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Literature Review

Trends and Directions in Online Learning Research in Physics and Astronomy Education: A Bibliometric Analysis

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ABSTRACT

This study aims to explore trends and directions in online learning research in the fields of physics and astronomy, with a particular focus on the integration of online learning technologies in these disciplines. With the rapid development of information and communication technology (ICT), online learning has significantly changed education by overcoming traditional time and geographical constraints. This study examines key questions related to the evolution of online learning in these complex topics, highlighting the impact of educational technologies such as simulation, augmented reality (AR), virtual reality (VR), and machine learning. Additionally, challenges related to technology access and digital literacy are identified as barriers to the implementation of these technologies. To analyze trends in this field, a bibliometric approach was used with data obtained from the Scopus database, which includes articles related to "online learning" in physics and astronomy published between 2005 and April 2025. This analysis utilized tools such as R and VOSviewer to assess publication trends, citation patterns, leading authors, and institutional contributions. A total of 472 articles were selected for analysis, revealing significant growth in publications after 2015, particularly following the global pandemic, which heightened interest in online education methods. The findings indicate that the number of publications and citations has increased rapidly, with China leading in contributions. Leading journals such as *Applied Sciences* and *Sensors* and key authors such as Wang Y and Liu Y have made significant contributions to this field. Emerging topics in this research include the application of machine learning and the integration of personalized learning technologies. The results of this study provide valuable insights into the development of online learning strategies in physics and astronomy education, with an emphasis on the need for continuous innovation and collaboration in this rapidly evolving field.

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1. INTRODUCTION

Recent developments in information and communication technology (ICT) have significantly impacted education (Baako & Abroampa, 2023; Rienties et al., 2012). Adoption of online learning approaches marks one major change since they allow learning to occur free from time and geographic

constraints. Currently, technology integration has significantly advanced online learning, spanning from primary to higher education (Adedoyin & Soykan, 2023; Gjerde et al., 2021; Greenhow et al., 2022; Yu, 2022). Because it provides chances to investigate improvements in more flexible, efficient, and inclusive learning environments, the direction of online learning research has grown increasingly important. Policymakers, teachers, and researchers are now more and more fascinated by knowing how online learning might be included in many disciplines, including more difficult ones like physics and astronomy. A comprehensive investigation on the direction and trends of online learning can offer significant insights for the development of learning models more in line with the demands of the times (Leo et al., 2021; Rahman, 2014). To thus ascertain the degree of its influence on the quality of education and learning, it is crucial to map the development of research in this subject, particularly in regard to its use in physics and astronomy education.

Physics and astronomy education, due to their complex nature, require tailored online learning approaches to effectively convey content and help students grasp difficult concepts. Physics, a study of natural events, and astronomy, which looks at celestial bodies and the universe, demand strong interaction between theory and experiment. Learning physics and astronomy sometimes requires sophisticated tools and experiments, and applying mathematical models, which need strong visual and spatial knowledge. Consequently, both call for approaches to learning that can successfully mix theory with application. Online learning has evolved as a solution enabling students to access materials, simulations, and experiments electronically, given the fast advancement of technology. This helps pupils to grasp challenging ideas and creates chances for more general access to physics and astronomy education, even in places with poor educational facilities.

Studies on patterns and orientations in online learning for physics and astronomy education show that developments in these learning strategies are rather dynamic. Numerous studies have looked at how interactive learning tools, computer simulations, and internet media could enhance physics and astronomy classes. For physics experiments or astronomy models available online, for instance, the utilization of simulations gives students chances for exploration previously unthinkable in conventional classrooms (Feigelson et al., 2021; Sen et al., 2022). Furthermore, becoming more common in assisting visualisation-based learning in physics and astronomy are the creation of learning environments like augmented reality (AR) and virtual reality (VR) (Lai & Cheong, 2022; Matovu et al., 2023). Despite the benefits, challenges such as limited access to technology, varying levels of digital literacy among students, and insufficient teacher training remain significant obstacles to effective online learning in these fields. Research in this area is therefore absolutely essential to find how particular strategies and technology might be maximised for online learning in physics and astronomy.

A clear understanding of online learning research's progress, trends, and direction in physics and astronomy can be seen through bibliometric analysis. Using bibliometric analysis, researchers can spot publishing trends, citation count, and the impact of particular works or authors on the issue. Understanding publishing trends and often discussed subjects helps us to determine the major emphasis of research and the primary contributions made by different studies. Using bibliometric analysis, we also uncover linkages among authors, institutional affiliations, and nations most involved in this kind of research. Designing future research plans and appreciating worldwide contributions to the evolution of online learning in physics and astronomy depend much on this information. Consequently, the following research questions have to be answered in this study:

(1) What is the general knowledge of bibliometric analysis concerning trends and directions in online learning research in physics and astronomy?
(2) How many annual publications on this subject exist?
(3) Annually, how many citations are there?
(4) What are the most relevant sources in this research?
(5) Who are the most relevant authors?
(6) Which affiliations are the most influential?
(7) Which countries are the most active in this research?
(8) Which documents are the most cited?
(9) What are the emerging topic trends in research on bibliometric analysis?

2. METHOD

This study uses a bibliometric analysis design to examine trends and directions in online learning research in physics and astronomy education. Bibliometric analysis is a method used to analyze scientific publications based on bibliographic data that can describe developments, patterns, and connectivity within a field of research. The main advantage of bibliometric analysis lies in its ability to provide an objective quantitative overview of publication trends, citations, collaboration between authors, and the influence of

specific topics or articles (Aksnes et al., 2019; Li et al., 2021; Passas, 2024). Additionally, bibliometric analysis enables researchers to identify the most influential sources and authors in a field, as well as to examine the relationships between various research elements (Waltman, 2016). The data used in this study were obtained from the Scopus database, using the keyword "online learning." From the initial search, a total of 51,808 publications were obtained. The data was then filtered based on specific criteria, namely the publication period from 2005 to April 17, 2025, resulting in 50,381 articles. The data was further filtered by selecting the subject field of physics and astronomy, resulting in 2,026 articles. From this data, only documents of the article type were selected, resulting in 517 articles. Additionally, only journals were selected as the document type source, yielding 513 relevant articles. All selected articles were in English, resulting in 472 articles after the filtering and exclusion process. The period from 2005 to April 2025 was selected to capture the latest developments in online learning in physics and astronomy, particularly given the surge in online education research that occurred after the COVID-19 pandemic, and to see how it has changed compared to before COVID-19. On the other hand, the selection of articles from journals ensures that the study focuses on peer-reviewed research, which is generally considered a reliable source of academic knowledge.

Data analysis in this study was conducted using bibliometric software based on R and VOSviewer. Both tools are highly effective for managing, visualising, and analysing bibliometric data, such as the number of publications, citations, author affiliations, and collaboration networks between authors or institutions. This analysis process will focus on answering the research questions that have been previously established. Using Bibliometrix and/or VOSviewer, data analysis will be conducted to determine the answers to the research questions.

3. RESULTS AND DISCUSSION

In this discussion, nine important points related to the bibliometric analysis of trends and directions in online learning research in physics and astronomy will be discussed in depth. First, general data information on bibliometric analysis provides an overview of this topic. Second, an analysis of the number of publications each year to see how this research has developed over time. Third, a discussion of the number of citations received each year, which will provide insight into the extent of the influence of this research in the scientific community. Fourth, identification of the most relevant sources used in this research. The fifth is a discussion of the authors who have contributed the most to this research. Sixth, the most relevant institutional affiliations in this research will also be discussed to understand the collaboration between educational and research institutions. Seventh, an analysis of the countries most active in this research, as well as their contributions to the development of online learning in physics and astronomy. Eighth, the most cited documents will be identified, which can provide an indication of articles that have had a significant impact in this field. Finally, trends in this research will be discussed to understand the future direction of research in online learning in physics and astronomy.

3.1. Main Data Information

Figure 1 shows various statistics generated from a bibliometric analysis of research trends in the field of online learning, focusing on the period between 2005 and 2025. During this period, there were 132 sources contributing to publications related to this topic, resulting in a total of 472 documents. Interestingly, the annual growth rate of publications reached 6.46%, indicating a significant increase in online learning research in physics and astronomy. With a total of 1,513 authors, this research also reflects the broad contribution of various parties in this field.

Of the total number of authors, 31 authors produced works individually, indicating that there is still a contribution from individual authors, although collaboration is more dominant. International collaboration is also quite high, at 19.07%, illustrating the involvement of various institutions and countries in this research. In addition, the average number of authors in each document is 4.03, indicating that most articles are the result of collaboration between teams of authors. The keywords used by authors in their publications number 1,492, while the references recorded reach 17,784, indicating the large number of sources used to enrich and deepen this topic.

Figure 1. Main Data Information from the Article on Online Learning Research in Physics and Astronomy Education that was Analysed

The average age of the published documents is 4.78 years, indicating that most of the publications are fairly recent and relevant to the latest technological developments. Additionally, the average number of citations per document is 16.2, indicating that these articles are frequently referenced by other research, highlighting the significant impact of this research in the field. Overall, this data provides a clear picture of how far research in online learning in physics and astronomy has progressed, as well as highlighting the importance of international collaboration and team authorship in advancing this field.

3.2. Number of publications per year

Figure 2 shows the trend in the number of research publications on online learning in physics and astronomy from 2005 to 2025. In the early years, between 2005 and 2014, publications related to online learning in this field were very limited. Some years even recorded no articles published, while other years only recorded a few articles. This indicates that during this period, research on online learning in physics and astronomy was still in its very early stages of development. It is likely that online learning was not yet a major focus in science education, and research on its application was still minimal, both in terms of quantity and scope. In addition, online learning technologies and platforms, which were still in their infancy at the time, may not have been robust enough to attract significant attention from researchers in this field.

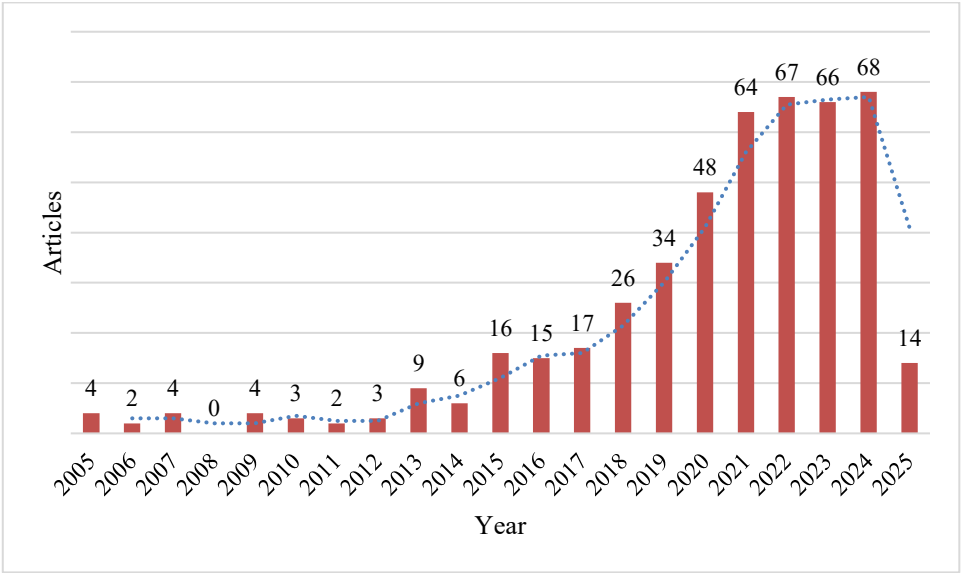

Figure 2. Number of Publications per Year

However, starting in 2015, the number of publications experienced a significant increase, reflecting major changes in the approach to science education. This increase coincided with the emergence and development of various online learning platforms such as MOOCs (Massive Open Online Courses), which encouraged more researchers to explore the potential and impact of online learning, particularly in physics

and astronomy. The highest peak in the number of publications occurred between 2020 and 2024, with the number of articles reaching 68 in 2024. This surge was almost certainly triggered by the COVID-19 pandemic, which forced schools and universities around the world to switch to online learning en masse (Adedoyin & Soykan, 2023; Bozkurt et al., 2020; Dhawan, 2020). Research on effective ways to implement online learning and its impact on physics and astronomy education became highly relevant and urgent. However, following this peak, predictions for 2025 indicate a significant decline, with only 14 articles expected to be published. This decline likely reflects stabilization following the pandemic-driven surge, during which much research already addressed the fundamentals of online learning, and attention may now shift to more specific or implementation-based research topics or approaches.

Technology is rapidly advancing in the field of education due to its ability to enhance accessibility, efficiency, and the quality of learning. With the availability of digital devices and the internet, information can be accessed quickly and easily by students and educators anytime and anywhere, thereby reducing geographical and time-related barriers. Additionally, in the fields of physics and astronomy, technology enables more interactive and personalized learning methods (Lämsä et al., 2018), such as educational apps, video-based learning, and digital simulations, which can be tailored to individual learning styles. This fosters innovation in teaching, enhances learning motivation, and opens new opportunities for more inclusive and adaptive education.

3.3. Number of citations per year

Figure 3 illustrates data on the Average Total Citations per Article (ATCpA) and Average Total Citations per Year (ATCpY) in the same study from 2005 to 2025. From this graph, we can see two quite different trends between the two, although both show fluctuations throughout the period. For ATCpA, represented by the black box, there are sharp fluctuations throughout the time range shown. From 2006 to 2015, ATCpA tended to fluctuate between low and medium numbers, with several spikes in 2012 and 2015, before experiencing a significant spike in 2020. This sharp spike can be attributed to increased attention to the research topic in line with the development of more relevant research technologies and methodologies at that time. However, after the peak, the number of citations per article began to decline sharply in 2024 and is expected to continue to decline in 2025. This suggests that although this research received a lot of attention at its peak, newer publications may be receiving fewer citations, or it may be related to topics that are becoming less relevant or have been researched more extensively.

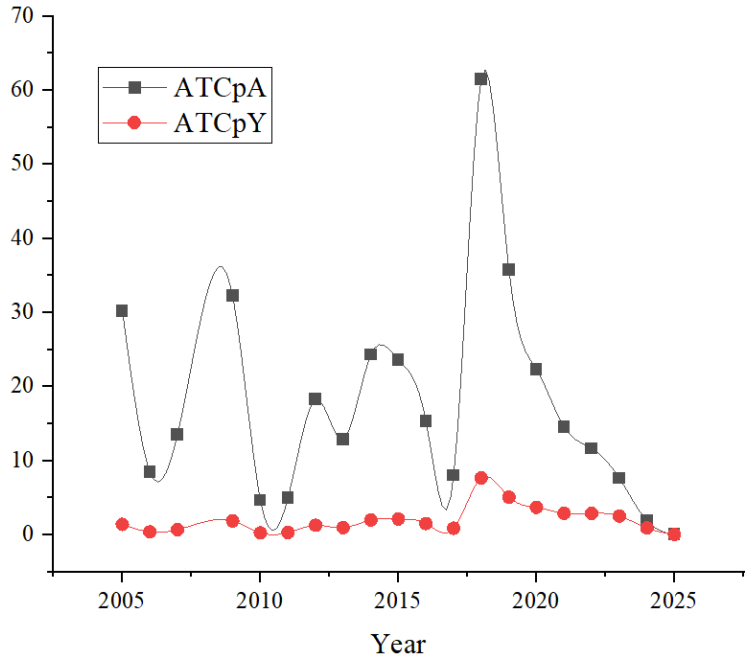

Figure 3. Average Total Citations per Article (ATCpA) and Average Total Citations per Year (ATCpY)

Meanwhile, the graph for ATCpY, represented by the red dots, shows a much more stable pattern with significantly lower numbers compared to ATCpA. Throughout the 2005 to 2025 time span, the number of citations per year for ATCpY never experienced a large spike, except for a slight increase seen in 2020. This may indicate that although the published articles received a number of citations, there was no spike as

significant as that seen in ATCpA. The increase in 2020, although not as large as ATCpA, may indicate that although research on online learning in physics and astronomy is increasing, citations per year are not as fast or as numerous as citations per article. The predicted decline for 2025 in ATCpY also suggests that, over time, this topic may begin to decline in relevance, or citations per year may become increasingly limited.

The Average Total Citations per Article (ATCpA) and Average Total Citations per Year (ATCpY) in a research area can be volatile due to several factors that influence the dynamics of recognition and relevance of a publication at a given time. In many research areas, ATCpA and ATCpY are often fluctuating, and this is normal (Huang, 2019; Sulistiawati et al., 2023). The fluctuation in ATCpA and ATCpY is influenced by many factors. First, the level of innovation and development in the research area can cause spikes or declines in the number of citations, especially when new findings or technological developments attract the attention of the scientific community. Second, the research life cycle also influences citations; newer articles may take time to gain citations, while older articles may reach their peak citations after a certain period. Third, changes in research trends or focus within the academic community can lead to a decline in citations on certain topics if attention shifts to new research areas. In addition, external factors such as restrictions on access to articles, changes in journal policies, and advances in digital platforms for publication can also contribute to citation fluctuations. All these factors together cause ATCpA and ATCpY in a research area to fluctuate over time.

3.4. Most relevant sources

Figure 4 shows the most relevant sources in research on online learning in physics and astronomy, based on the number of documents published. One of the main sources that has produced the most publications related to this topic is the journal Applied Sciences (Switzerland), with a total of 83 documents published. This shows that this journal has made a significant contribution to the scientific literature on online learning in the field of physics and astronomy. Next, Sensors, with 41 documents, is also a relevant source, followed by Sensors (Switzerland) with 28 documents and IEEE Sensors Journal with 20 documents. These journals appear to focus on research related to sensors and related technologies that can be applied in experiments or online learning applications in physics and astronomy.

Additionally, there are several other journals that also make important contributions despite having fewer publications, such as IEEE Transactions on Instrumentation and Measurement with 11 documents and ISA Transactions with 12 documents. Journals like Entropy, Advances in Science, Technology, and Engineering Systems, Nature Communications, and Physical Review Physics Education Research also make significant contributions by publishing several documents related to this topic. Overall, this data provides a clear picture of the most frequently used scientific sources in online learning research in physics and astronomy, reflecting collaboration across various disciplines and the application of cutting-edge technology in education.

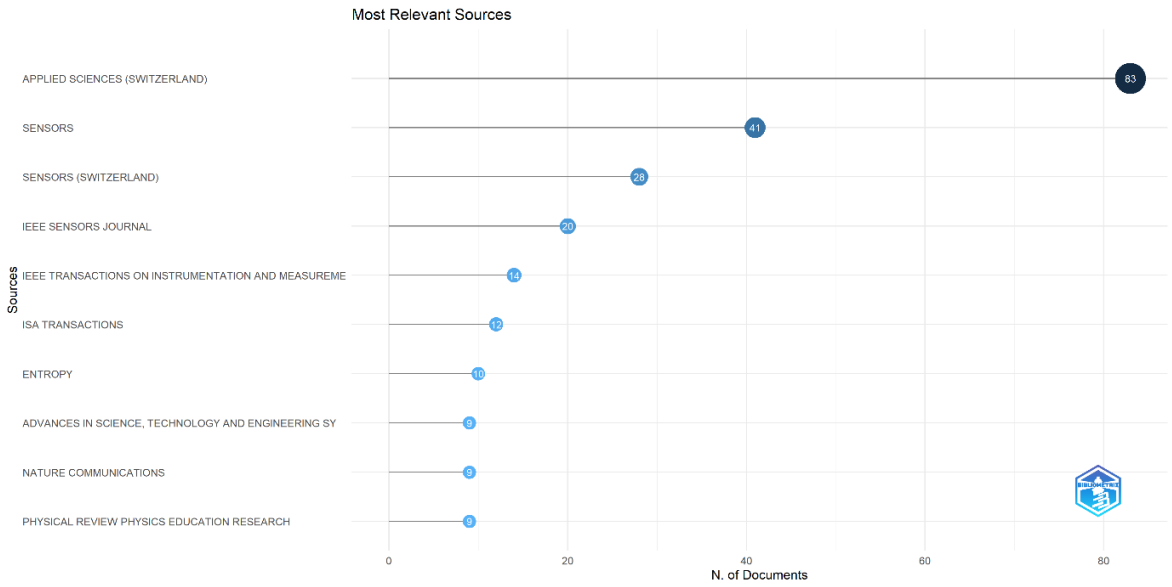

Figure 4. Most Relevant Sources

Journal information or sources that have the most impact on a research area are crucial because they provide insights into trends, current topics, and major developments in that field (Ball & Tunger, 2006). High-impact journals typically contain research that has a significant influence (Hou & Ma, 2020), both

theoretically and practically, in shaping the direction of scientific knowledge. By identifying these journals, researchers can avoid duplicating existing research and focus more on topics that have not been explored much. In addition, influential journals are often published by reputable publishers and have undergone a rigorous peer review process, so their quality and validity can be trusted. Knowing these sources also helps researchers build strong references in their work, increase the credibility of their research, and strengthen their arguments by citing widely recognized works. On the other hand, by accessing impactful journals, researchers can also collaborate with leading authors, opening up opportunities for further discussion and broader academic networking. Not only that, but authors researching topics related to online learning in physics and astronomy can use these journals as targets for their publications. This can help them find the most appropriate publication targets so that their articles will be read and referenced more widely.

3.5. Most relevant authors

Figure 5 shows the most relevant authors in research on online learning in physics and astronomy based on the number of documents they have published. The author who contributed the most is Wang Y, with 16 documents published on this topic. This indicates that Wang Y has a very significant role in this field of research, with contributions exceeding those of other authors. He is followed by Liu Y, who has 11 documents, and Wang X and Wang H, who have contributed 9 documents each. These four authors show that there is a group of authors with the same surname, Wang, who are consistently involved in research related to online learning.

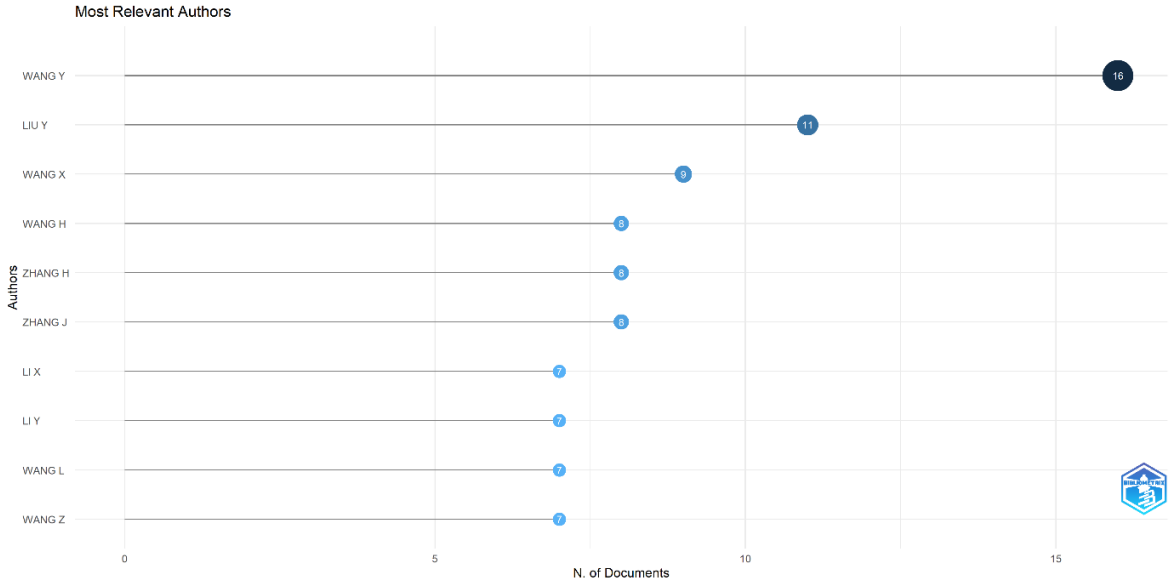

Figure 5. Most Relevant Authors

In addition, there are several other authors who have also made important contributions with fewer papers, such as Zhang H, Zhang J, Li X, Li Y, Wang L, and Wang Z, who have between 7 and 8 papers each. This diversity of authors with varying contributions reflects the strong collaboration between various individuals in this field of research. Through this data, we can see that certain authors, especially those with the same last name, appear to be very active in developing research in online learning in physics and astronomy, indicating the existence of a close collaboration network in this research.

3.6. Most relevant affiliations

Figure 6 shows the most relevant institutional affiliations in research on online learning in physics and astronomy, based on the number of articles published. Tsinghua University emerges as the most contributing institution, with a total of 28 articles published on this topic. This university is followed by Zhejiang University with 25 articles, and Peking University with 22 publications. The presence of these leading universities in China demonstrates the important role of higher education institutions in the country in developing research on online learning in physics and astronomy.

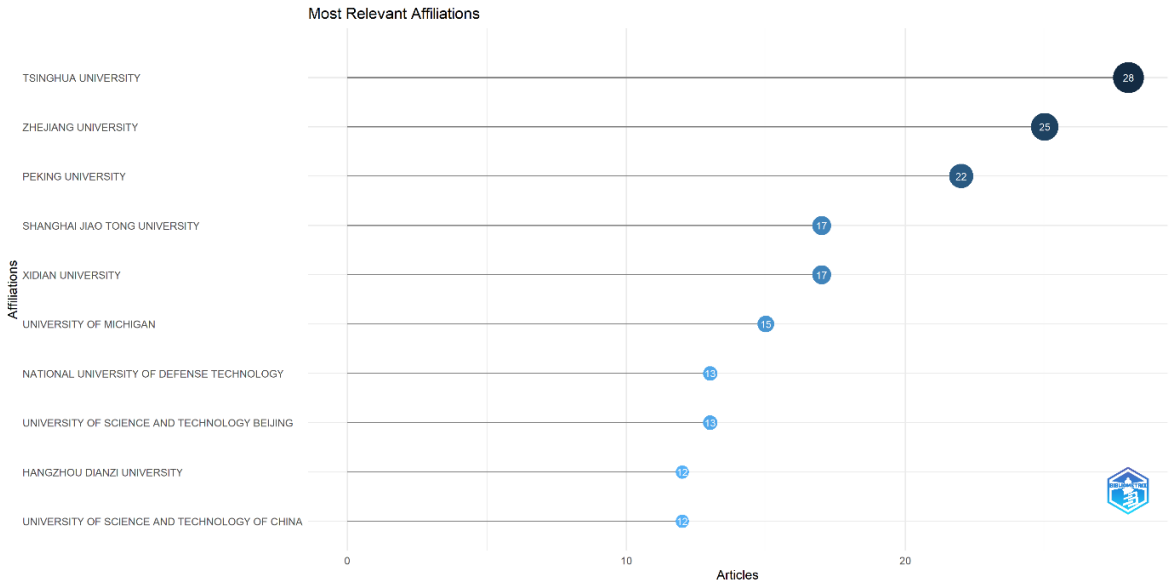

Figure 6. Most Relevant Authors

In addition to these universities, several other institutions have also made significant contributions, such as Shanghai Jiao Tong University and Xidian University, which have published 17 articles each. The University of Michigan is also listed as an important international affiliate in this research, with 15 articles published. Several other universities, such as the National University of Defense Technology, the University of Science and Technology Beijing, Hangzhou Dianzi University, and the University of Science and Technology of China, also contributed significantly, with each publishing between 12 and 18 articles. This data indicates that research in online learning in physics and astronomy is not only driven by universities in China but also by international institutions collaborating on this topic. The diversity of affiliations reflects the importance of cross-national and institutional collaboration in developing innovative online learning methods applicable to these disciplines.

3.7. Most relevant countries

Table 1 shows the distribution of articles published related to online learning in physics and astronomy by country, as well as the proportion of articles categorized as single-country publications (SCP) and multi-country publications (MCP). China is the country with the largest contribution, with 160 articles, accounting for approximately 33.9% of the total articles published. Of these, the majority are single-country publications (SCP), with 137 articles (approximately 85.6%), while only 23 articles (14.4%) are multi-country publications (MCP). These figures reflect China's dominance in online learning research in this field, which is largely conducted by authors from domestic institutions.

Table 1. Most Relevant Countries

Country	Articles	Articles %	SCP	MCP	MCP %
China	160	33,9	137	23	14,4
USA	37	7,8	33	4	10,8
Korea	27	5,7	21	6	22,2
Spain	13	2,8	10	3	23,1
United Kingdom	13	2,8	7	6	46,2
Japan	10	2,1	7	3	30
Indonesia	9	1,9	8	1	11,1
Saudi Arabia	9	1,9	6	3	33,3
India	8	1,7	5	3	37,5
Australia	7	1,5	5	2	28,6

In second place, the United States has 37 articles (7.8%), with 33 articles (89.2%) being SCP and 4 articles (10.8%) being MCP. This indicates that although its contribution is smaller compared to China, research from the United States is more focused on international collaboration. Other countries, such as South Korea, Spain, and the United Kingdom, also made significant contributions, with 27 articles (5.7%), 13 articles (2.8%), and 13 articles (2.8%), respectively. Among these countries, the United Kingdom stands out with 46.2% of its articles classified as MCP, reflecting a very high level of international collaboration.

Some countries with smaller contributions, such as Japan, Indonesia, Saudi Arabia, India, and Australia, also demonstrate significant levels of international collaboration. For example, South Korea, with 22.2% MCP, and India, with 37.5% MCP, show a higher tendency to collaborate with researchers from other countries. Despite the smaller number of articles, these countries are participating in global research on online learning, highlighting the importance of cross-national collaboration in the advancement of knowledge in physics and astronomy. This data reflects the significant global involvement in this research, with the majority of articles involving international collaboration, particularly between countries with large contributions such as China, the United States, and the United Kingdom.

Multinational publications or those involving collaboration between researchers from various countries are very important in research because they can improve the quality, credibility, and global impact of the research (Freshwater et al., 2006). This collaboration enables the exchange of ideas, methods, and perspectives, enriching research outcomes and making them more comprehensive. Additionally, publications involving researchers from different countries are often considered more credible and have a higher chance of being accepted at the international level, thereby increasing visibility and the number of citations. International collaboration also expands academic networks, creates opportunities for joint grants, and allows access to diverse resources, such as research facilities and data that may not be available in one country. On the other hand, cross-national research is essential for addressing complex global issues (Smith et al., 2011), such as climate change and pandemics, which require a holistic approach. Thus, multinational publications not only strengthen the quality of research but also contribute more significantly to solving global problems.

3.8. Most cited documents

Online learning in Physics and Astronomy has become an increasingly important area in educational research. This is evident from the articles that are frequently cited, as shown in Table 2. With the increasing use of digital technology, research related to online learning has grown to create more effective methods for delivering complex scientific material. The most cited articles provide insights into trends and significant contributions in this field. Highly cited articles are often considered influential works that shape the direction of further research, and this applies to the topic of online learning in Physics and Astronomy.

The article by Choi et al. (2018) with 566 citations demonstrates a major contribution to understanding aspects of online learning. Although this article has the highest total number of citations, its lower citations per year (TC per Year) of 70.75 indicates that while it was highly influential initially, its impact may be diminishing over time. On the other hand, the article by Cai et al. (2019), with 536 citations and a higher TC per Year (76.57), shows that this research remains relevant and widely used in recent studies. This indicates that the findings presented in the article remain important in the context of recent developments in online learning.

Additionally, newer articles such as Dogan et al. (2023), despite being recently published, have already begun to gain significant attention with 133 citations and a high TC per Year (44.33). This indicates that this research contributes to newer and more relevant trends in online learning in Physics and Astronomy. The Normalized TC also reveals that the article by Dogan et al. (2023) has a very large impact relative to other articles, with the highest score (17.35), indicating that although this article is relatively new, the findings presented have a significant influence among researchers.

In a more in-depth analysis, although some articles such as Prezioso et al. (2018) and Esqueda et al. (2018) have lower total citations, they still contribute to specific understanding in online learning, even though their impact is not as great as newer articles. This reflects that not all articles with high citations necessarily include revolutionary findings or have long-term relevance. Most articles with low citations are more focused on specific issues that may affect a limited audience but still hold significant value in the development of online learning.

Table 2. Most Cited Documents

Author(s) and Publication Year	Total Citations	TC per Year	Normalized TC
Choi et al. (2018)	566	70,75	9,20
Cai et al. (2019)	536	76,57	14,99
Duan et al. (2020)	238	39,67	10,65
Hu et al. (2018)	225	28,13	3,66
Prezioso et al. (2018)	167	20,88	2,72
Mujahid et al. (2021)	160	32,00	10,99
Esqueda et al. (2018)	138	17,25	2,24
Dogan et al. (2023)	133	44,33	17,35
Luo et al. (2022)	129	32,25	11,04
Hooshyar et al. (2020)	110	18,33	4,92

Overall, this data indicates that while older articles such as Choi et al. (2018) and Cai et al. (2019) remain relevant, newer research such as that published by Dogan et al. (2023) shows that online learning in Physics and Astronomy continues to evolve and attract significant attention among researchers. More innovative and relevant research aligned with the latest advancements in technology and pedagogy can pave the way for new discoveries that enrich how we teach and learn in the context of science.

3.9. Topic trends in online learning research

Figure 7 is a visual representation of a bibliometric analysis using VOSviewer that illustrates the relationships between various keywords frequently appearing in research on "online learning." This keyword network shows the connections between concepts related to the main topic and various interacting subtopics. At the center of the network, we can see the word "online learning" as the main keyword, surrounded by more specific terms such as "machine learning," "students," "teaching," "distance learning," and "higher education." This shows that online learning is not only related to the use of technology but also to broader concepts in education, such as teaching methods, distance learning, and the application of machine learning in education.

In addition, there are also a number of keywords related to advanced technologies such as "neural networks," "algorithm," "data mining," and "adaptive control systems." These words indicate the involvement of high technology in the development of methods and tools to improve the effectiveness of online learning, especially in terms of personalization and adaptation of learning. Furthermore, there is a connection between "federated learning" and "adversarial machine learning," which indicates a growing trend in the use of safer and more decentralized machine learning techniques in online learning. On the other hand, keywords related to "emotion," "face recognition," and "pandemic" highlight the human and social dimensions that influence the implementation of online learning, especially in situations such as a pandemic, where distance learning methods have become increasingly important. This network provides a comprehensive overview of how various technological and pedagogical elements are interconnected in online learning research, and reveals a growing trend toward the integration of advanced technologies to support education in diverse contexts.

Although currently a research trend, adaptive control systems have been around for a long time, for example, in the 1958 study "A survey of adaptive control systems" (Aseltine et al., 1958). However, previous studies did not focus much on education, and now adaptive control systems are beginning to be widely adopted in the field of education. This indicates the development of educational research in a more advanced direction by integrating multidisciplinary approaches in problem solving, especially the integration of technology.

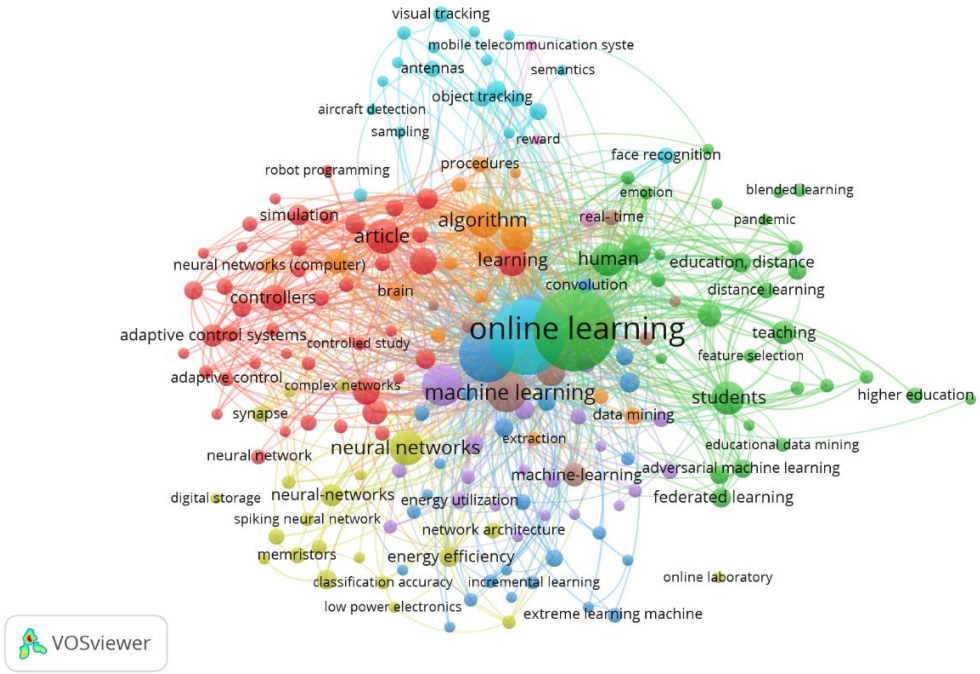

Figure 7. Visual Representation of Keyword Networks

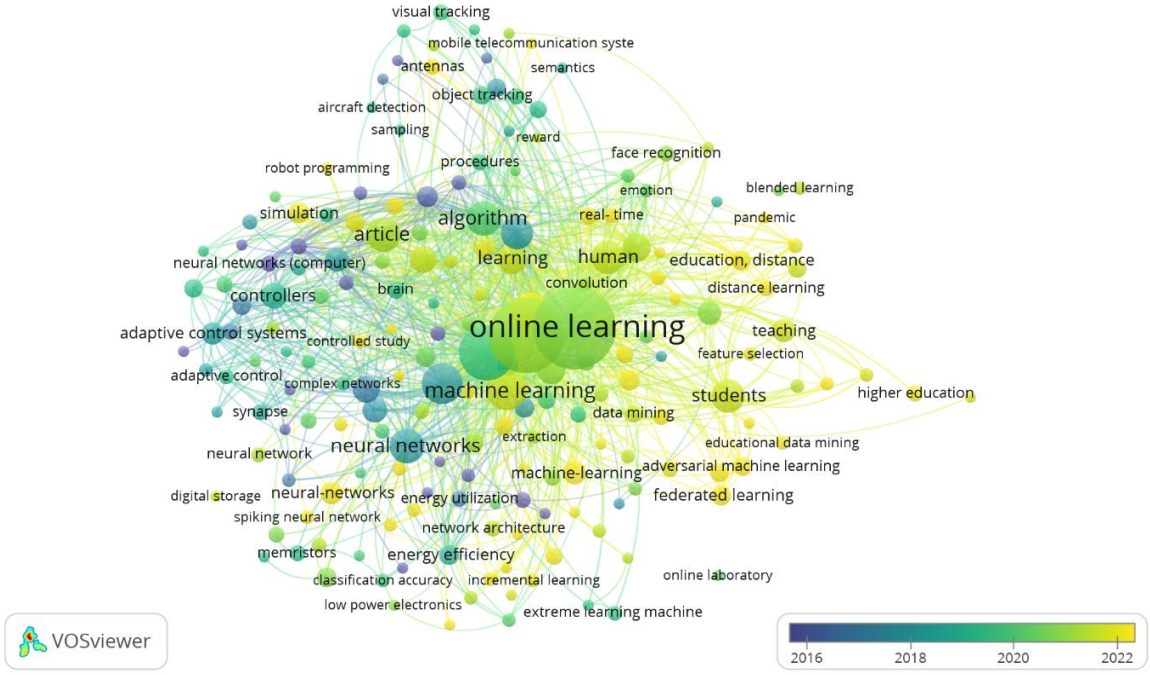

Figure 8. Overlay Visualization

Based on the overlay visualization information in Figure 8, topics based on keywords that have been worked on in the last few years can be seen. It can be seen that for recent research, several keywords have emerged, such as "higher education," "distance learning," and "machine learning." This indicates that the current research trend in the field of online learning in physics and astronomy is heavily focused on higher education. In this study, we can see that one of the research directions that has been extensively explored in recent times is machine learning.

4. CONCLUSION

This study presents an in-depth bibliometric analysis of trends and directions in online learning research in physics and astronomy education. Based on the data obtained, this study shows significant growth in the number of publications and citations in recent years, especially after 2015. This increase reflects the growing interest and attention to the application of technology in education, especially in the context of online learning in physics and astronomy. International collaboration has also proven to be an important element in this research, with numerous contributions from authors and institutions from various countries.

From the analysis of sources, authors, and affiliations, it can be concluded that China plays a dominant role in this research, followed by significant contributions from the United States and other European and Asian countries. Leading authors and major universities in China and abroad also indicate that this research is strongly driven by cross-national and interdisciplinary collaboration. Relevant journal sources, such as Applied Sciences and Sensors, play a major role in the literature related to this topic, with various articles focusing on technologies that support online learning. On the other hand, topic trend analysis shows a clear shift in research, from an initial focus on algorithms and neural networks to the application of new concepts such as federated learning, adversarial machine learning, and blended learning. These developments are closely related to the need to create more efficient, secure, and personalized learning systems, with an increased interest in human aspects, such as facial recognition and the influence of emotions, which are increasingly being introduced in online learning.

Overall, research on online learning in physics and astronomy continues to evolve, driven by technological innovation and international collaboration. Although there has been a decline in the number of publications in recent years, current trends indicate that this topic remains relevant and has the potential to develop further, especially with the continued advancement of technology and the adaptation of online learning in various educational contexts.

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