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Original Research

Internet of Things (IoT) in Education: A Bibliometric Review

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Abstract

The Internet of Things (IoT) has made our surroundings more innovative and responsive, which has improved our lives. This research aims to provide a comprehensive overview by describing the descriptive parameters of publications, visualizing co-authorship and citation patterns, extracting the authors' keywords, and determining the impact and research performance of the IoT in education. Subsequently, this paper provides an orientation for researchers to understand better the main progress and gaps in this scientific publication. From 2006 to 2021, a comprehensive inspection of 2503 documents in the Scopus database was accomplished. Based on the findings, the number of publications increased steadily, with a hike in publication numbers in 2020. Scholars from China contributed approximately 467 of the total global publications among 103 other countries. In addition, of the other 160 outlets, Advances in Intelligent Systems and Computing was the most prolific source title. Generally, there is sustained interest and increased research in this field, apart from establishing novel methods and directions. Accordingly, an in-depth examination of the IoT in education research may assist researchers and practitioners in advancing prospective knowledge in this subject by identifying gaps.

Keywords: Internet of Things, Scientific publications, publication trends, Scopus database, Bibliometric Review.

Introduction

The Internet of Things (IoT) has made the co-existence of both the digital and physical worlds a reality, making our surroundings more innovative and responsive and critical to improving our lives. The concept of the IoT was availed through Kevin Ashton in 1999, who postulated that humans had created almost all of the estimated 50 petabytes of data available on the Internet - using either typing, record button pushing, digital photo-taking, or bar code scanning (Ashton, 2009). It is portrayed that the IoT has facilitated people's lives by connecting them to a global network of billions of physical objects that collect and share data (Cornel, 2015). The IoT has evolved into a multi-layer technology platform that includes hardware, software, connectivity, and a user interface to manage data flow, communication, application functionality, and device automation (Aazam, Zeadally & Harras, 2018; Lombardi, Pascale & Santaniello, 2021). Hence, many previous studies have attempted to define this system in various ways, such as the Internet of Everything, the Internet of Anything, the Internet of People, the Internet of Signs, the Internet of Services, the Internet of Data, or the Internet of Processes (Bucchiarone, Marconi, Pistore & Raik, 2017; Oriwoh & Conrad, 2015; Shafiq, Szczerbicki & Sanin, 2018).

When we examine the history of computing technology, we see that computers have been connected via various topologies since the first network was invented in 1972 (Leiner et al., 1997; 2009). Presently, the IoT has been deemed progressively prevalent due to the merger cost of sensors, accelerating the IoT's growth. In 2015, Cornel predicted that the IoT network would integrate more than 25 billion electronic gadgets by 2020, and due to the rapid and dynamic advancements in internet communication, the totality of devices connected to the IoT would exceed 30 billion during the same period. Additionally, existing 4G networks have been extensively utilized in the IoT. They constantly evolve to cope with future IoT applications (Li, Da Xu & Zhao, 2018).

Recently, the emerging digital era has conspicuously seen a surge in the impact of IoT-enabled devices, which have offered new technological opportunities besides raising some inevitable concerns. Many industries, such as healthcare (Ahmadi, Arji, Shahmoradi, Safdari, Nilashi & Alizadeh, 2019; Ganai et al., 2022), construction (Jiang, 2020), agriculture (Chen & Yang, 2019), and transportation (Zhang & Lu, 2020) are increasingly leveraging this technology. Thus, today's world has a tremendous new resource (the Internet of Things) to change things much better and more sustainably to the advantage of current and forthcoming generations, both in industrial, business, and educational processes. Moreover, at the global level, numerous market analysts are astounded by the tremendous repercussions of the IoT on our daily lives (Qadri, Nauman, Zikria & Vasilakos, 2020). This scenario occurred as the IoT became more accessible and prevalent, pushing businesses to enhance their customers' experiences (Lo & Campos, 2018).

The objective of the education sector is to improve the learner experience, increase efficiency, and provide a necessary, effective, and efficient teaching and learning environment based on the needs of the students (Abdullah, 2022). IoT and other technologies will play a significant role in education since many students want individualized learning delivered to their desks (Chweya, Ajibade, Buba & Samuel, 2020). This is significant because the transformation of the digital world for the better, or the "next big thing" in the world, has numerous advantages and provides day-to-day answers (Lakshmi, Saxena, Koli, Joshi, Abdullah & Gangodkar, 2022). As a result, technology is advancing faster than ever and reshaping our environment (ibid). Similarly, the recent exploitation of the IoT has altered the educational landscape, with implications for educational improvement at all levels, including schools, colleges, and universities, for better academic instruction (Jiang, 2016). The IoT is transforming traditional teaching practices and educational institution infrastructure. Due to the multipronged facet of the IoT in education and its use as a technology tool to improve academic infrastructure and subjects, these factors became ongoing research and development efforts (Gul, Asif, Ahmad, Yasir, Majid & Malik, 2017). Furthermore, the IoT has become a new player in the educational environment that can assist all concerned individuals (students, teachers, and lecturers) and objects (physical and virtual) in academic settings such as schools, colleges, and universities in interacting (ibid). The IoT is an enthralling and stimulating topic that will pique the interest of students, teachers, and lecturers while providing an excellent platform for teaching computer science principles.

Several IoT scenarios benefit students, teachers, and lecturers in the education sector by addressing various models, goals, subjects, and perceptions (Jiang, 2016). IoT devices are ~~is~~ used in online education and laboratory settings to monitor students and objects (Srivastava & Yammiyavar, 2016; Valpreda & Zonda, 2016). Besides, a system based on the IoT enables increased knowledge about agricultural food production and consumption (Gunasekera, Borrero, Vasuian & Bryceson, 2018). Another study on the IoT aimed at educating students with special needs, such as children with autism spectrum disorders, is being conducted (Sula, Spaho, Matsuo, Barolli, Miho & Xhafa, 2014). Despite the few available studies on incorporating the IoT into the educational domain, a consolidated and coherent viewpoint still lacks. On the other hand, while beneficial, adopting the IoT in education introduces several new implementation challenges. A likely reason is that numerous studies have analyzed and synthesized IoT and its applications in multiple fields; however, research does not provide a complete overview of IoT's educational applications (Al-Emran, Malik & Al-Kabi, 2020).

This study applied bibliometric review to examine the critical ideas and publication trends in IoT education research. This element is crucial because the bibliometric method provides a macroscopic summary of enormous scientific literature and is essential for proper decision-making among experts on a particular issue. The bibliometric review was conducted in the field of education across a variety of subdomains; (i) technology-enhanced learning in higher education (Shen & Ho, 2020), (ii) worldwide educational artificial intelligence (Song & Wang, 2020), (iii) social media for teaching and learning within higher education institutions (Hashim, Rashid & Atalla, 2018), (iv) leading school change and improvement (Kovačević, J. & Hallinger, 2019), and (v) physical education (Tomanek & Lis, 2020). However, the primary limitation is a scarcity of bibliometric reviews on the IoT in education. Consequently, this study is intended to fill gaps in the bibliometrics review on the IoT in education research. This is because previous studies amalgamated to the IoT in education revolved around a subset of studies, such as a comparative study of Chinese and foreign research (Dai, Zhang, Zhu & Zhao, 2021), the history, present, and future of smart learning (Chen, Zou, Xie & Wang, 2021), and scientific production and thematic breakthroughs in smart learning environments (Agbo, Oyelere, Suhonen & Tukiainen, 2021).

In this bibliometric review, the authors are specifically interested in the aspects concerning the IoT in education research to (i) describe the descriptive parameters of publications such as publication evolution, prominent sources, influential countries and institutions, and active authors, (ii) to visualize the co-authorship and citation patterns of the IoT in education, (iii) to extract keywords and generate a map depicting the co-occurrence of the terms in academic works about the IoT in education, and (iv) to figure out the impact and research performance on the IoT in education.

Materials and Methods

This study examined the publication trends of the IoT in education over the last 15 years, from 2006 until October 2021. In this study, we did not set the initial data for the first papers indexed in the Scopus database. Consequently, 2006 was the initial publication year indexed in Scopus. In recent years, there have been robust methods for finding and analyzing research in the literature and establishing a system for literature analysis that has piqued many scholars' interest. In this context, the bibliometric review provided a macro-level summary of the enormous scientific literature and is crucial for academics to make informed conclusions. Also, it is an efficient research technique that enables scholars to thoroughly analyze significant material of the research contents (Gall, Nguyen & Cutter, 2015; Zhou, Goh & Li, 2015).

Strategy for data collection and retrieval

Data in this bibliometric review was retrieved on 31 October 2021. The authors examined the Scopus database for scholarly papers in any language that discussed the IoT in education. Bibliometric analysis can be performed in any language because it only reviews metadata and does not require reading the entire article. Scopus was chosen as the database due to its comprehensive collection of high-quality abstracts and citations to peer-reviewed articles (Choudhri, Siddiqui, Khan & Cohen, 2015). To attain relevant results of metadata, the phrases with quotation marks as follows were searched within article TITLE-ABS-KEY; “Internet of Things” OR “Internet 4.0” OR “Internet of Everything” OR “Web of Thing” AND (“school” OR “college” OR “university”). The data revealed 2503 publications from 2006, with two papers focused on the IoT in education research being deposited in the Scopus database. The progression for conducting the review is shown in Figure 1.

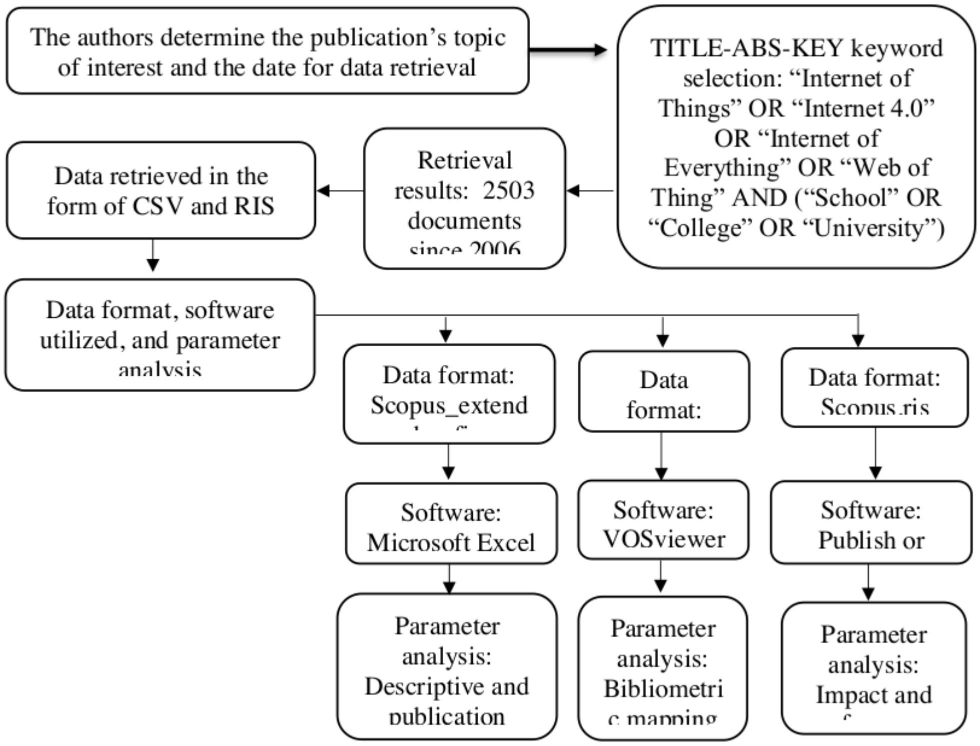

Figure 1. The flowchart of data collection and data retrieval

The progression of conducting a bibliometric review

The collected metadata was analyzed to denote descriptive and publication trends, map the nexus of bibliometric indicators, and define the impact and performance of research over the period scrutinized. The processes began with creating tables using an Excel spreadsheet to describe descriptive and publication trends for 2503 datasets. Then, tables and graphs were created to visualize the available bibliometric indicators: the evolution of scientific production, the most frequently cited scientific journals, the countries with the highest production, the researchers' institutional affiliations, and the most productive authors. A software program called VOSviewer was used to perform the bibliometric mapping. The procedure was initiated to visualize the co-authorship and citation patterns. Also, the technique was applied to extract keywords and generate a map depicting the co-occurrence of the terms related to the IoT in education research. Finally, the impact and performance of the research theme were analyzed using the Publish or Perish (PoP) software.

Preliminary description of the publications

This study identifies preliminary descriptions of publications such as source types, document types, and languages before the bibliometric analysis is detailed. This study acknowledged that conference proceedings grow into the most common source types on the IoT in education research, accounting for 1298 of the 2503 total documents. Journal papers are the second most common document type, accounting for 753 papers, while book series are ranked third, accounting for 397 papers. With fewer than 50 documents, the remaining source types were books and trade journals. Regarding document types, conference papers were the most interesting academic works, with 1538 publications from previous scholars. The second document type is articles, which has 702 documents, and the third source is conference reviews, with 121 publications. Other document types, such as book chapters, reviews, books, and erratum, were less than 50 documents. In the meantime, editorials, notes, business articles, data papers, and short surveys were less than ten publications throughout 15 years. Based on the bibliometric metadata collected in this study, it was firm that most publications were written in English with 2248 publications, Spanish with 19 publications, and Chinese with 18 publications. Other languages, such as Portuguese, Russian, Italian, French, German, Japanese, Polish, and Turkish, were fewer than ten publications.

Results

The following section details the results of the bibliometric review of the 2503 documents discovered between 2006 and 2021.

The evolution of scholarly publications

It is critical to track publishing trends annually to recognize the potential research topic for further study. Also, it is vital to assist readers and future researchers in determining the significance of a study's theme. In addition, it could pique the interest of future researchers who wish to fine-tune the factors affecting the growth or decline of a year-based publication. As illustrated in Figure 2, the rate of scientific publication on the IoT in education increased steadily from 2006 to 2014. However, the publication experienced a slight decrease in 2015, dropping minimally to 78 documents. The number of publications rocketed sharply by more than 100 between 2016 and 2020, with a hike in publication rate of 535 in 2020. Moreover, the number of publications slumped to 443 in 2021. The declined number of publications in 2021 could be due to the data retrieval in October and the entire year's publications not being entirely deposited.

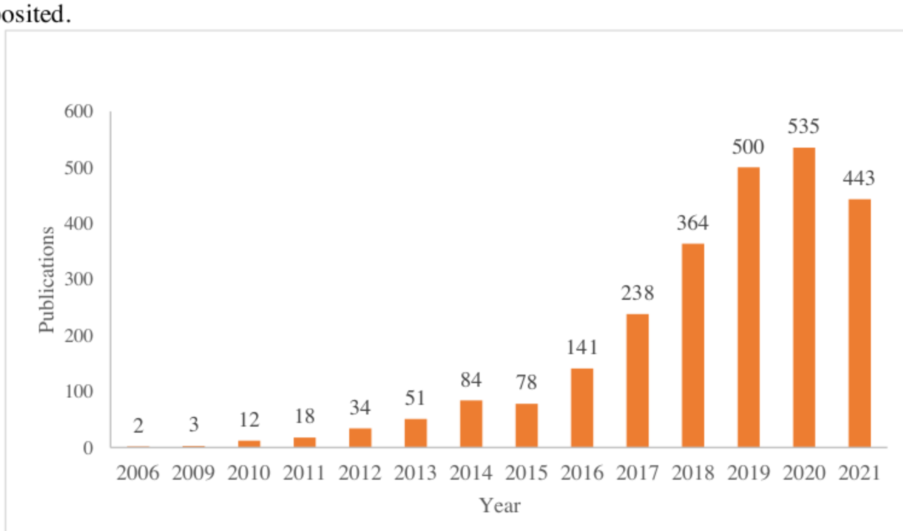

Figure 2. The global trend of publications

The most prominent scientific source titles

Advances in Intelligent Systems and Computing, with 133 publications, is the top scientific source title among 160 prominent scientific source titles, as shown in Figure 3. The second-highest ranking goes to Lecture Notes in Computer Science, including the subseries Lecture Notes in Artificial Intelligence and Bioinformatics, with 59 publications. The Journal of Physics Conference Series was ranked third, publishing 56 academic works. The Pervasive Computing Technologies for Healthcare contributed 42 publications, followed by the ACM International Conference Proceeding Series, which contributed 41.

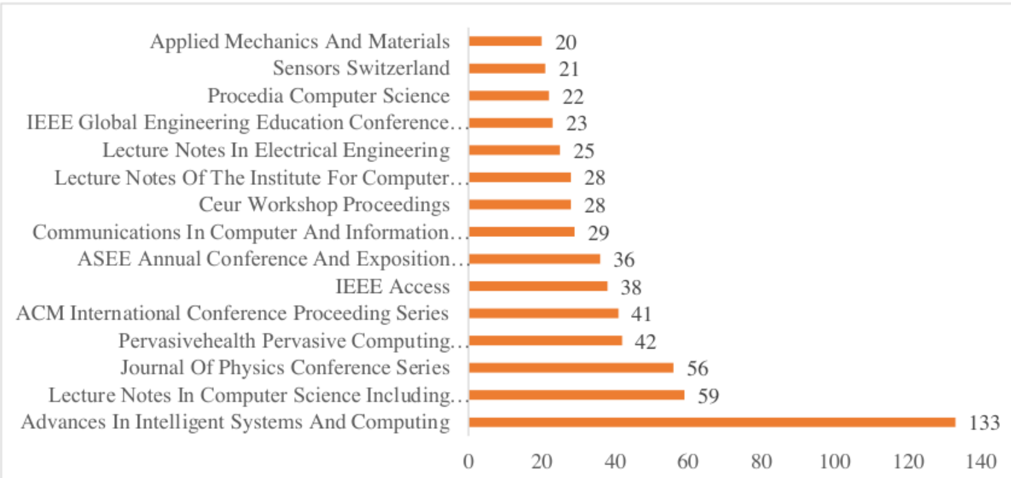

Figure 3. Prominent scientific source titles

Figure 4 shows the map of citation analysis of the prominent scientific source titles related to the study of the IoT in education. In this analysis, the relationship and relatedness of the source titles can be further explored. The analysis was based on five minimum documents and at least one citation per document, which yielded 55 sources that have been selected. According to visualization results, the most important source was Advances in Intelligent Systems and Computing. This primary source was grouped with IEEE Design and Test, IEEE Internet of Things Journal, and Lecture Notes in Computer Science in the same cluster indicated in the green node. The Advances in Intelligent Systems and Computing has a substantial citation nexus with a total link strength of three sources: IEEE Internet of Things Journal, Lecture Notes in Computer Science, and Risti Revista Iberica De Sistemas E Tecnologias De Informacao. It is depicted that the closer the sources, the stronger they relate to each other and have stronger citation links between them.

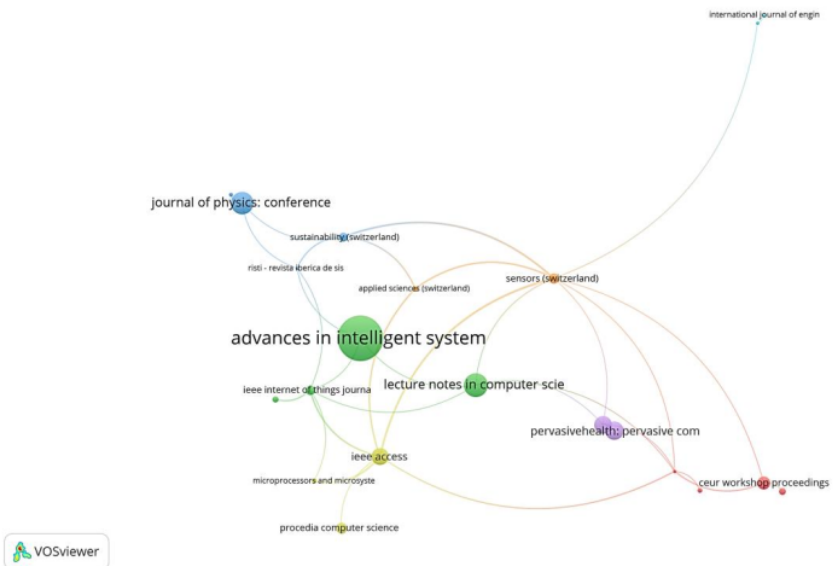

Figure 4. Network visualization of the citations by source titles

The protruding countries and institutional affiliation

Scholars from 103 countries have engaged in disseminating research on the IoT in Education. It can be ascertained that the authors from China contributed more academic works than any other country, with 467 publications. The United States is another prominent linked country, with 339 publications (Figure 5).

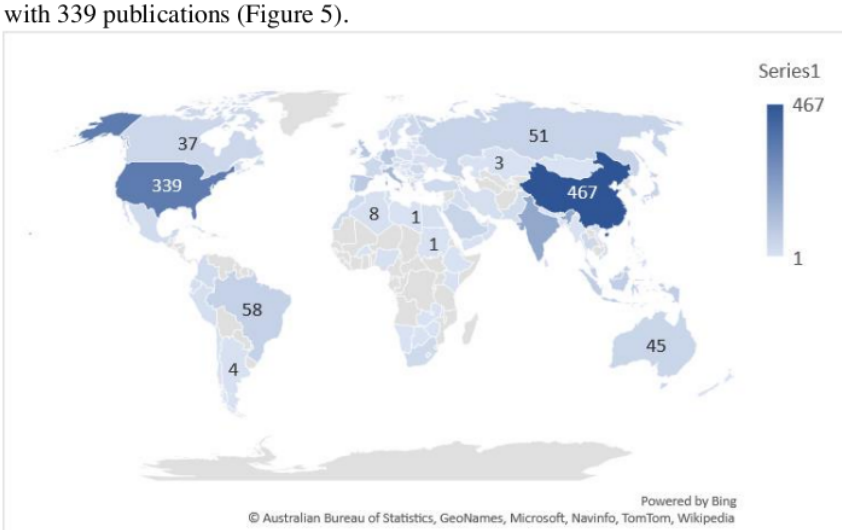

Figure 5. Dispersal of publications by countries

A network map using VOSviewer was applied to visualize countries' contributions to the IoT in education research, as shown in Figure 6. The procedure to generate the map is established with the five minimum documents and at least one citation per document. The design has been settled in 68 countries to be selected in this review. Based on the map, the authors from China have a close relationship with the United States and the United Kingdom, which shows a strong citation link. In this context, the closer the countries are in the diagram, the stronger their citational relatedness. At the same time, the nodes represented the number of publications that those countries have published. China has been the leading country in terms of publication output because, in 2016, the Chinese government spent 1.57 trillion yuan (USD 235.9 billion) on research and development (R&D), up 10.60% from the previous year, and by around 5% of the money spent on basic research, compared to the 6% invested by the United States in 2012 (Jia, 2017).

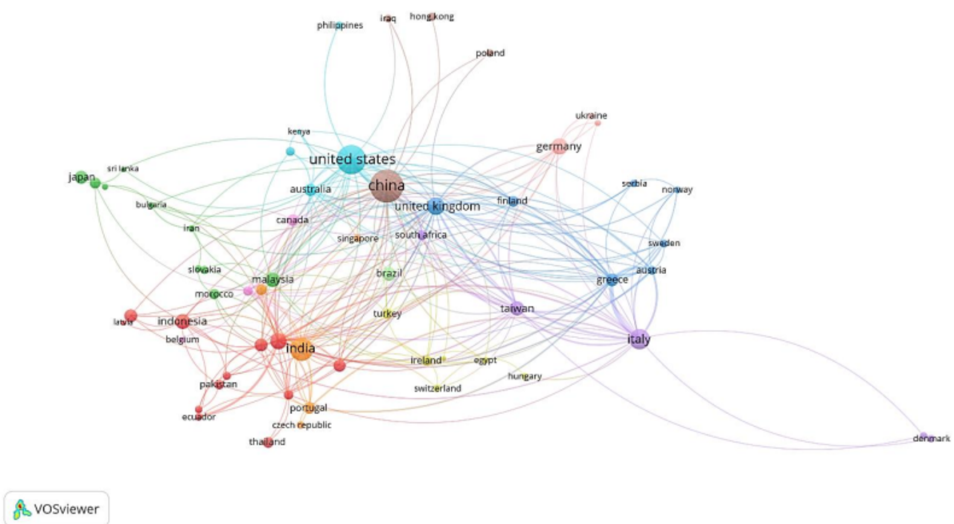

Figure 6. Network visualization of the citations by countries

This review has also considered the involvement of the institutions in the IoT in education research. i.e., based on at least ten publications from 160 institutions. Table 1 reveals that the Computer Technology Institute in Greece published the highest number of publications on the IoT in education, with 26 publications (2.54%). Arizona State University in the United States was the second-highest (15 publications; 1.46%), followed by the Beijing University of Posts and Telecommunications in China (14 publications; 1.37%) in the third rank. According to the institutional analysis, the top institutions involved in researching the IoT in education are monopolized by Italian institutions: Politecnico di Torino, Università degli Studi di Brescia, Sapienza Università di Roma, and Alma Mater Studiorum Università di Bologna. These institutions have the most powerful impact on profitability and engagement in Italy's education research in the IoT.

Table 1
Top institutions

Institutional Affiliation	Country	Publication(s)	Percentage (%)
Computer Technology Institute	Greece	26	2.54%
Arizona State University	United States	15	1.46%
Beijing University of Posts and Telecommunications	China	14	1.37%
Ministry of Education China	China	13	1.27%
Politecnico di Torino	Italy	13	1.27%
Università degli Studi di Brescia	Italy	13	1.27%
Universidad Politécnica de Madrid	Spain	13	1.27%
Sapienza Università di Roma	Italy	13	1.27%
Alma Mater Studiorum Università di Bologna	Italy	12	1.17%
Bina Nusantara University	Indonesia	12	1.17%
University Politehnica of Bucharest	Romania	11	1.07%
Universidade de São Paulo	Brazil	11	1.07%
Georgia Institute of Technology	United States	11	1.07%
University of Žilina	Slovakia	10	0.98%
University of Oulu	Finland	10	0.98%
Sichuan University	China	10	0.98%
Aalborg University	Denmark	10	0.98%
Qatar University	Qatar	10	0.98%
Aalto University	Finland	10	0.98%

The leading authors

Since 2006, a total of 2503 academic works on the IoT in education safety knowledge research have been written by 159 authors. The most prominent author in IoT in education was Mylonas, G., who wrote 19 publications, as shown in Table 2. This table lists the author's information with more than seven publications on the IoT in education, ranked by the number of publications. Italian authors were among the most prolific authors who published academic works on the IoT in education over the last 15 years, as indicated by Table 2.

Academic advancements in digital technology make collaboration and sharing of discoveries more straightforward. Thus, this study investigated the authors' collaboration by conducting a co-authorship review with VOSviewer. The bibliometric mapping of author co-authorship relationships allows for the representation of information to make author relationships more understandable. Collaborative efforts among scholars in academic research are commonplace. The least number of publications of articles by an author set in VOSviewer for this co-authorship analysis was five. This means that each author in Figure 7 has published at least five articles in this field. The nodes represent the number of documents; the more significant the nodes, the more documents a specific author publishes. The Scopus database has indicated that Wang, J. is the most productive author, linked to another 17 authors with a total link strength of 23. Wang, J. has a close co-authorship with Zang, Y., Li, G., Ning, H., Zhang, J., and Chen, J. Other authors with significant contributions to the research community are Li, Y., Li, Z., Wang, X., Zhang, X., and Zhang, Y.

Table 2
Leading authors

Rank	Author	Country	h-Index	Citation	Total Publication in Scopus Database	Publication in the (IoT) in Education
1	Mylonas, G.	Greece	16	718	60	19
2	Amaxilatis, D.	Ireland	10	407	49	15
3	Chatzigiannakis, I.	Italy	28	2511	181	11
4	Chen, Y.	United States	28	2774	183	8
5	Ciribini, A.L.C.	Italy	12	523	47	7
6	Rico-Bautista, D.	Colombia	6	95	37	7
7	Rinaldi, S.	Indonesia	24	1934	172	7
8	Tagliabue, L.C.	Italy	14	612	71	7

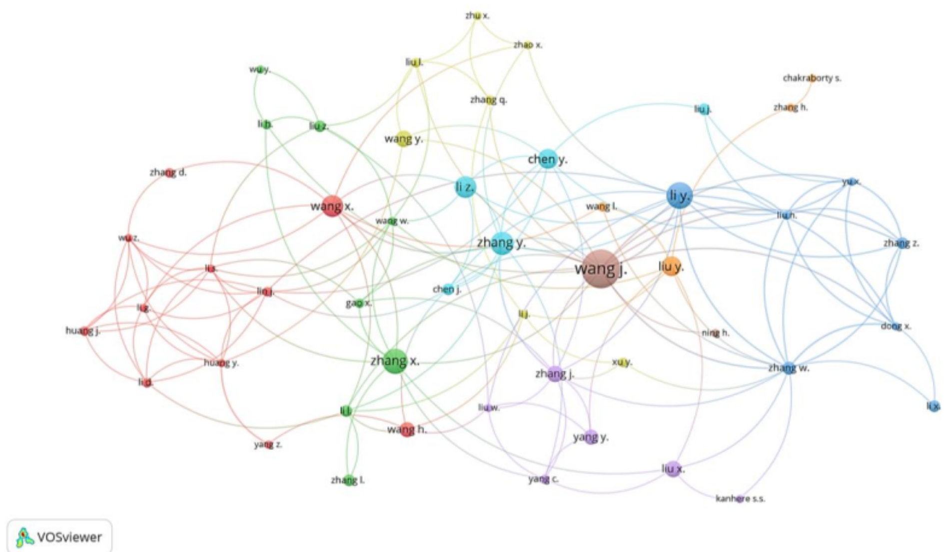

Figure 7. Network visualization of the co-authorship among authors

The foremost themes of the publications in prior research

Keywords represent the main contents of existing research and the areas studied within the confines of a given domain. In previous research, the co-occurrence of author keywords highlights the main research areas and themes of the IoT in education. In this analysis, VOSviewer mapped the keywords of the authors. The frequency of occurrence of keywords is proportional to the size of the nodes in this analysis. Concurrently, adjacent lines represent bibliographic links, with the strength of co-occurrence determined by respective line thickness. Figure 8 provided an overlay diagram of the authors' keywords in which the connecting lines' color, node size, font size, and thickness illustrate the relationship with other keywords. The minimum number of occurrences of keywords in this analysis is 20. The study resulted in 30 keywords out of 5951. The yellow color of the nodes on the diagram represented the most recent keywords, and the blue nodes signified the older terms found in this study.

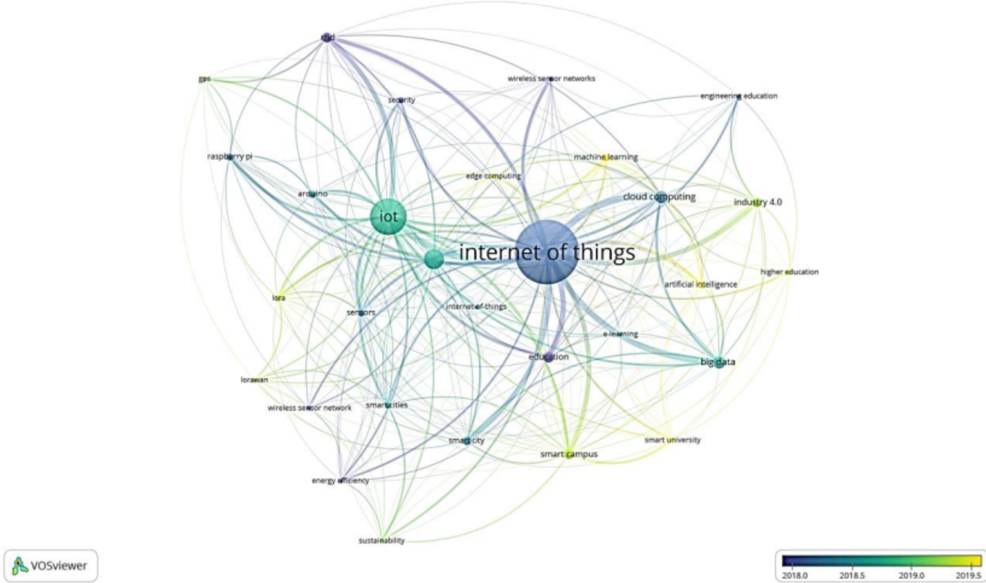

Figure 8. Overlay visualization of the co-occurrence of authors' keywords

The overlay visualization in Figure 8 illustrates the evolution of the IoT in education over time. In this visual, keywords within the blue-colored range (or magenta) indicate research activities relevant to the IoT in education with an older average publication year. In contrast, keywords used in more recent average publication years are in the yellow-colored range. Thus, it can be construed that before 2019, the predominant keywords used were in the likes of "internet of things", "cloud computing", "wireless sensor networks", "RFID", "security", "e-learning", "big data", and "education". These keywords have a strong relationship with the IoT. Before 2019, the association of keywords showed that the IoT in education research had focused on electronic payment systems, networks of spatially dispersed and dedicated sensors, on-demand availability of computer system resources, information extraction, and teaching with electronic resources. After 2019, the emergence of the recent keywords is "machine learning," "smart university", "smart campus", "higher education", "edge computing", "artificial intelligence", "sustainability", "industry 4.0", and "Lora", and "Lorawan". After 2019, it is anticipated that the research on the IoT in education will focus on network modulation, the integration of higher education and intelligent technologies, the computational processing of sensor data, and the machine simulation of human cognitive processes.

The impact and performance of the publications

A factor used to assess the impact and performance of the IoT in education research is the number of citations and citations per year-citation metrics for the retrieved documents as of 31st October 2021. Within 15 years (2006-2021), the IoT in education has garnered 14762 citations. Harzing's Publish and Perish software has developed the citation metric by importing RIS format files from the Scopus database. Table 3 lists the most cited publications (based on the number of citations) in the Scopus database with at least 92 citations.

Table 3
Most-cited publications

Rank	Authors	Year	Title	Cited	Cited per Year
1	Hermann, M., Pentek, T., & Otto, B.	2016	Design principles for industrie 4.0 scenarios	1178	235.60
2	Welbourne, E., Battle, L., Cole, G., Gould, K., Rector, K., Raymer, S., M Balazinska, M., & Borriello, G.	2009	Building the Internet of things using RFID: The RFID ecosystem experience	499	41.58
3	Mainetti, L., Patrono, L., & Vilei, A.	2011	Evolution of wireless sensor networks towards the Internet of Things: A survey	363	36.30
4	Kaplan, A., & Haenlein, M.	2019	Siri, Siri, in my hand: Who's the fairest in the land? On the interpretations, illustrations, and implications of artificial intelligence	325	162.50
5	Oztemel, E., & Gursev, S.	2020	Literature review of Industry 4.0 and related technologies	323	323.00
6	Perera, C., Liu, C.H., & Jayawardena,S.	2015	The Emerging Internet of Things Marketplace from an Industrial Perspective: A Survey	295	49.17
7	Bahrin, M.A.K., Othman, M.F., Azli, N.H.N., & Talib, M.F.	2012	Industry 4.0: A review on industrial automation and robotic	232	46.40
8	Wang, J., & Katabi, D.	2013	Dude, where's my card? RFID positioning that works with multipath and non-line of sight	199	24.88
9	Lee, H-C., & Ke, K-H.	2018	Monitoring of Large-Area IoT Sensors Using a LoRa Wireless Mesh Network System: Design and Evaluation	175	58.33
10	Fortino, G., Russo, W., Savaglio, C., Shen, W., & Zhou, M.	2018	Agent-oriented cooperative smart objects: From IoT system design to implementation	121	40.33
11	Kortuem, G., Bandara, A.K., Smith, N., Richards, M., & Petre, M.	2013	Educating the internet-of-things generation	116	14.50
12	Ji, Z., Ganchev, I., O'Droma, M., Zhao, L., & Zhang, X.	2014	A cloud-based car parking middleware for IoT-based smart cities: Design and implementation	115	16.43
13	Haddud, A., DeSouza, A., Khare, A., & Lee, H.	2017	Examining potential benefits and challenges associated with the Internet of Things integration in supply chains	92	23

According to the data in Table 3, an article titled "Design principles for Industrie 4.0 scenarios," written by Hermann, M., Pentek, T., and Otto, B. and published in 2016, became the most cited paper, with 1178 citations and 235.60 citations per year. According to this article, the rapid surge in the integration of the IoT into the industrial value chain has been primarily instrumental in the takeoff of Industrie 4.0., which has undoubtedly become of prime importance for most businesses, research institutions, and higher-learning institutions. Still, there is no agreement on what it entails. This is considered the most impactful article concerning the IoT in education research for 15 years.

Another impression article was written by Welbourne, E., Battle, L., Cole, G., Gould, K., Rector, K., Raymer, S., M Balazinska, M., and Borriello, G., published in 2009 with the title "Building the internet of things using RFID: The RFID ecosystem experience" obtained the highest number of citations of a total of 499, equivalent to 41.58 citations per year. The function or role of the University of Washington's RFID Ecosystem as a microcosm for the IoT is demonstrated by this article. The designing and successful development of a series of web-based tools and applications by the authors were aimed at helping users better understand, manage, and control their RFID data and privacy settings. The applications were tested in the RFID Ecosystem over two fortnights to see how users adopted and used the tools and applications and their qualitative reactions.

The influential articles published in 2019 and 2020 ranked among the top five most-cited publications on the IoT in education. In addition, the article was written by Oztemel, E., and Gursev, S. in 2020, and it received 323 citations per year, becoming the highest score of citations on the list. The article is a literature review on Industry 4.0 and related technologies. One of the contributions of this study is the articles listed in Table 3, which benefit future researchers and readers who want to supplement their literature review with the most influential articles on IoT in education research.

Discussion

A bibliometric analysis is critical because it can ascertain the efficacy of previous research. The current study demonstrates that for over 15 years, 2,503 publications on the IoT in education have been indexed in Scopus. Thus, the bibliometric review aimed to (i) describe the descriptive parameters of publications such as publication evolution, prominent sources, influential countries and institutions, and active authors, (ii) to visualize the co-authorship and citation patterns of the IoT in education, (iii) to extract keywords and generate a map depicting the co-occurrence of the terms in academic works linked to the IoT in education, and (iv) to figure out the impact and research performance on the IoT in education. This bibliometric review can be used as a guide for those interested in examining the IoT in education publications. This study gives pertinent information that can point researchers and readers toward appropriate field publications and the most illustrious areas of study for their respective pieces of literature.

The publication evolution research revealed a progressive growth rate increase over 15 years. The IoT and its applications in education globally are being encouraged. Additionally, there has been an increase in interest in the IoT, which enables physical objects, sensors, and actuators to connect via the Internet, transforming tertiary-level institutions or colleges and educational institutions. Such institutions and universities may create a complex environment for their students and faculty by utilizing the IoT. Prior research revealed that, following 2019, the formation of current keywords centered on network modulation, integrating higher education and intelligent technologies, the computational processing of sensor data, and the machine simulation of human cognitive processes. This conclusion demonstrated that research in the IoT in education currently integrates things into the internet. New opportunities for applications and services in education can result in innovations that facilitate teaching-learning. These activities enabled educators to better understand their students' learning pace, and learning challenges were designed for more effective and meaningful experiences to make disseminating and acquiring knowledge and skills at all levels of education more accessible and efficient.

Advances in Intelligent Systems and Computing are among the most prominent scientific source titles on the IoT in education. The authors discuss the theory, applications, and design methodologies of Intelligent Systems in this scientific source. Furthermore, nearly all fields are encircled by Advances in Intelligent Systems and Computing, including engineering, natural sciences, information technology, economics, business, e-commerce, the environment, healthcare, and life science. This information in the source title is the best gateway for researchers and readers to obtain related information on the IoT in education research. This study established that G. Mylonas, the Greek author, was the most prolific author, having authored 19 articles. This study also presented that the Computer Technology Institute in Greece became the most potent institution, publishing 26 articles on the IoT in education. Over the next decade, the IoT will undoubtedly disrupt society, the economy, education, and how we work, play, and interact with our surroundings. Thus, improving communications using the IoT in Greece is necessary to benefit the future Knowledge Society (Mitroulia, Nikou, Zotos & Armakolas, 2019).

Over the last 15 years, Italian authors have been among the most prolific authors of academic publications on the IoT in education, as depicted in Table 2. In Italy, IoT-based educational activities have become an intriguing way to promote better enthusiasm for learning, with the system being rated positively by students and enhanced student engagement besides improved performance in class as highlighted by educators (Mylonas, Paganelli, Cuffaro, Nesi & Karantzis, 2021). Concerning the protruding countries of the IoT in education, China contributed more academic works than any other country and has a close relationship with the United States and the United Kingdom, which shows a strong citation link. This information allows us to better understand how authors from the United States and the United Kingdom co-authored most publications on the IoT in education in China. It has been stated that developing countries have enormous opportunities for human and economic development. Thus, research in China helps bring to the attention of interested parties myriad opportunities for keen individuals to determine suitable allies for collaboration purposes and for planning their research direction, particularly with Europe. This is because Europe, in essence, encompasses advanced nations that advocate IoT research through the European Union Framework funding for consortia (Dlodlo, Foko, Mvelase & Mathaba, 2012).

Notably, the authors with the most citations were Hermann, M., Pentek, T., and Otto, B., who received 1178 citations and 235.60 citations per year. One of their papers, "B"Design principles for Industrie 4.0 scenarios", published in 2016, is worth reading and incorporating into the literature review. The data in Table 3 allowed us to depict and explain the scenario and landscapes of scientific production of the IoT in education research through high-impact publications. The publications listed will aid future researchers in scrutinizing literature related to the IoT in education research. The information provides a comprehensive overview, including focus areas of the IoT in education research. It reflects the fundamental principles in the values and goals of the IoT in education research.

Conclusion

The main goal of this bibliometric review was to identify publication trends and research gaps in IoT research. The authors retrieved 2503 metadata on the IoT in education research from the Scopus database, allowing an examination and visualization of the topic's present trends and conditions. The initial publication stored in the Scopus database depicted two publications; however, the publication has increased significantly over the last decade, with more than 100 pieces of the publication since 2016. This pattern demonstrates the emergence of this novel research area. This research also discussed the most prominent scientific sources, countries, and institutions. This study also included mapping citations by sources and countries, co-authorship among the authors, and co-occurrences of the authors' keywords. Finally, there was a discussion on the primary themes of the IoT in education in prior research and the impact and performance of the IoT in education research.

As for the co-occurrences of the authors' keywords, there are several critical areas for further research concerning the previously identified gaps. Before 2019, this period's keywords were dominated by niche terms such as "internet of things," "cloud computing," "wireless sensor networks," "RFID," "security," "e-learning," "big data," and "education." These keywords are inextricably linked to the IoT. The keyword association revealed that IoT research in education has concentrated on electronic payment systems, spatially dispersed and dedicated sensors networks, on-demand availability of computer system resources, information extraction, and teaching with electronic resources. After 2019, the emergence of the recent keywords is "machine learning", "smart university", "smart campus", "higher education", "edge computing", "artificial intelligence", "sustainability", "industry 4.0", and "Lora", and "Lorawan". The IoT research in education is expected to focus on network modulation, integrating higher education and intelligent technologies, the computational processing of sensor data, and the machine simulation of human cognitive processes. However, additional keywords in this field must be explored to eliminate specific concerns as revealed through the study, particularly studies related to the management and ecosystem of the IoT in education and the value of the IoT application in vocational education and science, technology, engineering, the arts, and mathematics education.

A bibliometric review can project or shed light on the cutting edge of a particular area of study or subject. Even though this work contains essential material, several limitations should be addressed to assist readers and future researchers comprehend. This study drew its core data from the Scopus database. Three other databases that may benefit the bibliometric review are Dimensions, Microsoft Academic, and Google Scholar. The potential researcher will also visualize vast amounts of data in various contexts using additional software programs such as the R package, BibExcel, CiteSpace, and SciMAT.

Recommendations

For researchers, policymakers, and practitioners, the present study provided an in-depth assessment of the present situation, emphasizing shortcomings besides proposing a plan for the IoT in education research. As a result, those who are keen may adopt the proposed routes to fill current knowledge gaps and/or enhance the available pool of knowledge and practice in educational studies related to the IoT. The main topics or keywords associated with the IoT in education have been discovered in this study. As a result of the bibliometric investigation, a proposal for future research might be generated based on publication growth trends and author keywords. These facets are essential for future researchers to expand on the background or solve general concerns with prior IoT in education research. Additionally, they may employ another review methodology, such as a narrative review, scoping review, systematic literature review, or meta-analysis, to build on the links identified in this study.

Additional research should be undertaken to ascertain the IoT trend in education publications on interventions aimed at specific target groups, academic content or program curriculum, educational pedagogy, teaching staff, resources, and evaluation. Incorporating particular themes such as vocational education and science, technology, engineering, the arts, and mathematics education is recommended. Therefore, advancing the IoT in education research is frequently a vital and critical component of analyzing and synthesizing the IoT and its applications across multiple disciplines.

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