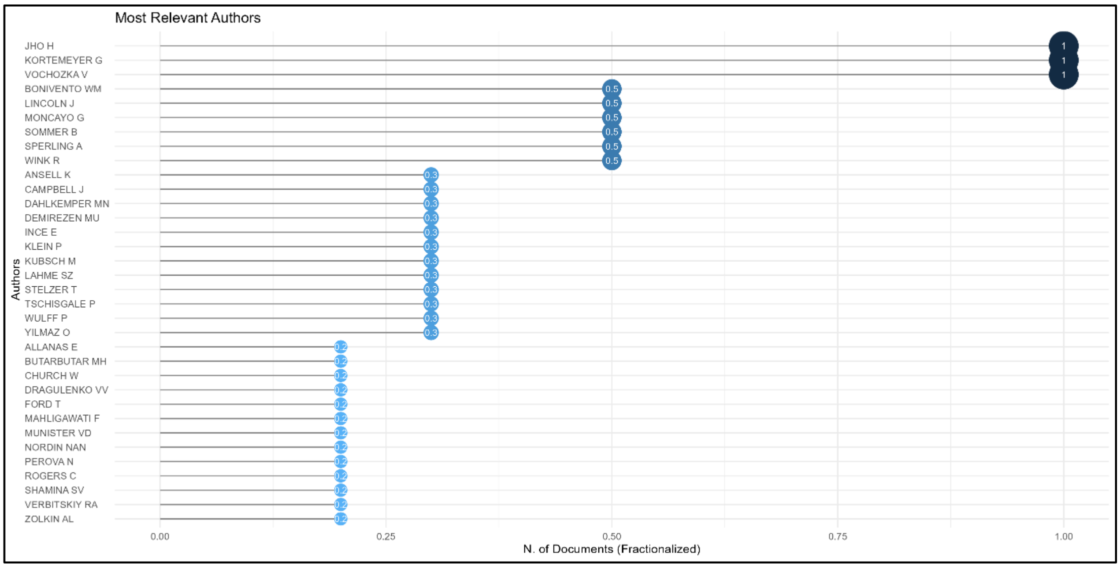

Figure 9. Most relevant authors based on their fractionalized frequency

In addition, a thorough compilation of data regarding the quantity of each document was obtained from the thirty-four most prominent authors who searched for papers on artificial intelligence (Figure 9). Jho H, Kortemeyer G, and Vochozka V are the three most influential authors, each having written a single document. Bonivento WM, Lincoln J, Moncayo G, Sommer B, Sperling A, and Wink R have authored 0.5 articles. The persons listed from 10th to 21st, after the ninth position, are Ansell K, Campbell J, Dahlkemper MN, Demirezen MU, Ince E, Klein P, Kubsch M, Lahme SZ, Stelzer T, Tschisgale P, Wulff P, and Yilmaz O. Each individual has authored 0.3 documents. The remaining 13 persons include Allanas E, Butarbutar MH, Church W, Dragulenko VV, Ford T, Mahligawati F, Munister VD, Nordin NAN, Perova N, Rogers C, Shamina SV, Verbitskiy RA, Zolkin AL. Each of them possesses a document score of 0.2.

Table 1. Ten most global cited documents (n = 24, google scholar database)

R	Title	Author (s)	Year	TC
1	Could an artificial-intelligence agent pass an introductory physics course?	Kortemeyer	2023	78
2	How do physics students evaluate artificial intelligence responses on comprehension questions? A study on the perceived scientific accuracy and linguistic quality of ChatGPT	Dahlkemper et al.	2023	17
3	Discussion for how to apply artificial intelligence to physics education	Jho	2020	12

R	Title	Author (s)	Year	TC
4	Integrating artificial intelligence-based methods into qualitative research in physics education research: A case for computational grounded theory	Tschisgale et al.	2023	9
5	Application of artificial intelligence and digital technologies in the organization of the educational process of specialists in the field of physics, engineering and metrology	Shamina et al.	2021	9
6	The andes physics tutoring system: Lessons learned	VanLehn et al.	2004	4
7	Physics-Based Artificial Intelligence Integrated Simulation and Measurement Platform	Kajbaf and Fazayeli	2021	3
8	Artificial intelligence in Physics Education: a comprehensive literature review	Mahligawati et al.	2023	2
9	Physics with robotics: Using LEGO® MINDSTORMS® in high school education	Church et al.	2010	2
10	The Role of Integrating Artificial Intelligence and Virtual Simulation Technologies in Physics Teaching	Jing and Ouyang	2023	2

Table 1 presents the data on the most globally cited Documents. Ten documents are widely regarded as the most frequently cited documents globally. The text titled "Could an artificial intelligence agent pass an introductory physics course?" by Kortemeyer (2023), has received the most citations, totalling 78. In addition, in 2023, there will be articles authored by Dahlkemper et al. (2023) titled "How do physics students assess the effectiveness of artificial intelligence responses to comprehension questions? A study on the perceived scientific accuracy and linguistic quality of ChatGPT", the paper received recognition through 17 citations. In 2020, Jho, H. published a paper titled "Discussion for How to Apply Artificial Intelligence to Physics Education" with 12 citations (Jho, 2020). The paper "Integrating Artificial Intelligence-Based Methods into Qualitative Research in Physics Education Research: A Case for Computational Grounded Theory" by Tschisgale P. et al. is ranked fourth in 2023 (Tschisgale et al., 2023). It references the ninth source. The article "Application of Artificial Intelligence and Digital Technologies in the organization of the educational process of specialists in the field of physics, engineering and metrology ", authored by Shamina, S.V. et al., ranks fifth in 2021 with nine citations (Shamina et al., 2021). The following is a scholarly essay by VanLehn, K. et al. titled "The Andean Physics Tutoring System: Lessons Learned." It was published in 2004 and has received four citations (VanLehn et al., 2004). The article titled "Physics-Based Artificial Intelligence Integrated Simulation and Measurement Platform" was authored by Kajbaf, H. and Fazayeli, F. It includes three citations (Kajbaf & Fazayeli, 2021). In 2023, Mahligawati, F. et al. published a comprehensive literature analysis titled "Artificial Intelligence in Physics Education: a comprehensive literature review" (Mahligawati et al., 2023). The review includes two quotes. The article authored by Church, W. et al. in 2010, titled "Physics with robotics: Using LEGO® MINDSTORMS® in high school education," has two citations that rank ninth among all the citations (Church et al., 2010). Lastly, in the tenth position, namely in the paper titled "The Role of Integrating Artificial Intelligence and Virtual Simulation Technologies in Physics Teaching", authored by Jing, Y. and Ouyang, F. in 2023, there are two citations (Jing & Ouyang, 2023).

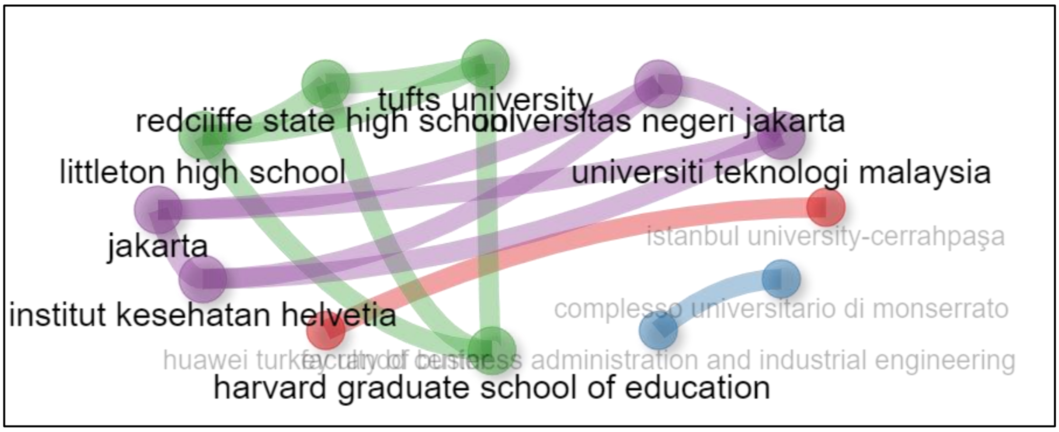

Figure 10. Collaboration network for authors based on institution

The subsequent findings offer a comprehensive summary of the author's collaboration network organized by institutions. We have obtained data about writers and their associated institutions through data analysis. Subsequently, we analyzed the collaborative network among these writers, focusing on their affiliations. According to Figure 10, Harvard Graduate School collaborates with Tufts University, Redcliffe State High School, and Littleton High School. The forthcoming collaboration encompasses the State University of Jakarta, Universiti Teknologi Malaysia in Jakarta, and the Helvetia Health Institute

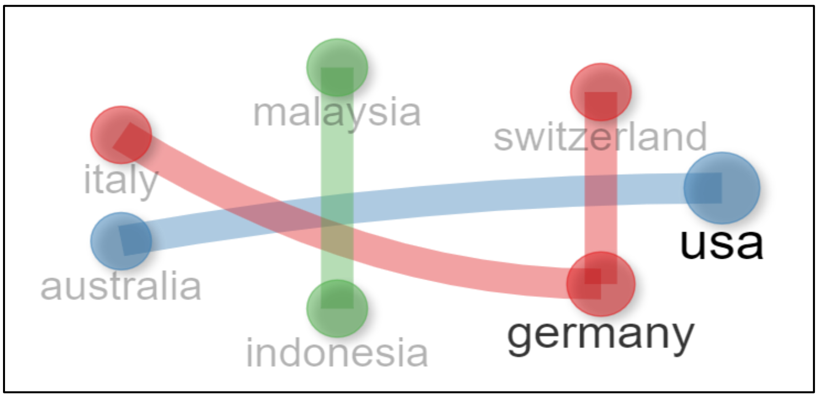

Figure 11. Collaboration network for authors based on countries

The following findings describe the Collaboration Network for Authors categorized by countries, according to the data collected from the analysis of the Collaboration Network for Authors based on Countries depicted in Figure 11. The United States collaborates with Australia, Germany forms partnerships with Italy and Switzerland, and Indonesia cooperates with Malaysia.

The subsequent analysis produces a treemap that displays information about the author's 50 keywords. The size of the keyword segment in the tree map grows in direct proportion to the box size (Keim et al., 2006; Vliegen et al., 2006). Previous studies have utilized the box size in the TreeMap to indicate the frequency of each term and examine major subjects in a specific field. They have supported this assumption. Based on the tree map presented earlier, the terms "artificial intelligence," "deep learning," and "students" together make up 4% of the whole nested rectangle. Previous studies have shown that phrases like "artificial intelligence," "deep learning," and "students" are frequently employed in the academic literature concerning technology and education (Corrin et al., 2022; Gurcan et al., 2021; Lindner & Romeike, 2019; Zawacki-Richter & Latchem, 2018). The following analysis gives the data regarding the patterns of subjects from 2010 to 2024. Deep learning attracted significant interest as an area of study in 2023 and rapidly became a prominent and compelling topic (Al Ka'bi, 2023; Wang et al., 2022; Y. Zhang et al., 2024). *Artificial intelligence* is an intriguing issue that has garnered interest and academic discussion since approximately 2022 (Labadze et al., 2023; Y. Zhang et al., 2024). Discussions regarding students extended from 2013 to 2020. Nevertheless, the conversation concerning high school was just recorded and only achieved attention in 2010. The topic of education computers also emerged in an article released in 2021 by Aleedy et al. (2022). chatbots emerged as a subject of conversation only in 2024 (Y. Zhang et al., 2024).

VOSviewer analysis results

The analysis conducted with VOSviewer identified 12 distinct clusters. Figure 12 presents a network representation illustrating the interconnections between these 12 groups.

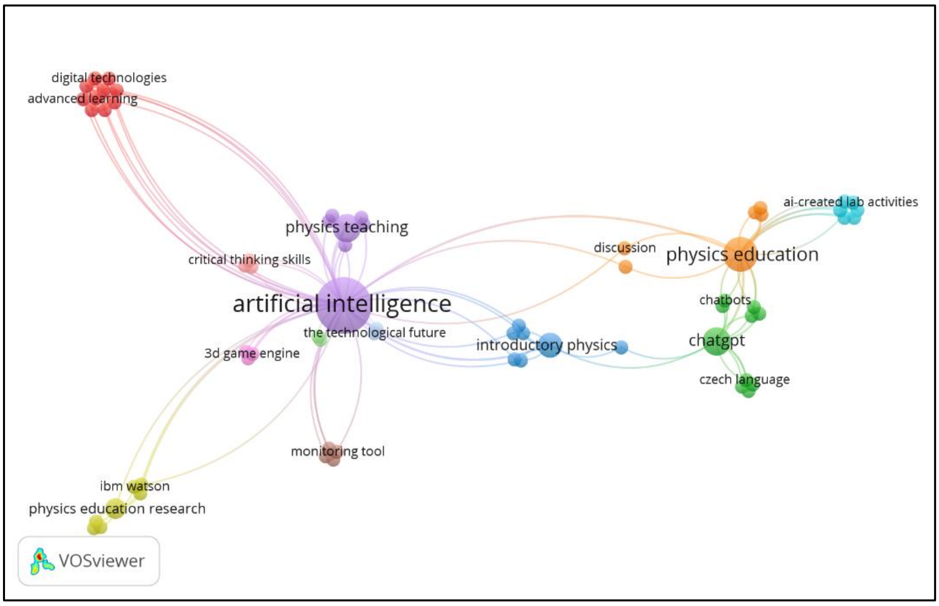

Figure 12. Network visualization

Table 2 exhibited the clusters from terms linked to AI in physics education.

Table 2. The formed clusters of keywords related to AI in physics education

Number of cluster	Number of items	Cluster name	Keywords included in cluster
1	10	Advanced Learning and Educational Technologies	advanced learning; digital technologies; e-learning; education computing; educational process; embedded systems; engineering education; higher vocational education; matrix approach; research results
2	10	Chatbot Applications in Physics Education	Chatbots; Chatgpt; czech language; hydrostatic pressure; linguistic quality; lower-secondary physics; scientific accuracy; student perception; teaching and learning; text difficulty analysis
3	7	Assessment Methods in Physics Education	Assessment; cheat sites; differentiated feedback; differentiated instruction; introductory physics; online course; pre-trained language models
4	7	Computational Approaches in Physics Education Research	computational grounde teory; ibm watson; machine learning; natural language process; physics education research; qualitative research; short-answer categorization
5	7	Innovative Approaches to Physics Teaching	artificial intelligence; experiments; fairy tales; physics teaching; primary education; primary school; virtual simulation
6	6	AI Applications in High School Physics Education	ai-created lab activities; assignment creation; generating presentation; generative ai; grading help; high school

Number of cluster	Number of items	Cluster name	Keywords included in cluster
7	6	Literature Review and Analysis in Physics Education	Discussion; fasttext algorithm; literature review; misconceptions detection; physics education; transformers model
8	4	Tools and Techniques for Physics Education Enhancement	monitoring tool; physics problem solving; reflection; translation
9	3	Virtualization and 3D Simulations in Physics Education	3d game engine; physics; virtualization
10	3	Promoting Critical Thinking in Secondary School Physics	critical thinking skills; scientific attitudes; secondary school
11	2	General Topics in Physics Education	Education; physics learning
12	2	Emerging Technologies in Physics Education	electronic unit; the technological future

The initial cluster focuses on advanced learning and educational technologies. This cluster focuses on the integration of digital technology and advanced teaching methodologies in the domain of physics education. The research aims to enhance the quality of teaching and learning in physics by employing cutting-edge educational technology, innovative learning approaches, and computational tools. The second cluster centers around the utilization of chatbot applications in the realm of physics teaching. This collection of research examines the application of chatbots and conversational AI agents in physics education. The study investigates the effectiveness of chatbots in improving teaching and learning processes. The analysis encompasses various factors, such as the quality of language, accuracy of scientific information, viewpoints of students, and the complexity of texts in physics-related scenarios. The third cluster focuses on the assessment methods employed in physics education. This research group investigates various evaluation procedures and approaches in physics education, explicitly emphasizing using artificial intelligence technologies. The study examines the utilization of diverse feedback, adaptable assessments, digital evaluation methods, and the capacities of language models in the grading and assessment processes. The fourth cluster centers on utilizing computational methods in studying physics education. The works in this cluster concentrate on employing computational tools and techniques in physics education research. The following entails utilizing machine learning, natural language processing, and qualitative analytic techniques to extract significant insights from educational data, categorize student responses, and guide teaching approaches. The fifth cluster aims to develop innovative approaches for instructing physics. The research done in this cluster aims to investigate innovative and unconventional approaches to teaching physics, particularly by incorporating artificial intelligence. The study investigates using AI-powered simulations, experiments, storytelling techniques, and virtual environments to enhance student engagement and understanding in physics education.

The sixth cluster focuses on implementing artificial intelligence (AI) applications in the context of high school physics instruction. This cluster specifically centers on using artificial intelligence in the context of high school physics instruction. The study investigates the implementation of artificial intelligence (AI) in high school physics curricula. Specifically, it focuses on AI-generated lab activities, automated grading systems, generative AI for assignment creation and presentations, and the overall integration of AI technologies. The seventh cluster focuses on the performance of literature reviews and analyses, specifically in physics education. The project's objective is to combine current information, detect misunderstandings, and investigate the capabilities of AI approaches, such as transformer models and text analysis algorithms, in assisting with literature reviews and analysis procedures. Eight clusters of tools and strategies are possible to enhance physics education. This cluster explores a range of technologies and strategies designed to improve physics education. The study investigates monitoring tools, problem-solving techniques, reflective practices, and translation processes, emphasizing utilizing artificial intelligence and computational methods to enhance these endeavors. The ninth cluster focuses on implementing virtualization and 3D simulations in physics education. This study cluster examines the application of virtualization and 3D simulations in physics education. The projects investigate incorporating 3D gaming engines, virtual environments, and simulations to develop engaging and interactive educational experiences in physics classes. The tenth cluster fosters the development of critical thinking skills in the context of secondary school physics. The primary objective of this cluster is to enhance critical thinking abilities and foster scientific mindsets in the context of secondary school physics instruction. The study investigates methods and techniques to promote critical thinking, problem-solving skills, and scientific attitudes in physics courses for secondary school students. The eleventh cluster pertains to a broad subject in physics education. This cluster comprises overarching subjects and expansive domains of investigation within the field of physics education, including studies on pedagogical processes, instructional approaches, and overall patterns in physics education. The twelfth cluster focuses on the latest advancements in physics teaching. The research conducted in this cluster investigates nascent technologies and their prospective implementations in physics education. The studies examine the effects of state-of-the-art technologies, such as electronic devices and future technological breakthroughs, on teaching and learning methods in physics education.

The findings from these clusters emphasize the immense capacity of AI technology to transform physics education in different areas, encompassing enhanced learning methodologies, assessment techniques, creative teaching approaches, and computational research methods. The clusters highlight the significance of AI-driven technologies such as chatbots, virtual simulations, and generative AI in facilitating captivating, customized, and immersive learning experiences. Moreover, the study investigates using artificial intelligence (AI) to automate the grading process, generate assignments, analyze literature, and promote the development of critical thinking abilities in physics education. Continuing with the investigation, a more in-depth examination of how AI technologies can be seamlessly integrated into physics classrooms, creating adaptive assessment systems, and exploring AI-driven tools to encourage problem-solving and scientific attitudes could significantly improve teaching and learning methods. Moreover, utilizing the capabilities of natural language processing and machine learning to examine educational data and rectify misunderstandings could result in significant findings and focused interventions in the field of physics education.

Figure 13 displays the overlay visualization. The result allows us to see the progression and interplay of these subjects during the designated time frame.

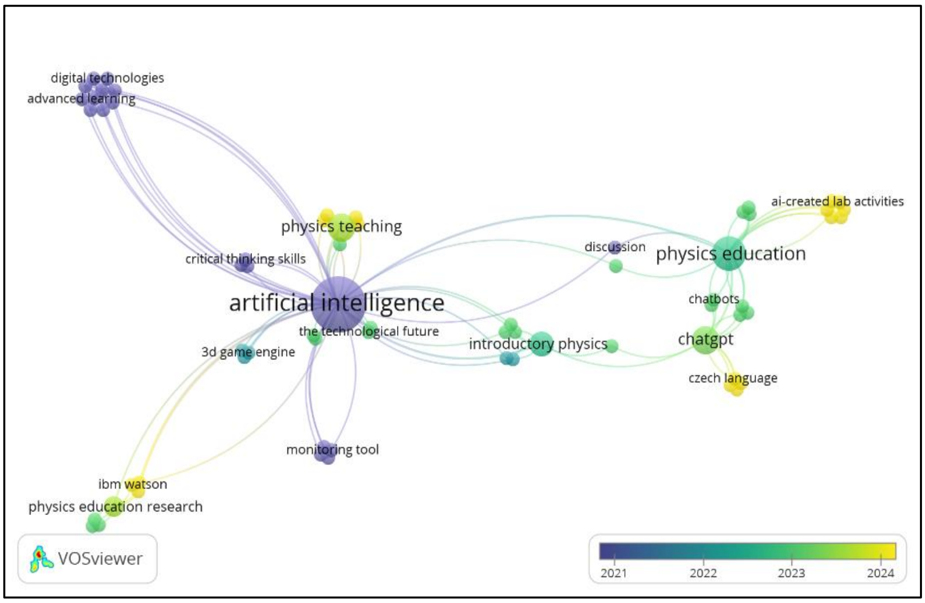

Figure 13. Overlay visualization

The subsequent findings delineate the overlay visualization. According to Figure 13, 2021 had the highest number of articles about artificial intelligence. In addition to artificial intelligence, there is virtualization, a 3D gaming engine, differentiated feedback, and instruction this year. The following topics will be discussed in 2023 or later: virtual simulation, education, physics learning, cheat sites, assessment, electronic unit, the technological future, literature review, chatbots, teaching and learning, fast text algorithm, transformers model, misconception detection, linguistic quality, scientific accuracy, student perception, chatGPT, pre-trained language models, and introductory physics. The topics that will be discussed in 2024 or later include IBM Watson, short-answer categorization, natural language processing, fairy tales, primary education, experiments, primary school, Czech language, text difficulty analysis, hydrostatic pressure, lower secondary physics textbooks, grading assistance, presentation generation, AI-created laboratory activities, generative AI, high school, and assignment creation.

The overlay visualization of Figure 13 demonstrates the significant advancement of research on artificial intelligence in physics education over time, with the most significant number of publications recorded in 2021. This year, various topics were explored besides artificial intelligence, including virtualization, 3D game engines, differentiated feedback, and differentiated training. Researchers are currently focusing on investigating virtual simulations, expanding educational applications, physics learning, cheat sites, assessment methods, electronic units, technological advancements, literature reviews, chatbots, teaching and learning strategies, fast text algorithms, transformer models, identifying misconceptions, analyzing linguistic quality, evaluating scientific accuracy, studying student perceptions, integrating ChatGPT, utilizing pre-trained language models, and applying introductory physics concepts. The visualization indicates that researchers are projected to prioritize various topics in 2024 and beyond. These include IBM Watson, short-answer categorization, natural language processing, fairy tales, primary education, experiments, primary school education, the Czech language, text difficulty analysis, hydrostatic pressure, lower secondary physics textbooks, grading assistance, presentation generation, AI-created lab activities, generative AI, high school applications, and automated assignment creation.

There is an increasing fascination with virtual simulations, 3D gaming engines, and AI-generated lab activities. It suggests investigating the possibilities of immersive and interactive learning environments to improve students' comprehension and involvement with physics ideas. Researchers could examine the efficacy of these devices in promoting hands-on learning experiences and cultivating practical skills acquisition. Furthermore, the rise of subjects concerning evaluation, personalized feedback and instruction, academic dishonesty platforms, and pre-programmed language models underscores the significance of creating artificial intelligence-based assessment and feedback systems designed explicitly for physics education. These systems can offer tailored and flexible learning experiences while also tackling concerns related to academic honesty and identifying misconceptions. In addition, the emphasis on chatbots, ChatGPT, natural language processing, and linguistic quality analysis indicates an increasing desire to utilize conversational AI and language models to enhance the teaching and learning of physics education. Researchers could investigate the possibilities of these technologies in facilitating engaging discussions, offering tailored teaching, and improving student-teacher interactions. Moreover, subjects like IBM Watson, short-answer classification, and text difficulty analysis highlight the necessity for sophisticated computational methods and machine learning strategies to scrutinize and comprehend educational data in physics education. These methodologies have the potential to offer significant insights and facilitate informed decision-making in the areas of curriculum creation, instructional tactics, and student support systems.

Moreover, the emphasis on elementary education, folklore, scientific investigations, and rational mindsets in subsequent stages implies an acknowledgment of the significance of cultivating scientific knowledge and analytical reasoning abilities from a young age. Researchers could explore novel methodologies for imparting physics principles and fostering scientific inquisitiveness among younger students. Overall, the overlay visualization presents a comprehensive and varied research landscape in applying artificial intelligence in physics education, encompassing numerous subjects and areas of investigation. Collaborations between researchers, educators, and technology specialists from different fields could help create advanced AI-driven solutions that transform physics education. These solutions would improve student learning outcomes and prepare future generations for technological progress.

Figure 14 depicts the network visualization related explicitly to the chatGPT keyword. It graphically illustrates the degree of similarity or interconnection between various keywords in the examined dataset.

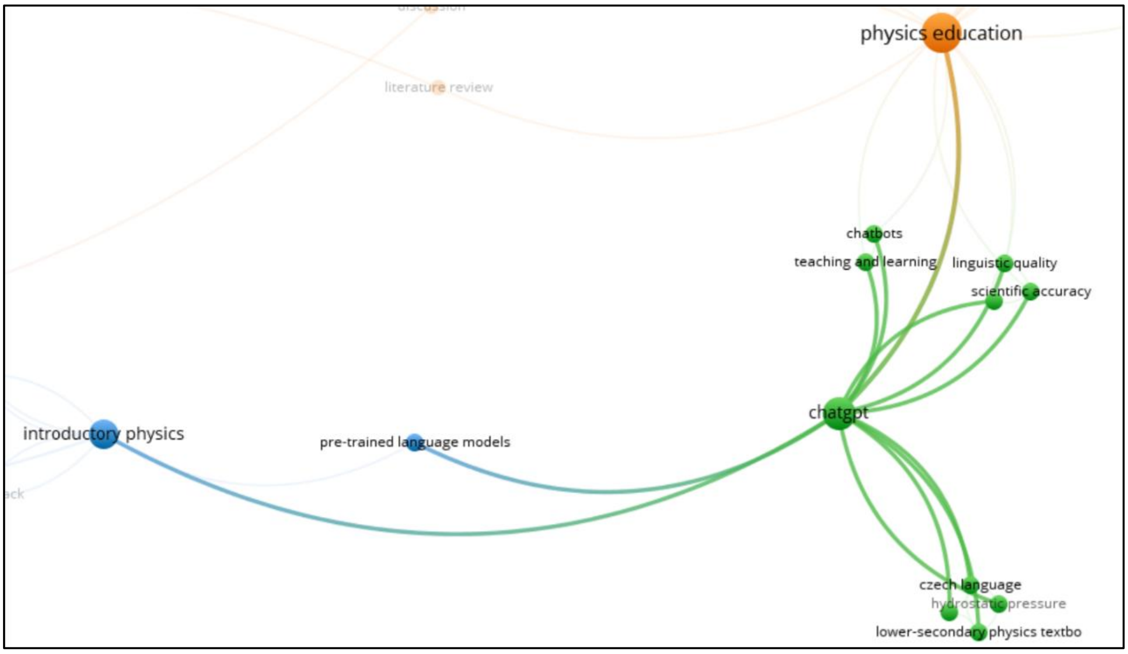

Figure 14. Topics related to ChatGPT

This keyword is associated with chatbots, education and learning, linguistic precision, scientific correctness, student perception, hydrostatic pressure in the Czech language, analysis of text complexity, physics textbooks for lower-secondary education, introductory physics, pre-trained language models, and physics education. The primary subject revolves around chatbots, namely, using ChatGPT as an AI chatbot to facilitate teaching and learning. Subtopics stemming from this subject encompass the domains of education and knowledge acquisition, which pertain to the assessment of ChatGPT's proficiency in responding to inquiries regarding fundamental concepts in physics. In addition, divisions are dedicated to assessing the language quality and scientific accuracy of ChatGPT's responses by studying students' perceptions in these areas. The research findings indicated that students regarded ChatGPT's linguistic quality favorably. However, its scientific accuracy requires thorough evaluation (Dahlkemper et al., 2023). The branches of the Czech language hydrostatic pressure and text difficulty analysis pertain to a study examining the difficulty level in ChatGPT's Czech text and comparing it to physics textbooks used in lower-secondary education. ChatGPT's proficiency in answering fundamental physics questions can be assessed using lower-secondary physics textbooks and introductory physics branches (Vochozka, 2024). The utilization of pre-trained language models, such as ChatGPT, in the field of physics education is a focal point of research, as indicated by the presence of both pre-trained language models and physics education branches (Kortemeyer, 2023). The publication by Wink & Bonivento (2023) explored the advantages of using artificial intelligence in physics education. The figure's topic mapping corresponds to the research findings, including performance assessments, user opinions, and the potential difficulties and opportunities of incorporating ChatGPT into physics instruction and learning.

The VOSViewer analysis of the dataset about artificial intelligence in physics education indicates that research in this domain has undergone significant advancements in recent years. The analysis identified 12 primary topic clusters, which included chatbot applications like ChatGPT, assessment methods, computational approaches, 3D virtual simulations, AI integration in high schools, promotion of critical thinking, and exploration of emerging technologies such as natural language processing and machine learning. The overlay visualization depicted the temporal evolution of research, exhibiting a zenith in scholarly publications in 2021. Furthermore, it revealed a transition in emphasis towards incorporating pre-trained language models, identifying misconceptions, and utilizing artificial intelligence in primary and secondary education in the forthcoming years. The detailed examination of the ChatGPT topic unveiled its associations with factors such as linguistic excellence, scientific precision, student perspectives, and its prospective utilization in instructing and acquiring introductory physics principles. These findings indicate substantial prospects and a strong desire to incorporate artificial intelligence to improve the quality of physics instruction at different educational levels. The results of the VOSViewer analysis align with prior studies that have shown the beneficial effects of artificial intelligence (AI) on educational processes (Dai & Wang, 2021; Laureano et al., 2022; Ge et al., 2018; Han, 2019; Shi et al., 2024). These findings support and contribute to the increasing evidence indicating that incorporating AI technology can greatly improve educational experiences, specifically in physics education.

IV. CONCLUSION AND SUGGESTION

The bibliometric analysis and visualization demonstrated an upward trajectory in research focused on incorporating artificial intelligence (AI) technology into the field of physics education. Notably, there was a significant surge in publications during the period spanning from 2020 to 2023. The overlay visualization depicted the progression of research topics, emphasizing the current focus on chatbot applications, assessment methodology, computational approaches, and virtual simulations. Research on integrating artificial intelligence (AI) in physics education has shown a variety of approaches. One such approach involves evaluating chatbot systems like ChatGPT to determine their linguistic abilities, scientific accuracy, and effectiveness in interactive teaching. Studies have also investigated AI-driven evaluation systems, adaptable learning experiences, and computational tools for data analysis and identifying misconceptions. In addition, scientists have investigated using virtual simulations, 3D game engines, and AI-generated laboratory tasks to offer engaging and interactive educational experiences.

We made recommendations for future study directions based on our bibliometric findings regarding trends and patterns in AI research in physics education. Subsequent investigations should prioritize comprehensive assessments of the precision and excellence of AI models about diverse physics subjects and educational tiers. Developing AI-driven assessment systems that are accurate, fair, and transparent is of utmost importance. These systems should be designed to eliminate bias and guarantee consistent and impartial evaluation of all students. Investigating blended learning methods that combine AI-powered simulations and virtual worlds is crucial. Studies should evaluate the impact of these methods on students' comprehension of physics ideas and practical abilities.

Facilitating interdisciplinary collaborations that harness the power of AI in physics education can create new opportunities for innovation. For example, collaborations among physicists, educators, and AI developers have the potential to provide innovative tools and approaches that are very efficient. In addition, longitudinal studies could be carried out to assess the enduring effects of AI on learning outcomes, information retention, and the acquisition of scientific abilities in physics education. Although AI has the potential to improve physics education significantly, it is essential to recognize the existing limitations of the research and the necessity for additional studies in various educational settings. Exploring the adaptation of AI for under-resourced schools or diverse cultural situations can yield valuable insights into the broader applicability of AI in education.

Although these findings show promise, our research has certain limitations. Using Google Scholar and Scopus databases indicates that future studies could be improved by including additional databases like Web of Science (WoS). Furthermore, future studies could employ a systematic literature review to conduct a more thorough study and gain a more nuanced comprehension of the subject matter.

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