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A Comparative Study of Chinese and Foreign Research on the Internet of Things in Education: Bibliometric Analysis and Visualization

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ABSTRACT Known as the third revolution of information technology, the Internet of Things (IoT) embodies the transformation of human technology from ''virtual'' to ''reality''. The application of IoT in education has risen the concerns of both researchers and practitioners. However, there are few research on using bibliometric to visually analyze the hotspots and trends of the IoT in education. In this study, a total of 2257 articles, including (1) 1243 domestic articles from 2005 to 2021; (2) 1014 foreign articles from 2005 to 2021, were collected for comparative analysis between China and foreign countries using the visualization software CiteSpace. The results show that authoritative journals both at home and abroad have paid varying degrees of attentions to the basic theories, emerging technologies and applications of IoT in education. The number of research literatures on this topic is generally increasing year by year. It is particularly worth mentioning that in the field of the IoT in education, on the one hand, the United States, China and Spain are the top three major countries actively participate in, and their international academic cooperation is relatively close; on the other hand, the main research findings are concentrated in the northern and eastern hemispheres, while there is less distributed in the southern and western hemispheres. Regrading research directions, on the whole, much attention has been paid to the construction of smart learning environment; to be specific, its research focus has shifted to the deep integration of intelligent technology and education (e.g., learning feedback supported by IoT technology is delivered to student with the purpose of improving teaching effect). However, in general, the application of IoT in education is still in its infancy, and the scope of practical application is relatively limited. Therefore, future research will concentrate on construction of smart education environment, curriculum teaching and data-driven education evaluation, in order to inaugurate a new situation capable of carrying out experimental teaching, presenting abstract concepts and connecting realistic situations.

INDEX TERMS Internet of Things (IoT), education, bibliometric analysis, visualization, CiteSpace.

I. INTRODUCTION

The Internet of Things (IoT) is imperceptibly penetrating all aspects of people's daily lives. Most people in society enjoy the artificial and smart life brought about by IoT technology. The concept of the IoT, which is originated from the radio frequency identification (RFID) system [1], [2], was proposed by the Automatic Identification Center established by the Massachusetts Institute of Technology (MIT) in 1999 [3]. According to a Cisco report, by 2022, among all networked devices in the world, wireless devices will account for 43% [4]. IoT plays an essential way in connecting these devices for data communication. According to the definition provided by the International Telecommunication Union (ITU) [5], IoT mainly facilitates the interconnections between things-to-things (T2T), human-to-things (H2T) and human-to-human (H2H).

Today, IoT technology has been widely used in the following ten major application fields: logistics [6], transportation [7], security [8], energy [9], medical [10],

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architecture [11], manufacturing [12], home [13], [14], retail [15], and agriculture [16], [17]. Due to its ubiquitous nature, academic institutions/scholars are seeking to incorporate the IoT into educational activities, which can benefit students, teachers, and the entire education system. For instance, the ''Horizon Report (2017 Higher Education Edition)'' pointed out that the six emerging technologies affecting higher education were short-term adaptive learning, mobile learning, medium-term IoT, next-generation information management systems, long-term artificial intelligence (AI), and natural user interfaces [18]. Furthermore, in 2019, Abdel *et al.* stated that the model of education was undergoing a transformation and thus a smart education environment [19] was being developed, which combined different information and communication technologies aiming to activate the learning process and adapt to the needs of different students [20].

Environmental construction is one of the most important parts of education. Governments at home and abroad have increased their investments in education infrastructure at all levels over the past few years, where IoT equipment has been widely used in the smart education environment. In the proposal of Education Informatization 2.0 [21], the era of smart education was using IoT-related technologies to comprehensively gather educational big data and accurately perceive students' learning situation. However, it was still quite challenging to understand students' real-time learning status, which required more IoT technologies and innovative applications. Therefore, it is necessary and significant to study the application of IoT in education all over the world.

With increasingly advanced technologies being incorporated into educational activities, studies on the IoT in education are becoming popular around the world; however, there are few research in the field of IoT in education from the perspectives of bibliometrics [22] and visualization. Thus, this study aims to analyze the authors, institutions, hotspots and frontiers regarding the research status of Chinese and foreign IoT applications in education using the bibliometrics method and mapping knowledge domains [23]. Notably, this study can provide certain reference for further research on Information and Communication Technology (ICT) in education and promote the development of IoT.

Based on the above research purposes, the following questions are mainly discussed in this manuscript:

Q1. What is the overall situation of IoT research in education?

Q2. What are the temporal and spatial distribution characteristics of Chinese and foreign scholars?

Q3. Which journals do Chinese and foreign scholars prefer to publish articles in this field?

Q4. What are the hotspots and frontiers?

To address these questions, this study compares the researches of domestic and foreign scholars on the IoT in education and adopts information visualization software CiteSpace to conduct the corresponding data analysis.

The rest of this paper is organized as follows: Section II introduces the data sources, data processing and methods used in this study. Section III describes the research results in detail, including the spatial and temporal distribution characteristics, as well as the hotspots and frontiers of the IoT in education. Section IV discusses the detailed results of the analysis. Section V concludes the study and outlines avenues for future research.

II. METHODS AND DATA SOURCES

A. METHOD

A general research framework is proposed based on CiteSpace software in this study. As shown in Figure 1, using the proposed framework, we can explore the application hotspots and emerging trends at home and abroad for general cases (rather than one particular research case).

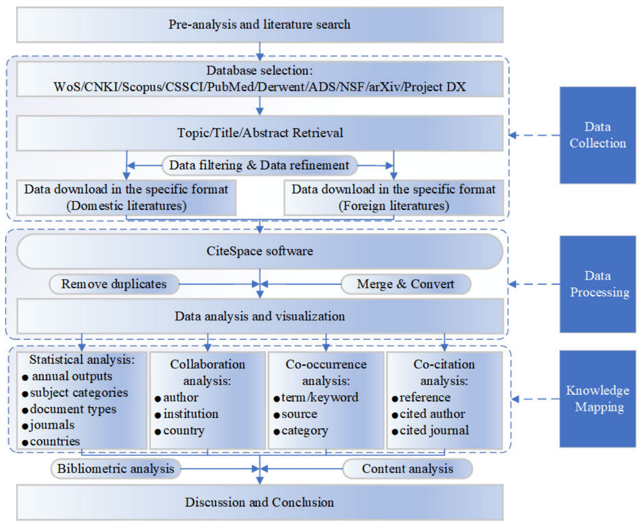

FIGURE 1. Research framework.

First, as a statistical analysis method originated in the early 20th century, bibliometrics is widely applied to scientific research in various disciplines [24], [25]. In this study, bibliometrics is in general used to (i) study quantitative research on literatures [26]; and (ii) assess and quantify the growth trends of a particular topic, where the evaluation indicators are objective [27].

Second, mapping knowledge domains, involving theories and methods of several disciplines (such as applied mathematics, graphics, information science and information visualization technology), develops laws based on a variety of methods and techniques to produce a two-dimensional figure known as knowledge mapping [28]. It is combined with metrological citation analysis, co-occurrence analysis and other methods, so as to display the evolution trend, research hotspots, and frontier fields of research objects using visual mapping [29]. As shown in Figure 1, we can generate the knowledge mappings by using CiteSpace which is a visual analysis software developed by Chen [30] from Drexel University, the USA using the Java language. Due to the capability of presenting the structure, rules and distribution of scientific knowledge through visualization, CiteSpace has been widely used in research areas such as smart cities [31] and new energy vehicles [32]. The visualized mapping obtained through the analysis of such methods is named as "scientific knowledge atlas" [33].

B. DATA SOURCES

Data is crucial for mapping knowledge domains, and its breadth and depth can greatly affect the accuracy of the research. To ensure the scientific nature, the data used in this study come from representative and authoritative data sources that meet the requirements of CiteSpace, including (i) domestic data from the China National Knowledge Infrastructure (CNKI) database; and (ii) foreign data from the Web of Science (WoS) database [34]. CNKI, which is the world's largest Chinese journal full-text database, has abundant literature resources as well as sound retrieval functions [35], [36]; while, WoS is one of the most famous scientific citation index databases around the world [37], [38]. The search topics for the domestic literatures include two parts: the first part is a string composed of keywords related to the IoT, such as "Internet of Things", "sensor", "RFID", "perception", "ubiquity" and "ubiquitous network" [39]; and the second part is a string made up of the keywords related to education, such as "education", "teaching", "study", "campus", "classroom", and "library". The Boolean expression of these two parts is "AND". Similarly, the search topics for the foreign literatures also include the same two parts. Finally, the search topics for the foreign literatures are selected in terms of "Internet of Things" or "sensor" AND "education".

Considering that the existing keywords search methods [40]–[42] were not highly accurate and difficult to be applied to automatic document selection, we used manual methods to strictly control the scientific and comprehensiveness of the literature selection process, as suggested by [43]. To be specific, two researchers were asked to follow the three major steps of "document type", "topic field", "title, abstract, keywords" (see Figure 2) during the refining process of the literatures, so to guarantee the reliability and objectivity of both the articles selection and deletion [44], [45]. Finally, in CNKI, 1263 Chinese papers related to the IoT published from January 1997 to June 2021 are found; and then, in WoS, 1014 foreign papers related to the IoT published from 2005 to 2021 are found. Both Chinese and foreign data types are selected as articles. Figure 2 shows the specific search steps.

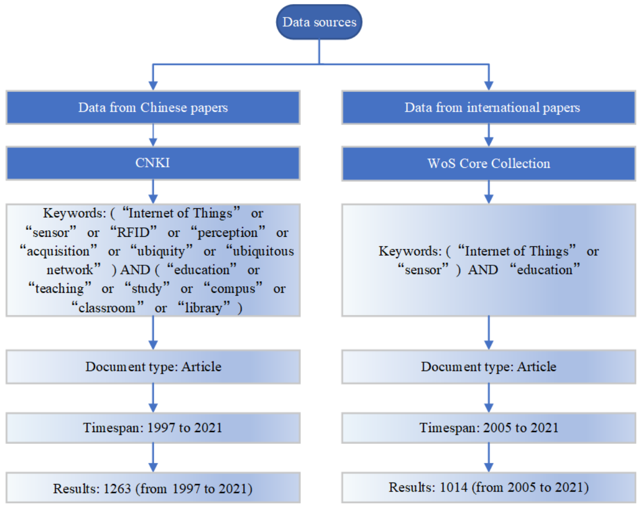

FIGURE 2. Procedures used to retrieve the research data.

C. DATA PROCESSING

In terms of network analysis (countries, institutions and authors) and burst detection (keywords, countries, institutions and authors), the CiteSpace (version 5.7.R2) is used in this study. The parameters in CiteSpace were set as follows: (i) the domestic and foreign timespan were both at 2005-2021. The reason we did not use the literatures published from 1997 to 2004 is that, during this period the domestic publications on the related topics were discontinuous and sporadic. Therefore, we excluded this period and chose the period the same as abroad for visual analysis and comparison; (ii) regarding the term source, each bibliographic record contained four textual fields, which provided unstructured text that can be processed and analyzed as a part of visual analytic process. The title, abstract, author, keywords and keywords plus were chosen for the analysis; (iii) node type = country, institution, author, keyword; (iv) we selected the top 50 levels of the most-cited or occurred items from each time slice for countries, institutions, authors and keywords. This standard has been recommended in many previous studies [46], [47]; (v) pruning = Minimum Spanning Tree (MST) and pruning sliced networks. In order to obtain the most significant network, we selected the Minimum Spanning Tree pruning algorithm for the domestic and foreign keyword co-occurrence networks and the cooperation networks of foreign institutions. The advantages of MST included that the calculation is simple and quick, and the results can be obtained quickly, avoiding the loss of relatively important nodes in the pruning process [48]. Other settings remain the default. Figure 3 shows the parameter settings of the foreign co-occurrence network of keywords, where the node type is "Keyword", the selection criterion is the top 50 per slice, and the pruning algorithm used is MST.

III. RESULTS AND ANALYSIS

A. TIME DISTRIBUTION

After the statistical processing of the data, it can be found that, in recent years, both the Chinese and foreign scholars' research literatures on the IoT in education show an increasing trend year by year (see Figure 4). It can be seen that there is a small gap in the total number of studies at home and abroad from 2005 to 2021, where the number of Chinese publications (i.e., 1243) is larger than that of foreign countries (i.e., 1014). In terms of when the first related manuscript

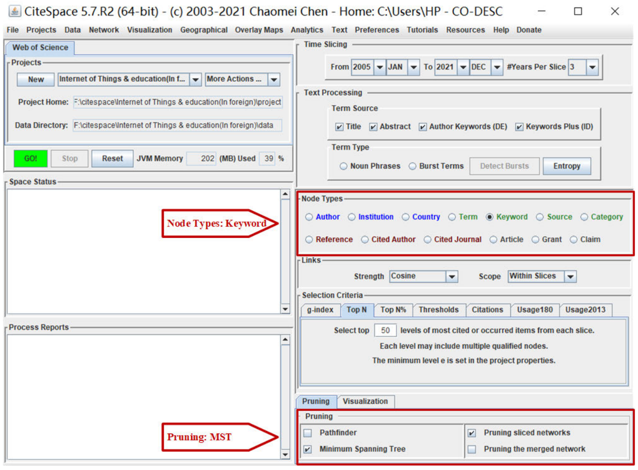

FIGURE 3. **The parameter settings of the foreign co-occurrence network of keywords.**

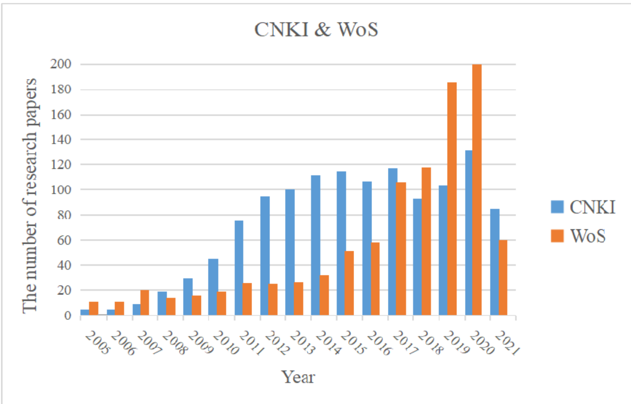

FIGURE 4. **Annual distribution and the quantitative gap regarding the research on the IoT in education between Chinese and foreign scholars.**

is published in the database, the year is 1997 in the CNKI database; whereas, it is 2005 in the WoS database. From the perspective of the growth rate, foreign literatures have been increasing year by year on the whole, especially in 2017, where the growth rate nearly doubles compared with that of the last year. In 2020, the annual outputs of related studies come to a peak all over the world. Compared with foreign countries, a significant increase in the volume of domestic papers starts from 2008, reaching its peak in 2020.

Furthermore, to clearly grasp the gap and the trends of Chinese and foreign scholars in terms of the number of papers on this topic each year, the gap is expressed by subtracting the number of papers of the five authoritative databases in the CNKI from the number of WoS Core Collection database papers. From the perspective of the total number of articles published, although the first related topic article included in the CNKI database is earlier than that in foreign countries, the domestic research interest on the IoT in education is not as notable as abroad between 2005 and 2007. Since 2008, China has been in a leading position, but the gap between domestic and foreign countries has been narrowing. It is worthwhile that the volume of foreign publications once surpasses China in 2018, and the number of outputs in the direction of IoT in education at home and abroad reaches the historical maximum in 2020. Although 2021 is not over yet, judging from the historical value of previous years, the research enthusiasm in this field at home and abroad is likely to continue in the future.

B. SPATIAL DISTRIBUTION

1) ANALYSIS OF MAIN COUNTRIES

To grasp the cooperation distribution in major countries, we processed 1014 foreign papers through the cooperation network analysis function of CiteSpace and obtained the cooperation distribution of the relevant major countries and regions. The relevant data are presented in Tables 1 and 2.

TABLE 1. **An overview of the top 10 countries ranked by published volume.**

Country	Number of research papers	Centrality
USA	238	0.29
China	125	0.07
Spain	84	0.29
Germany	61	0.01
England	57	0.17
Korea	56	0.01
India	43	0.18
Canada	43	0.07
Italy	37	0.07
Australia	36	0.09

As can be seen from the visualization results (see Figure 5), the United States and China occupy the first (centrality 0.29) and the second (centrality 0.07) places, respectively, and Spain ranks in the third place (centrality 0.29), indicating that the United States, China and Spain are the top three countries in the development process of the IoT in education. All these three countries are closely cooperating with most countries or scientific research institutions in the cooperation network. From the frequency of the emergence of the countries (see Table 1), 125 papers are published in China, ranking second, which is approximately 53% of the United States' output. The centrality of a node is a graph-theoretical property that quantified the importance of the node's position in a network [49]. Compared with the centrality of the United States, China's position in the national cooperation mapping is not high. As the previous analysis shows, there is still room for

TABLE 2. **Regional distribution of the published volume in major countries.**

Hemisphere position	Country	Number of research papers
Northwest	USA	238
Northeast	China	125
Northeast	Spain	84
Northeast	Germany	61
Northeast	England	57
Northeast	Korea	56
Northeast	India	43
Northwest	Canada	43
Northeast	Italy	37
Southeast	Australia	36
Northeast	Japan	34
Northeast	Netherlands	28
Northeast	France	25
Northeast	Turkey	24
Southwest	Brazil	21
Northeast	Finland	20
Northeast	Serbia	19
Northwest	Mexico	16
Northeast	Saudi Arabia	16
Northwest	Greece	15
Northeast	Malaysia	15
Northeast	Sweden	14
Northeast	Poland	14
Northeast	Ireland	13
Northeast	Romania	13
Northeast	Singapore	13
Northeast	Denmark	13
Northeast	Russia	13

improvement in the amount of research that can be done by Chinese scholars referring to the foreign academic circles. Not only that, the centrality value of other countries in the cooperation network is not high, so it is still necessary for researchers around the world to continue to study on the IoT in education. Except for the United States, China and Spain, the rest of the top 10 countries are Germany (centrality 0.01), England (centrality 0.17), Korea (centrality 0.01), India

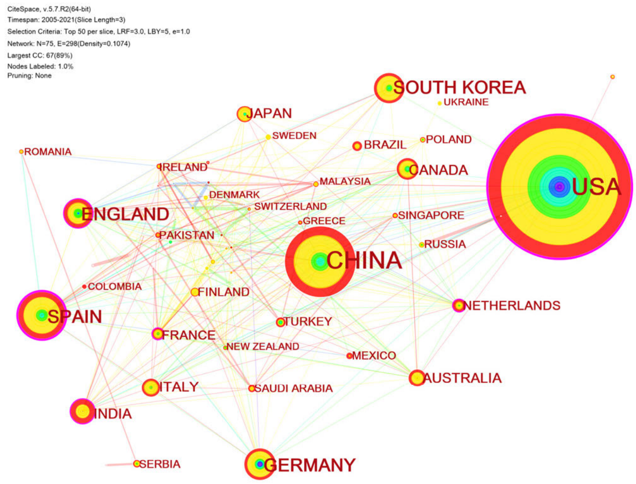

FIGURE 5. **The country co-authorship network of research on the IoT in education.**

(centrality 0.18), Canada (centrality 0.07), Italy (centrality 0.07), and Australia (centrality 0.09).

Table 2 shows the spatial distribution characteristics of the research development in each country. Comparing the Northern and Southern Hemispheres, the research results are mainly concentrated in the countries of the Northern Hemisphere and less distributed in the countries of the Southern Hemisphere. In the Northern Hemisphere countries and regions, the research findings are mainly concentrated in the USA, China, Spain, Germany, England, and Korea; whereas, in the Southern Hemisphere countries and regions, the research achievements are mainly concentrated in Australia and Brazil. From the east-west perspective, the research results are less widely distributed in the Western Hemisphere, such as Brazil, Mexico and Greece [50].

2) NETWORKS OF CO-AUTHORS AND CO-INSTITUTES

To grasp the distribution of cooperating institutions and authors of research on the IoT in education, 1014 foreign papers and 1043 domestic papers were processed to obtain the network of the cooperating institutions and authors (see Figures 6, 7).

Let us put China first for analysis. The research achievements in China mainly come from higher education institutions, university affiliations (including research institutes, libraries), journals and educational technology associations. According to Figure 6, the main institutes of higher education actively involved in this area include Beijing Normal University, East China Normal University, Central China Normal University, Jiangsu Normal University, Northeast Normal University, Shanghai Jiao Tong University, Wuhan University and Nanjing University. In terms of the co-author networks (see Figure 7), Xianmin Yang from Jiangsu Normal University, put forward the connotations and characteristics, and the goal of smart education [51]. Qian Fu and Yu Song

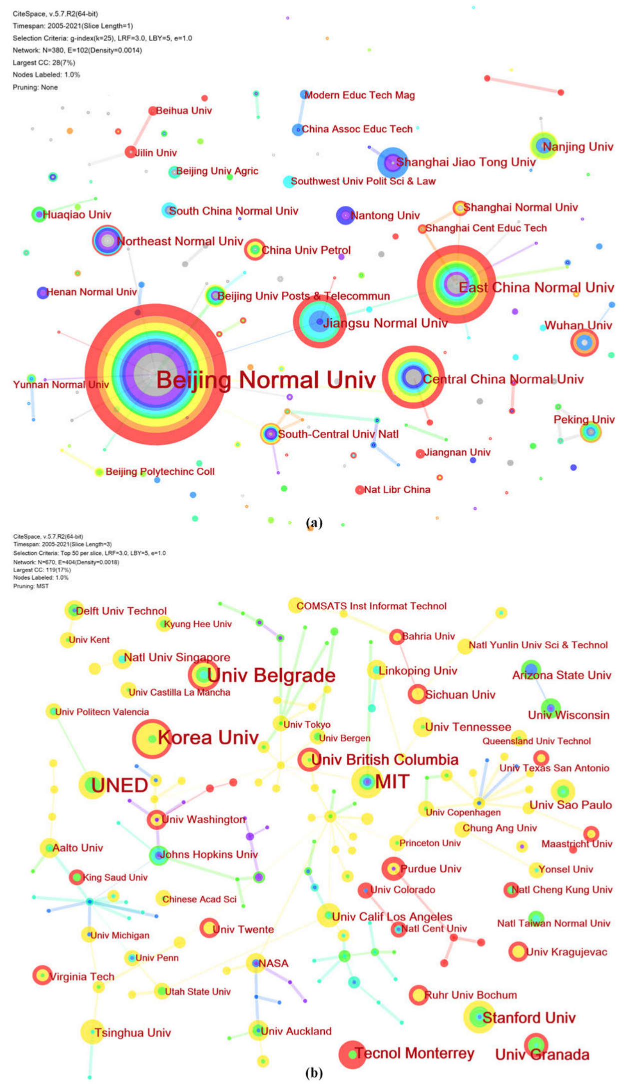

FIGURE 6. **Network of the institutes and the strongest collaborations between them (a) in China and (b) in foreign.**

from Beijing Normal University developed a management system of an IoT educational resource database to popularize the application of IoT [52]. Additionally, research institutes affiliated to higher education institutions actively involved in this area include the Computing Center of Shanghai University and Beijing Advanced Innovation Center for Future Education. Libraries also play an important role in higher education research institutions, including Shanghai Jiao Tong University Library, South-Central University for Nationalities Library, Huaqiao University Library and Beijing Agricultural University Library. The main journal involved is the *Modern Educational Technology Magazine*. Besides, the Association for Educational Technology has also carried out some research on the educational application of the IoT. According to Figure 6(a), there is a lack of extensive cooperation between institutions in China, and most of the cooperation is inter-school cooperation; therefore, the core organization needs to be further constructed.

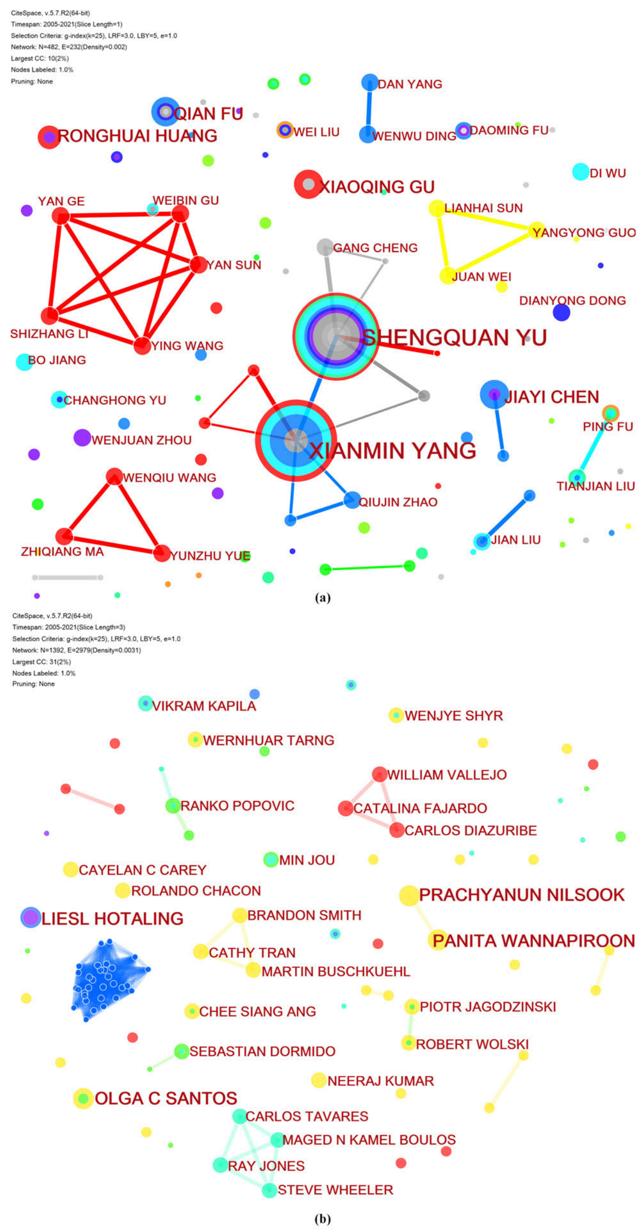

FIGURE 7. **Network of co-authors and the strongest collaborations between them (a) in China and (b) in foreign.**

The research teams on this subject in China mainly include Shengquan Yu, Xianmin Yang, Xiaoqing Gu, Qian Fu, Jiayi Chen, Ronghuai Huang, Tianjian Liu, Wei Liu, Wenqiu Wang and Bo Jiang (see Figure 7(a)). Among the authors, Xianmin Yang appears most frequently with Shengquan Yu in addition to their collaboration with Gang Cheng; partnerships with Qiujin Zhao are also formed but not close together. Some authors have also formed partnerships, such as Ping Fu and Tianjian Liu, Juan Wei, Yangyong Guo, and Lianhai Sun. One of the core functions of CiteSpace software is the detection and analysis of the diachronic trends in the frontier of the literature and the relationships between the research frontier and its knowledge. The detection and analysis of the research frontier are mainly realized by the extraction of "mutation words" [53]. According to Figure 7(a), except for Shengquan Yu and Xianmin Yang, the node's burst value of other authors is 0. The node color of Shengquan Yu and Xianmin Yang is red, and the burst value is 2.98 and 3.24 respectively, which indicates that Shengquan Yu and Xianmin Yang have contributed a lot to the research field in recent years and may form an author group with them as the core in the future.

The foreign research institutions on this topic mainly come from higher education institutions. The main research institutes include Korea University, Massachusetts Institute of Technology (MIT), Stanford University, University of Belgrade, Universidad Nacional de Educación a Distancia (UNED), Tecnológico de Monterrey, Prudue University, University of California, Los Angeles, Universidade de São Paulo, Universidad de Granada, University of British Columbia and Tsinghua University. As can be seen in Figure 6(b), Chinese research institutions actively participate in foreign academic cooperation. Among them, Tsinghua University and Sichuan University are the top two Chinese research institutions. Foreign research teams working on this study theme mainly center on Prachyanun Nilsook, Olga C Santos, Panita Wannapiroon, Liesl Hotaling, Chee Siang Ang, Wernhuar Tarng, Neeraj Kumar, Cayelan C Carey, Wenjye Shyr and Rolando Chacon.

From the perspective of cooperation between foreign institutions (see Figure 6(b)), in Serbia, the University of Belgrade cooperated with Singidunum University; moreover, in Pakistan, the COMSATS Institute of Information Technology cooperated with Bahria University and Pakistan University of Engineering and Technology. It shows that foreign institutional cooperation is still dominated in the same region. Meanwhile, from the perspective of the color and thickness of the connections between foreign institutions (see Figure 6(b)), the strength of cooperation is relatively weak and mainly local. From the perspective of international cooperation, cooperation between domestic and foreign institutions still exists, but stable contacts need to be established. When drawing the cooperative network for these universities or institutions, the size of the node indicates the institutions' participation in research, and the larger the node, the more literatures have been published by the institutions [54].

By comparing the cooperation mappings between domestic and foreign institutions and authors (see Figures 6, 7), it is found that the cooperation groups with more publications have started practical exploration on the IoT in education at a relatively early stage and the nodes on the visualization mappings are relatively scattered. Meanwhile, the connections are not long-term and there is a lack of core and stable cooperation groups.

3) DISTRIBUTION OF PUBLISHED JOURNALS

Since the domestic data from the CNKI database lack of the relevant cited information, the co-cited journal analysis of the domestic on the IoT in education is replaced by the statistical analysis function of the CNKI database. Meanwhile, to clearly understand the distribution of foreign journals published on this research topic, CiteSpace is used to process 1014 foreign samples to obtain the distribution of foreign co-cited journals (see Tables 3 and 4).

TABLE 3. Co-cited journals that ranked in the top 10 in china (frequency).

Frequency	Journal
80	*Journal of Distance Education*
77	*Information studies: Theory & Application*
68	*Information Science*
43	*Library and Information*
28	*Experimental Technology and Management*
26	*Research and Exploration in Laboratory*
24	*Modern Electronic Technology*
18	*Transactions of the Chinese Society of Agricultural Machinery*
18	*China Higher Education Research*
15	*China Educational Technology*

TABLE 4. Co-cited journals that ranked in the top 10 in foreign (frequency).

Frequency	Centrality	Journal
140	0.10	*Computer & Education*
124	0.00	*Sensors-Basel*
121	0.04	*Lecture Notes in Computer Science*
101	0.02	*Future Generation Computer Systems*
94	0.05	*Science*
90	0.02	*PLoS One*
84	0.03	*Computers in Human Behavior*
83	0.00	*Thesis*
75	0.02	*IEEE Access*
72	0.06	*Computer Networks*

According to the frequency of the co-cited journals (Table 4), the journals most frequently cited in foreign belong to the categories of computers, computer systems, educations, and sensors, namely, *Computer & Education, Sensors-Basel, Lecture Notes in Computer Science, Future Generation Computer Systems, Science, PLoS One, Computers in Human Behavior, Thesis, IEEE Access and Computer Networks*. Among the top 10 journals with a high citation frequency, the centrality of three journals (i.e., *Computer & Education, Computer Networks and Science*) among them is greater than 0.05, indicating that these three journals have not only been widely recognized but also locate in a very important position in this field.

Several highly cited articles published in the journal Lecture Notes in Computer Science, talked about the use of sensors and mobile phones to obtain responses and context-related learning interaction. The use of mobile phones increases the opportunities for interaction and cooperation among students [55]. A survey was conducted in Japan, in which researchers regularly sent 100 words to college students via email urging the students to study. The results showed that the students receiving the mobile email notifications displayed a better learning effect [56]. Along with the continuous integration of IoT technology in smartphones, we believe that mobile phones equipped with embedded sensors will completely change our future learning life [57]. Additionally, *Sensors-Basel and Lecture Notes in Computer Science* are cited 124 and 121 times respectively, which indicates that these two journals provide important reference value for the IoT development research in the field of education and thus deserve the researchers' high attention in this field.

In China, the top ten journals are mostly distributed in Library Information and Digital Library, Adult Education and Special Education fields, accounting for 67.5% of all studies, such as *Journal of Distance Education, Information Studies: Theory & Application, Information Science and Library and Information*. The other six journals are *Experimental Technology and Management, Research and Exploration in Laboratory, Modern Electronic Technology, Transactions of the Chinese Society of Agricultural Machinery, China Higher Education Research and China Educational Technology.*

C. RESEARCH HOTSPOTS AND FRONTIER

1) VISUAL ANALYSIS OF RESEARCH HOTSPOTS

In this part, we study the IoT hotspots by analyzing the distribution of keywords. The keyword co-occurrence network analysis function in CiteSpace was used to process 1243 Chinese samples and 1014 foreign samples respectively to obtain the distribution mappings of research hotspots in China and foreign (see Figure 8).

Keyword co-occurrence analysis mainly studies the frequency of keywords and the link strengths between co-occurrence keywords. Its function is to analyze the internal relations in an academic field and reveal its research hotspots and frontiers [31]. Figure 8 shows the keywords' co-occurrence knowledge mapping, presenting the hotspots focused on by Chinese and foreign scholars in this research topic.

From the frequency and centrality of the nodes in the keywords' co-occurrence mapping (see Figure 8(a)), the basic theories of domestic research on the IoT in education are rich, involving many branches such as basic education, higher education, vocational and technical education. Although the branches are relatively scattered, certain research trends have been formed with the changes of the times and policy backgrounds. The evolution of domestic research topics could be roughly divided into four stages. (i) In the first stage, the "Theory of meta-synthetic wisdom" [58] proposed by Mr. Xuesen Qian in the 1990s has a profound impact on the education field, and after that domestic scholars are doing the related theoretical research of smart education for a long time,

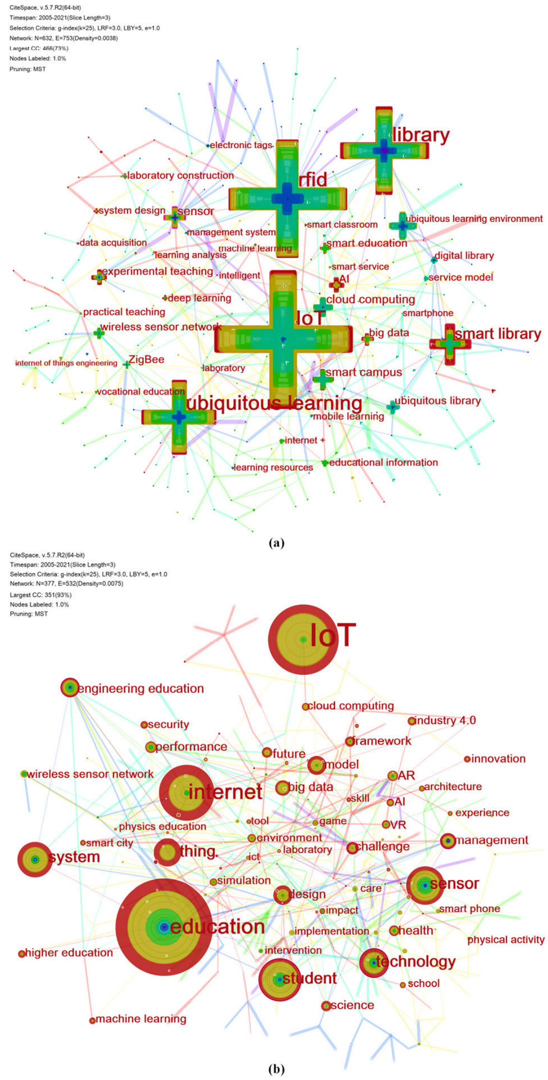

FIGURE 8. The co-occurrence network of keywords on the IoT in the education research field (a) in China and (b) in foreign.

such as "smart education", "smart campus", and "smart library" in Figure 8(a). (ii) Similarly, from the keywords of "technology", "IoT", "RFID", "sensor", "wireless sensor network", "laboratory construction", "experimental teaching", "practical teaching" and "service mode", the themes in the second stage are roughly divided into two categories: one is about the construction of smart learning environment, the other is about the practical research of information technology-assisted teaching. (iii) In the third stage, there are two types of themes that are obvious. One is the design of new teaching models such as "flipped classroom" and "MOOC" [59]. The other is about the analysis of learning needs under the deep integration of education and technology. (iv) In the last stage, the emergence of keywords, such as "deep learning" [60], [61], "cloud computing" [62] and "AI", indicates that the domestic education field begins to pay attention to smart education, cultivate innovative talents, and promote the deep integration between intelligent technology and education.

Compared with domestic research on the IoT in education that starts late but develops rapidly, most foreign research starts earlier. Combined with the keyword co-occurrence network (see Figure 8(b)) and related literature analysis, foreign research topics can be roughly divided into the following three parts. (i) The first is the construction of the smart learning environment, such as the keywords "environment", "smart city", and "IoT". (ii) What's more, teaching strategies and case design in smart learning environment are widely concerned by foreign scholars. As a result, smart education research supported by technology has become the second research theme abroad. The common technologies at this stage include "virtual reality (VR)" [63], "sensor", and "wireless sensor network". (iii) The last is personalized learning supported by machine learning technology [64], [65]. The research of personalized learning based on machine learning and data mining is a widely concerned problem abroad. It is worth noting that personalized learning based on the deep integration of emerging information technology and education has become a collective research hotspot and frontier at home and abroad.

Compared with the development of research themes at home and abroad, in general, there are still obvious differences and connections, which are embodied in four aspects. Firstly, at present, the domestic theoretical results are relatively rich, covering basic education, higher education, vocational and technical education, etc.; with regard to the foreign research, there are few systematic investigations on smart education theories, most of which aims to (i) build a smart learning environment supported by information technology at a practical level; and (ii) reuse AI and machine learning technology to serve the industrial upgrading of education. However, it should be noted that a complete and systematic theoretical system has not been formed across the world. The second is the level of teaching mode: China focus on the development of hybrid teaching, while foreign countries focus on deep learning theory and its application. Thirdly, at the level of learning environment, domestic scholars pay attention to the reconstruction of learning space, and foreign scholars attach great importance to the application of multi-dimensional environment. At last, in terms of learning subjects, domestic scholars pay more attention to the development of technology, while foreign scholars have carried out follow-up studies that focus on students' learning experience and feedback. From the perspective of application, the IoT in education is still in its infancy. The current application mainly aims to optimize the school education management, so as to promote the improvement of teaching effects. For example, the advantages of the IoT are used to optimize the daily affairs in school, and the ability of students to learn effectively is increased by improving the management efficiency.

2) VISUAL ANALYSIS OF HOTSPOT MIGRATION

In this paper, CiteSpace was used to draw timezone views for WoS sample documents and CNKI sample documents. A keyword co-occurrence timezone chart can directly show the inheritance and updates of research topics. The abscissa corresponding to the location of the keywords' node represents the time when it first appeared. The connection in timezone represents the inheritance relationship between keywords, the more connections, the stronger the inheritance relationship [66]. Based on the keyword co-occurrence timing analysis, we obtained the evolution path of the Chinese and foreign IoT in education research hotspots (see Figure 9). The results are as follows.

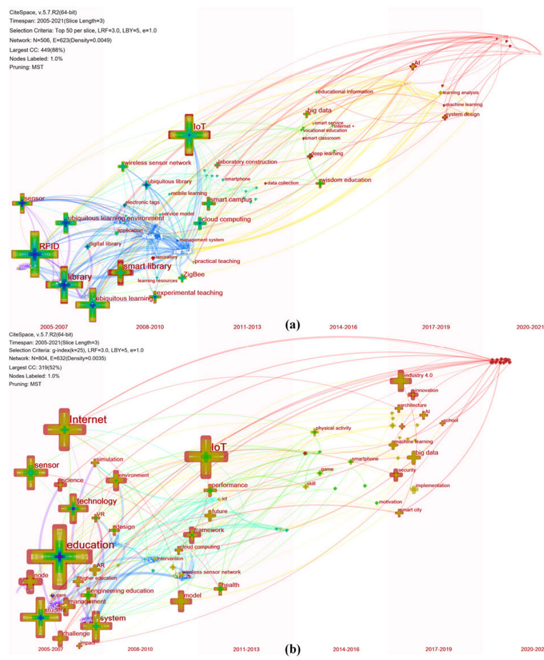

FIGURE 9. Keyword co-occurrence evolution of the IoT in education research (a) in China and (b) in foreign.

Chinese research on the IoT in education can be divided into three stages. The first stage is from 1999 to 2004. The domestic research hotspots are relatively isolated, and the main hotspots are system design, data acquisition and sensors. The second stage is from 2005 to 2014. The application of the IoT in education is more abundant, and the hotspots are growing vigorously. At this stage, the research on the IoT in education can be roughly divided into three areas: architecture, technology and communication. At present, the trend of the IoT architecture is either based on an Open System Interconnection Reference Model (OSI) layer or a Transmission Control Protocol/Internet Protocol (TCP/IP) layer. According to the percentage of the trend found during the IoT architecture layers review, most researchers chose three-layer or four-layer architecture surveys; while, the lowest percentage of surveys employed six-layer and seven-layer architecture [67]. Let us take the three-layer architecture as an example. (i) In the sensing layer, to be specific, the hotspots of the IoT in education are reflected in the sensors in the sensing layer, the wireless radio frequency identification, bar code, near-field communication [68] and ZigBee. For instance, ZigBee processes data from sensors, transmission and packet routing, which are applied in ubiquitous learning environments, such as libraries, laboratories and smart campuses. (ii) In the middleware layer, according to the literatures, the commonly used hardware in the application of the IoT in education are sensor, Arduino and the chip, CC2530 [69], [70]. The middleware supports communication between complex programs that are not intended to be connected. Hadoop [71] is often used here and Android is the commonly used platform. (iii) In the network layer, IoT communications involve many protocols that serve as a specific architecture layer, either IP-based or non-IP-based. IPv6 is the most preferred protocol for IoT communications because it is scalable and stable. Additionally, the 3G, 4G, 5G, and 6G used in mobile communications have been widely applied in the network layer. The third stage is from 2015 to today, the hotspots focus on intelligent technologies such as AI and deep learning, where the IoT gradually becomes combined with other technologies that are widely used in education.

Similarly, the research on the IoT in foreign countries can also be divided into three stages. The first and second stages are from 2005 to 2010 and from 2011 to 2013 respectively. Researchers focus on IoT, cloud computing, wireless sensor network, VR and augmented reality (AR) [72]–[74], etc. At this time, cloud computing and VR are the main technologies used in the field of education that are combined with the IoT, and the domestic use of VR technology is a little later. The keywords' occurrence of these two stages also predicts the technologies that may be used in the construction of smart campuses include the IoT, AR/VR, integration systems, blockchain [75], big data, robots, Unmanned Aircraft Vehicles swarm (UAVs) [76], [77], cloud and edge computing [78], and Cyber-Physical System (CPS) [79] in the future.

The third stage is from 2014 to now. The research hotspots become related to the following keywords: big data, AI, VR, machine learning, Industry 4.0, model, architecture, framework, security, innovation and motivation. Industry 4.0 is a future vision originally described in the high-tech strategy of the German government, which is conceived for information and communication technologies. Industry 4.0 includes initiatives, such as the industrial Internet, factories of the future, IoT, physical Internet, Internet of services and CPS, aiming to achieve a high degree of flexibility in production, higher productivity rates through real-time monitoring and diagnosis, and a lower wastage rate of materials during production [80]. An important part of the tasks in the preparation for Industry 4.0 is the adaption of higher education to the requirements of this vision, in particular engineering education. During this period, scholars at home and abroad begin to pay attention to the security and challenges of communication, where the keywords mentioned include trust, risk, attack and effectiveness.

IV. DISCUSSION AND CHALLENGES

A. DISCUSSION

When the "Smart Earth" impacts different fields, a new trend of thought will emerge. When this wave that intertwines with culture flows into the field of education, smart education comes into being. The essence of smart education is to build an ecological learning environment with technology integration and cultivate data wisdom, teaching wisdom, and cultural wisdom of human-computer cooperation in line with the principles of "precision, individuality, thinking and creation". In this way, teachers can display effective teaching methods, and learners can obtain appropriate personalized learning services and good development experience to cultivate smart talents with good value orientation, strong action, good thinking quality, and deep innovation potential. The IoT is one of the most important technologies to construct a learning environment. Its application is mainly reflected in typical learning environments, such as smart campuses, smart libraries and smart classrooms, especially smart libraries. In 2010, the first paper on the concept of a smart library appeared in China, titled "Smart Library Based on Internet of Things", which considered the smart library as a combination of a library, the IoT, cloud computing and intelligent devices. Since then, researchers have paid increasing attention to the concept of smart library.

China is one of the earliest countries to carry out research on the IoT; furthermore, the scale of the IoT industry has been expanding in recent years. Through the joint efforts of the governments and industry-related enterprises, certain achievements have been made in the key technologies, and the competitive advantage has been continuously enhanced. However, challenges are also being faced, such as the urgent need to improve the standards and specifications, improvement of core technologies, time for a large number of applications and hidden dangers of information security. Fortunately, the emergence and development of 5G, Low-Power Wide-Area Network (LPWAN) [81], blockchain, big data, AI and other new technologies provide countermeasures to solve some of these problems. For example, the development of 5G, Narrow Band Internet of Things (NB-IoT) [82], Long Range (LoRa) [83] and other communication technologies will meet the large-scale connection which could expand the possibilities of richer and wider application scenarios. Blockchain technology can be the key to overcoming the security challenges of IoT since it enables devices to directly share data without communicating through a centralized network so as to reduce the sensitivity of the IoT to network threats. In short, in the development of information and intelligent technology, the breakthrough development of these key technologies will greatly promote economic and social progress and bring profound changes to our production and life, including sustainable education.

B. CHALLENGES

IoT is known as the third revolution in the field of information technology. With the support of the IoT, educational institutions play an important role in improving the quality of learning, increasing knowledge acquisition and reducing the cost of learning. At the same time, the IoT is facing huge challenges and opportunities in the education ecosystem.

The first challenge is about the security and privacy of the IoT in education ecosystem. Many literature reviews believe that security is the weakest link on the IoT [84]. The main reasons are as follows: (i) insecure IoT devices. Due to resource constraints such as cost, size and power consumption, security has not been put in the first place in the development of many IoT devices. According to a recent study conducted by HP Fortify, the average security problem of each device was equivalent to 25%, and 70% of the most commonly used IoT devices were prone to security vulnerabilities [85]. (ii) Insecure network. The security of the IoT network is considered to be an urgent need of the educational industry, but the existing security architecture designed from the perspective of human communication is open to the outside world, and may not be suitable for the internet system [86]. More seriously, the intruder can access through the media access control address to perform "man in the middle" or "denial of service" attacks, such as distributed denial of service (DDoS) attacks. Different from general technical applications, IoT applications in education also face many threats such as lack of security in transportation and storage across multiple locations, and difficulty in maintaining hybrid systems. (iii) The lag of privacy and security solutions. Compared with existing systems, the rapidly growing IoT is widely adopted as a technology/tool unique to educational activities, requiring great care in ensuring data security and integrity. However, due to the lagging priority of privacy and security solutions, the lack of specific disaster recovery procedures has caused security vulnerabilities in the educational ecosystems.

The second challenge is related to the technology, especially in platforms and architectures, addressing, ubiquitous data management and communication technology.

(i) Designing a secure, flexible and cost-effective architecture is critical to the rapid adoption of IoT technology. Due to the diversity of connected heterogeneous devices in the IoT, it is necessary to maintain compatibility between all IoT layers to enhance connectivity and ensure delivery, and it is also more important that there are fewer and fewer universal platforms for the IoT in education. This is the main obstacle hindering the development of the IoT. In the past, the simple inquiry was conducted under the guidance of the teacher. Teachers selected variables for measurement and prepared the necessary tools for students. However, authentic inquiry encourages students to generate their own unique research questions, thereby broadening the scope of measurement variables. As time went by, there are three main technical problems encountered by students in the process of scientific inquiry. They are respectively "it is hard to have various measurement tools that meet the needs of students", "it is difficult to equip students with tools suitable for complex query programs developed by students themselves", and "the data analysis process is monopolized by specific student groups" [87]. (ii) Since science and technology are inseparable, it is particularly crucial to design certain devices based on IoT technology that meet the needs of students. IoT includes an extremely large number of nodes that generate a large number of contents, which can be accessed by the authorized users no matter where they are. This requires an effective addressing strategy, but due to the heterogeneity of identifier lengths used by various technologies, choosing a unique solution is extremely aggressive [88]. (iii) As IoT devices become more and more common, considering the large amount of data that cannot be processed by traditional data mining techniques and the lack of advanced data mining tools and competent data analysis, storage and management of such a large amount of data will become very challenging [89]. (iv) At the same time, due to resource constraints, the power and energy consumed by IoT devices have a lot to do with the choice of communication schemes. Now, most of them hold the view of wireless sensor networks, but scholars need to keep abreast of the latest developments in the field of communication in order to understand them and incorporate them into the designed architecture.

The third challenge involves law and regulation [90], [91]. When a large amount of data generated flows in different jurisdictions and is used by different parties, the process may bring some potential challenges, such as "who owns the data", "what should I do if the data is used improperly", "if someone is injured because of the inappropriate use of IoT devices, who is responsible". These problems involve the determination of data ownership, rights of use and responsibilities, which need to be defined by clear laws and regulations. Service providers can freely implement the IoT which poses severe challenges to the proposal of any IoT solution because the governments have not proposed a standard framework and regulations for IoT applications.

V. RESEARCH CONCLUSION AND TRENDS

A. RESEARCH CONCLUSION

According to the general research framework (see Figure 1), based on bibliometrics and mapping knowledge domains, this research conducted a quantitative analysis of the relevant literatures on the IoT in education and visualized the results. The four questions raised in the Introduction are summarized below.

First, China and the United States are in the leading position on the IoT in education research, whereas Spain and other countries are also very active in this field. The high-yield institutions in China are slightly different from those in foreign countries, and their types are more abundant. It is characteristic of foreign academic circles to conduct research with research universities as the core universities, such as Korea University, MIT, Stanford University, University of Belgrade, UNED and Tecnológico de Monterrey, who hold the main positions in this field. Through the research of scholars in this field, we find that the phenomenon of multi-author cooperation is not widespread at home and abroad. In the future, scholars should pay attention to cooperative research in the research field, mainly between researchers and research institutions, including interdisciplinary cooperation.

Second, considering the frequency and centrality of certain keywords, it is found that the IoT technology at home and abroad in the past few years focused on sensors, radio frequency identification, wireless communication technology, embedded technology, etc. However, in recent years, with the popularity of AI, big data, cloud computing, blockchain and nanotechnology, IoT technology begins to integrate with these technologies to promote the development of IoT in education, such as the establishment of a comprehensive and active teaching management system, the construction of a fully interactive and smart teaching and research environment, development of the innovative and open teaching mode, the expansion of the learning space and the cultivation of learners' autonomous learning ability. From the perspective of a smart education environment, the research of smart libraries has increased significantly. The smart library has been following the development of IoT and AI technology. By developing AI applications, such as natural language retrieval, audio and video information organization and retrieval, machine learning, big data analysis and literature translation, it aims to help users solve practical problems, provide better experiences for learners and improve the service quality of a smart library.

Although this study can provide some educational reference for the construction of IoT, it also faces some limitations. First of all, although we defend the authority and representativeness of the CNKI and WoS Core Collection as the database, some articles are still not included in our analysis due to sampling limitations, therefore the covered articles are still limited. Meanwhile, the purpose of this study is to investigate the development situation of the application of IoT technology in the field of education, which covers a wide timespan. However, it is found that both CNKI and WoS do not include literatures covering relevant subject terms in the early stage, resulting in the failure of our goal. Second, we note that multivariate retrieval in different databases will make the research more persuasive and scientific by selecting articles in different languages and covering different research areas from multiple databases. However, the foreign database WoS still contains a part of the articles published by domestic scholars, and the Chinese database CNKI also includes some articles composed by foreigners, which leads to some negative impact on this comparative study due to the minimal overlap of the initial database at home and abroad. In the future, researchers can use efficient screening algorithms instead of manually deleting documents that are not related to the topics to increase the rigor of the data set. Finally, due to the excessive number of literatures obtained by databases according to the retrieval conditions, the author chose to give up the breadth to pursue the accuracy of the research, so that manually screening the original literatures may lead to the loss of some references.

B. RESEARCH TRENDS

IoT technology will bring great challenges and opportunities to higher education, because these technologies can not only help create new interaction between environments and users, but also improve the core value of teaching and its evaluation effects in various educational environments. The future research will concentrate on construction of smart education environment, curriculum teaching and data-driven education evaluation, in order to inaugurate a new situation capable of carrying out experimental teaching, presenting abstract concepts and connecting realistic situations.

In the future, similar to the projects funded by the European Commission under the "Erasmus+ Strategic Partnership" program [92], we can use digital technology to design teaching tools; and then, promote the use of these tools to help students to overcome time and space limitations in scientific experiments exploration, where the IoT is programmed, but can also be transplanted during the manufacturing process. In the next, students will learn in such a smart environment;

Teachers can (i) use voice/face/gesture commands to initiate and manage classroom sessions; (ii) communicate with students even in different locations; (iii) identify students and recommend different resources to meet their personalized needs; (iv) evaluate students' attention, behavior, performance, interest and participation in the activities carried out; in turn, students can access learning resources remotely, including knowledge level, customized resources, discussions and real-time annotation of learning materials, teachers-students and students-students interaction based on location, time and date. In addition, the staff of the college can use the IoT technology to monitor and maintain the mental health of teachers and students, comprehensively and intelligently manage the equipment, so that the equipment can protect, repair and describe itself, and is compatible with previous old equipment. In the future, we need to gradually use IoT technology to make up for the disadvantages of certain aspects of education and promote the transformation and upgrading of education.

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