Knowledge Structure, Characteristics, and Global Research Trends Study of Smart Education Research: Bibliometric Analysis

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Abstract—This research aims to explain the knowledge structure, characteristics, and global trends of smart education research from the past to the present. This article is a bibliometric study with open-source tools, such as R-Studio, the biblioshiny package, and VOSviewer, to analyze the data and help visualize the network for presenting knowledge structure, characteristics, and global research trends, such as the production of annual publications, influential resources, most relevant or prolific authors, publication networks that co-citations, authors' international collaboration, the scientific production of each country or each institution, and future trends. This study examined 1,580 articles published in international journals in the Scopus database on smart education from 1986 to 2022. The most annual scientific production will be in 2021, at 296 articles. The most relevant sources are Smart Innovation, Systems and Technologies. The most influential author is Gwo-Jen Hwang. The most cited article has 293 citations. Trend topics that began to gain attention from 2021 – the present is Artificial Intelligence, COVID-19 and Smart Education, Artificial Intelligence, Internet of Things in Motor Themes will be developed further and remain the dominant topics in this research field. This article summarizes an overview, knowledge structure, characteristics, and global research trends of smart education research.

Keywords—smart education, knowledge structure, characteristics, global research trends

1 Introduction

Smart education empowers learners with 21st-century knowledge and skills to meet the needs and address the challenges of modern society with technology development, so nowadays, it plays an important role in creating a smart educational environment. Learning can happen anytime and anywhere and covers a variety of learning styles, such as formal and informal learning, personal learning, and social learning, and it aims to provide a continuity of learning experience for the learners. Learners will receive personalized learning services based on their learning contexts, and it also promotes the learners' intelligence and problem-solving skills in a smart environment where learners can learn flexibly as well as collaborate in the smart learning environment. Thus, it

can promote personal cognitive development in all aspects (emotional, cognitive, and physical), and the contents can be adapted [1]. Smart learning environments also result in the standard development of required learning, education, and training. The trends from an early research review of smart learning, smart education, and smart learning environments focus on two models: the smart learning model and the intelligence level model, which are comparable to the current standards in learning, educating, and training to create a foundational platform for the new standard development in education [2]. Even during the COVID-19 outbreak, most educational institutions had to change their way of teaching to use an online platform for a safe and positive learning environment for the learners, which is flexible to access learning and innovations [3]. Due to the COVID-19 pandemic, social distancing was required, and it affected education at all levels as students and teachers could not conduct physical school. With the limitation, it was likely to limit learners' opportunities to learn during times of social distancing [4]. The way of learning has shifted to an online format, although the aim of education still focuses on the development of learners' abilities. A way to manage the teaching and learning style is to apply technology to develop a virtual classroom. The heart of learning is the design of learning activities in the virtual classrooms which align with the course objectives, learning style, and learners' context [5]. Educators and educational institutions should consider the scope and established teaching approaches, which always require development and thoughtfulness in curriculum design, the learning environment, and the student-centered concept [6]. Smart education is a paradigm for improving learners' quality of life and lifelong learning [1].

Li & Wong [7] presented information about the current status and trends of smart education research, including author analysis, collaborations, keywords, and publication citations, which cover the analysis of other bibliographies as well. They collected data from two well-known and recognized databases, namely Web of Science (WoS) and Scopus, by using the search terms as follows: ["smart education" OR "smart learning"] and ["smart technology" AND ("education" OR "learning")]. Only publications in English. The data were analyzed using the CiteSpace program. The findings provide a picture of the social networks of the academics who conducted this study. The study analyzed the pattern of collaboration, the center of research and growing subjects, and citations in smart education to identify the overview and trends, collaborative networks, and keyword co-occurrence according to the information obtained from the bibliography.

In addition, [8] Guo, X., Li, and Guo, Y. studied and analyzed developmental pathways in the key area and scope of smart education research. They collected data from the Web of Science (WoS) from 2000 to 2021 by using CiteSpace and VOSviewer software. By analyzing the data, they analyzed categories, co-authors, international cooperation, regions, organizations, and authors by using mapping techniques to create knowledge structure maps, citation document analysis, citation analysis, reference, co-keyword analysis, and citation data analysis, including an analysis of the growing trend of this research to demonstrate the development of smart education research. In addition, [9] Wang et al. studied key issues of smart education in China by using bibliometric analysis and knowledge mapping techniques. This study was the smart education research study only published in China. The data were collected from China National Knowledge Infrastructure (CKNI), and CiteSpace was used to analyze the

data limited to the main journals of Peking University, CSSCI, and CSCD, totaling 245 articles. There are 204 articles in the journals and 41 theses. The results showed that (1) smart education began in 2003, while the publications continued periodically over the next ten years and increased annually from 2013 to 2017. The highest number of articles in 2017 was 52. (2) The word groups: smart education, educational informationization, intelligent education, and smart campus are the top four largest word groups in the realm of smart education in China. There are also similar studies belonging to [10] Agbo, Oyelere, Suhonen, & Tukiainen, who studied research trends, research findings, and specific topics of publications, including publication networks and interinstitutional, national, and regional collaborations on publications on smart learning environments from the Scopus database by using open-source bibliometric software. As well as Chen, Zou, Xie, and Wang, [11] their studies mainly focused on the specific structure of smart learning, including the key issues, evolutions, and distributions of the top contributors. The data were collected from the Scopus database between 1989 and 2019 by using descriptive statistical analysis, the Mann-Kendall trend test, and hierarchical clustering.

From the results of the above studies, there are only three studies related to the bibliometric analysis of smart education. In past research, the scope of the research analysis had not been defined regarding the principles used to define clear search terms. Therefore, in this research, the keywords will be defined, and they will cover smart education research framework of Zhu et al., [1] namely smarter education, smart pedagogy, smart learning environment, and smart learner in order to receive more reliable results covering smart education based on research frameworks by collecting data from the Scopus database and determining the period of article publications from the past to the present (2022) to understand the knowledge structure, characteristics and research trends in this field by using open source software to analyze the data and help visualize the network, such as topic trends and word growth, concept structure, co-occurring network of the authors, thematic map, intellectual structure, networks that co-citations, including an overview of the data, production of annual publications, average citations per year, influential resources, most relevant or prolific authors, international or institutional collaborations, work production of each country or institution, the most referenced works, and the referred citations of publications in this field.

Therefore, this bibliometric analysis provides an understanding of the knowledge structure, characteristics, and global research trends of smart education research for academics, researchers, and smart education practitioners by presenting comprehensive information on various issues mentioned above to explain the situation of knowledge about research in the smart education field that has been accepted to be published from the past to the present.

2 Methodology

This article analyzes international publications on smart education. All papers published from the past to the present (1986–2022) were selected in English only in the Scopus database, which was downloaded on December 23, 2022. The search terms used are as follows: TITLE-ABS-KEY ((“smart education”) OR (“smart pedagogy”)

OR ("smart learning environment") OR ("smart learner") OR ("smart learning")) AND (LIMIT-TO (LANGUAGE, "English")). There were 1,661 articles in total. After the papers without author names were filtered out, there were 1,580 articles left.

This study used the bibliometric analysis technique to understand the knowledge structure, characteristics, and global research trends of smart education research. Open-source software tools for bibliometric analysis are Bibliometrix, the Biblioshiny package [12], and VOSviewer [13].

3 Results and discussion

This section discusses the results of a bibliometric analysis on smart education. The results of the data analysis found that the smart education articles were first published in 1986. Smart education was cited in 43,260 publications, with an average of 6.39 citations per document.

3.1 Descriptive analysis

International publications on smart education in 1986–2022. Figure 1 shows that the number of articles has increased steadily over the past 36 years, with the highest number published in 2021 at 296 out of 1,580 articles. It was expected that smart education research would continue to increase (the data analyzed does not cover the end of 2022). Figure 2 shows the proportion of smart education publications included in the analysis of 11 categories: 594 articles (34.75%), two articles in press (0.13%), ten books (0.63%), 127 book chapters (8.04%), 846 conference papers (53.54%), 1 data paper (0.06%), 16 editorials (1.01%), 3 erratum (0.19%), 1 note (0.06%), 24 reviews (1.52%), and one short survey (0.06%).

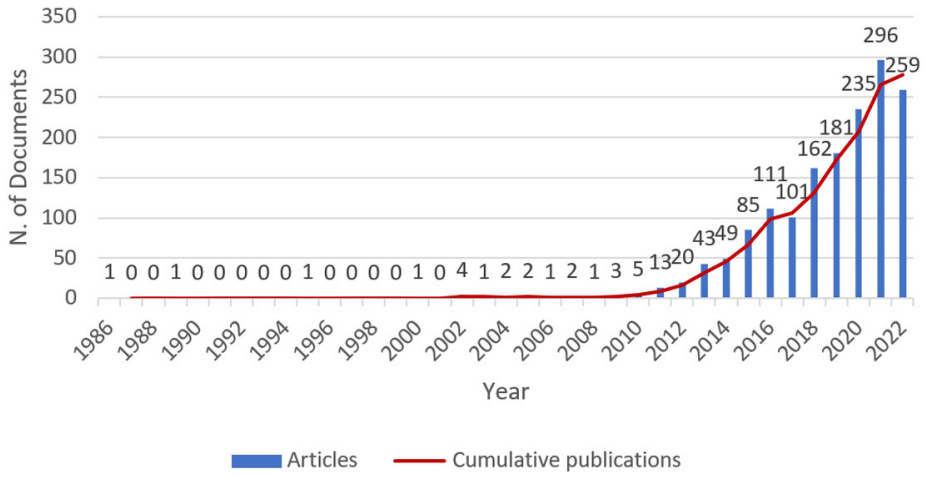

Fig. 1. Annual scientific production

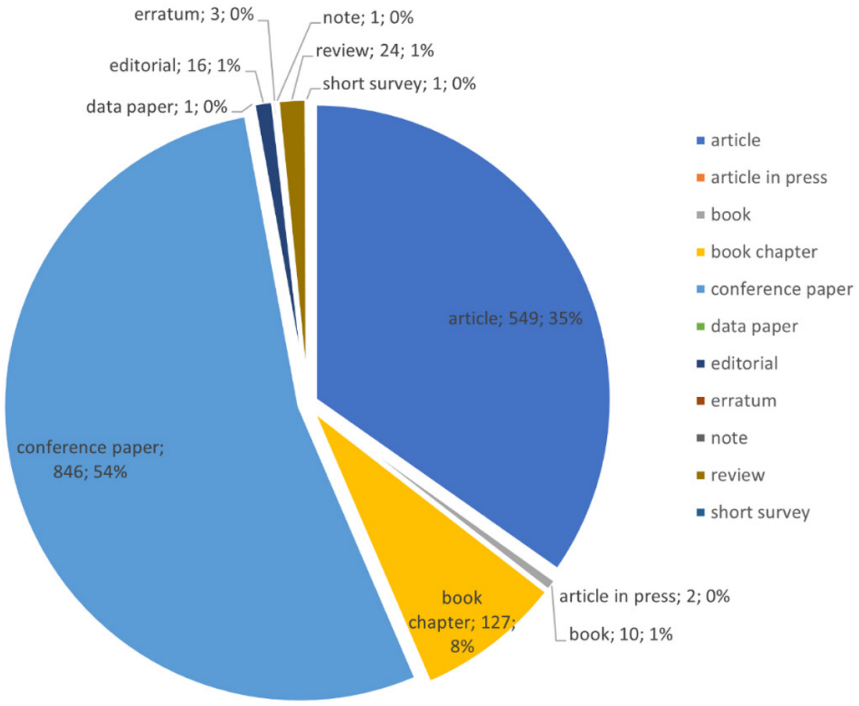

Fig. 2. Document type

3.2 Bibliometric analysis

This section presents characteristics of academic output on smart education in terms of evaluating the number of articles, authors, countries, institutions, journals, citations, and average citations per article, for example.

Publication development on smart education articles and background information. Table 1 shows the average citations per year. It was found that, in 1989, the most significant number of citations per article was 40, with an annual average of 1.21, meaning that the publications in 1989 contained the most citations in the smart education field. The second highest number of articles cited was 20.75 in 2002, with an annual average of 1.04. The third highest number of articles cited was 19 in 1995, with an annual average of 0.70.

Table 1. Average citations per year

Year	N	MeanTCperArt*	MeanTCperYear**	Citable Years
1986	1	6.00	0.17	36
1987	0	0	0	0
1988	0	0	0	0
1989	1	40.00	1.21	33
1990	0	0	0	0
1991	0	0	0	0
1992	0	0	0	0
1993	0	0	0	0
1994	0	0	0	0
1995	1	19.00	0.70	27
1996	0	0	0	0
1997	0	0	0	0
1998	0	0	0	0
1999	0	0	0	0
2000	1	5.00	0.23	22
2001	0	0	0	0
2002	4	20.75	1.04	20
2003	1	0	0	19
2004	2	3.50	0.19	18
2005	2	2.00	0.12	17
2006	1	10.00	0.63	16
2007	2	4.00	0.27	15
2008	1	13.00	0.93	14
2009	3	2.67	0.21	13
2010	5	12.00	1.00	12
2011	13	10.31	0.94	11
2012	20	4.25	0.42	10
2013	43	6.91	0.77	9
2014	49	18.27	2.28	8
2015	85	10.20	1.46	7
2016	111	13.74	2.29	6
2017	101	8.07	1.61	5
2018	162	9.01	2.25	4
2019	181	7.36	2.45	3
2020	235	5.63	2.81	2
2021	296	3.19	3.19	1
2022	259	0.58		0
Total	1580	6.36		

Notes: *MeanTCperArt is Mean Total Citation per Article, **MeanTCperYear is Mean Total Citation per Year.

Three fields plot. The Three Fields plot contains keywords, authors, and journal titles. Keywords are on the left, author names are in the middle, and journal names are on the right. Each publication in the gray line lists keywords and the journal's name that goes with that author. The gray line and box size represent the frequency with which they appear in the publications. Figure 3 shows that the most common keyword was smart learning, appearing 19 times out of the top 10 keywords, and that six authors used smart learning as a keyword. The most published author was Zhang Y, with 21 articles out of the top 10 authors. The journal titles with the most publications on smart education are Smart Innovation, Systems, and Technologies, in 38 articles from the top 5 journal titles. From the graph, it shows the link among 3 authors from the top 10 authors.

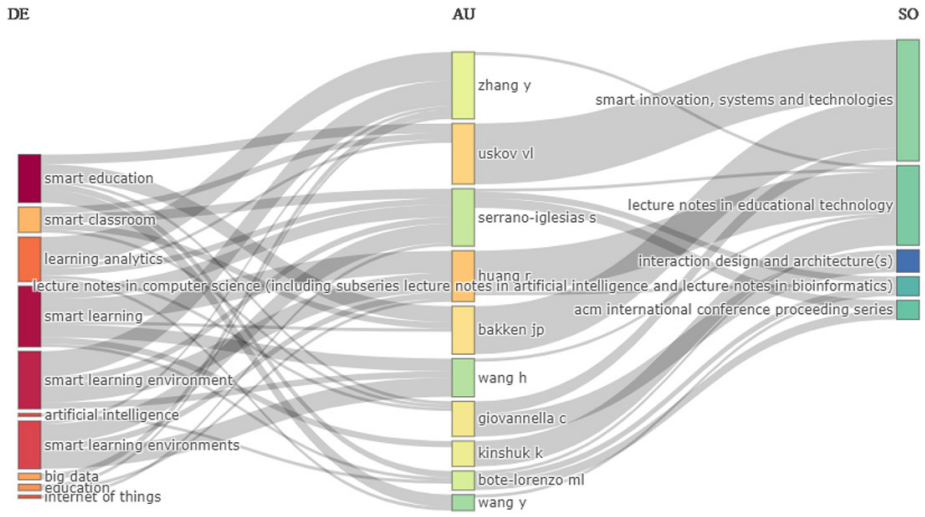

Fig. 3. Three fields plot

Most relevant sources on smart education. Figure 4 shows the top 10 journals that published the most smart education articles. The most published journal is Smart Innovation, Systems and Technologies, with 127 articles. The second most published journal is Lecture Notes in Educational Technology, with 67 articles. The third most published journal is the ACM International Conference Proceeding Series with 57 articles, followed by Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) with 47 articles, Advances in Intelligent Systems and Computing with 33 articles, Smart Learning Environments with 30 articles, Lecture Notes in Networks and Systems with 27 articles, Interaction Design and Architecture(s) with 21 articles, Lecture Notes in Electrical Engineering with 19 articles and International Journal of Emerging Technologies in Learning of with articles, respectively.

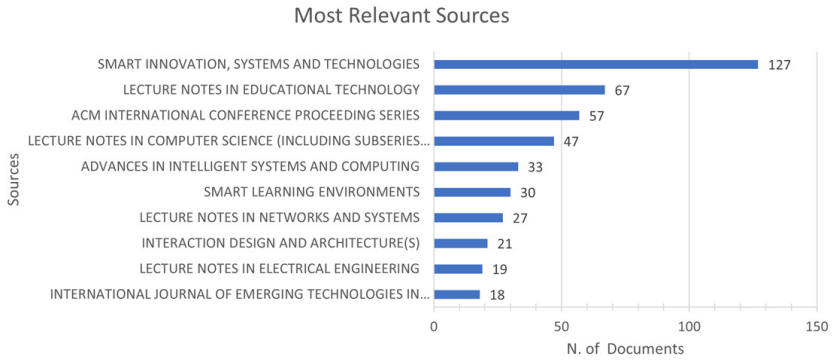

Fig. 4. The top 10 journal publishing smart education articles

Influential authors and their citation structure. This section describes the authors who have influenced publications on smart education. From Table 2, it shows that there were articles with a significant impact, for example, Gwo Jen Hwang from the National Taiwan University of Science and Technology, Taipei, Taiwan, with a total of 293 citations, an average citation of 32.56 per year, and the article is called definition, framework, and research issues of smart learning environments – a context-aware, ubiquitous learning perspective [14]. From Table 3, it was found that Gwo Jen Hwang is the most influential author, with a total of 319 citations. In addition, Vladimir L. Uskov [15] from Bradley University, Peoria, United States, has the most contributions of 21 articles with the highest h-index of 9 points.

Table 2. Most cited article from 1986–2022

R	Article	DOI	TC*	TCY**
1	HWANG GJ, 2014, SMART LEARN ENVIRON [14]	10.1186/s40561-014-0004-5	293	32.56
2	ZHU ZT, 2016, SMART LEARN ENVIRON [1]	10.1186/s40561-016-0026-2	268	38.29
3	SPECTOR JM, 2014, SMART LEARN ENVIRON [16]	10.1186/s40561-014-0002-7	185	20.56
4	MARINOVA D, 2017, J SERV RES [17]	10.1177/1094670516679273	161	26.83
5	ABDEL-BASSET M, 2019, CONCURR COMPUT PRACT EXPER [18]	10.1002/cpe.4515	150	37.50
6	AMPARORE D, 2020, MINERVA UROL NEFROL [19]	10.23736/ S0393-2249.20.03868-0	147	49.00
7	KINSHUK K, 2016, INT J ARTIF INTELL EDUC [20]	10.1007/s40593-016-0108-x	133	19.00
8	HUANG R, 2015, WORLD TRANS ENG TECHNOL EDU [21]	NA	125	15.63
9	WANG H, 2016, COMPUT MATER SCI [22]	10.1016/j. commatsci.2015.09.037	119	17.00
10	GOPE P, 2018, FUTURE GENER COMPUT SYST [23]	10.1016/j.future.2017.06.023	113	22.60

Notes: *TC is Total Citation, **TCY is Total Citation per Year.

Table 3. Most productive authors and the citation structure

R	Author	Affiliation	H-Index	G-Index	M-Index	TC*	NP**	PY Start***
1	HWANG GJ [14]	National Taiwan University of Science and Technology, Taipei, Taiwan	2	2	0.22	319	2	2014
2	RIEZEBOS P [1]	East China Normal University, Shanghai, China	1	1	0.14	268	1	2016
3	YU MH [1]	East China Normal University, Shanghai, China	1	1	0.14	268	1	2016
4	ZHU ZT [1]	East China Normal University, Shanghai, China	1	1	0.14	268	1	2016
5	USKOV VL [15]	Bradley University, Peoria, United States	9	15	1.13	234	21	2015
6	BAKKEN JP [15]	Bradley University, Peoria, United States	9	15	1.29	231	20	2016
7	CHEN NS [20]	National Sun Yat-sen University, Kaohsiung, Taiwan	5	6	0.5	226	6	2013
8	ESPERTO F [19]	Campus Bio Medico University of Rome, Rome, Italy	4	4	1.33	226	4	2020
9	KINSHUK K [20]	Athabasca University, Athabasca, Canada	6	14	0.6	221	15	2013
10	SPECTOR JM [16]	University of North Texas, Texas, United States	3	4	0.33	220	4	2014

Notes: *TC is Total Citation, **NP is Number of Production, ***PY start is Production Year start.

Trend topics. According to the author's keywords, the trending topics were analyzed by setting the parameter to 1986–2022, a minimum word frequency of 10, and a number of words per year of 3. Figure 5 shows the topic trends from 2014–2022, which can be noticed from the size of the blue circles indicating the frequency of the topics appearing in the articles. If the circles are big, it means the topics frequently appear in the articles. The most common topics were Smart Education, Smart Learning, Smart Learning Environment, E-Learning, Artificial Intelligence, Internet of Things, Machine Learning, Education, Mobile Learning, and Augmented Reality. Between 2014 and 2022, smart education was the most popular topic from 2018 to 2021 and most mentioned in 2020. From this graph, the artificial intelligence topic started gaining attention from 2020 to the present, and the COVID-19 topic began to gain attention from 2021 to the present. Currently, they had continued to be more well known.

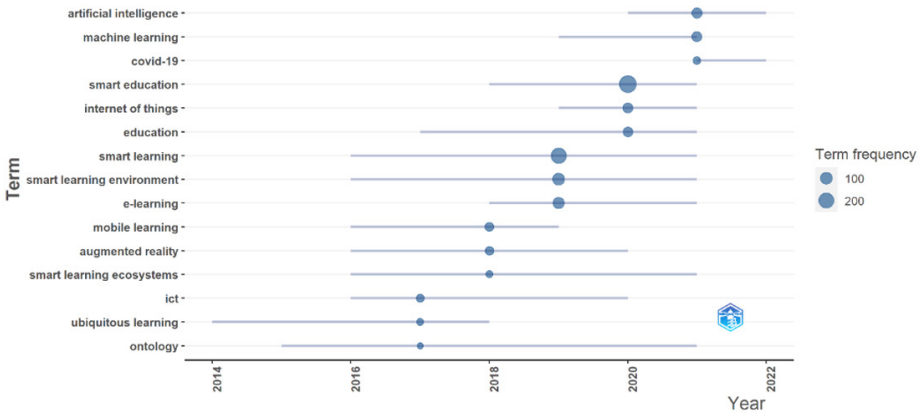

Fig. 5. Trend topics from 2014–2022

Thematic map. Figure 6 shows an analysis of the thematic map by clustering based on the authors' keywords. The thematic map is divided into four parts (Q1 to Q4): motor themes, niche themes, emerging or declining themes, and basic themes. The horizontal axis is the development degree (density), and the vertical axis is the relevance degree (centrality). These two properties measure whether a theme is developed or important. The greater the number of relationships a node has with other nodes in the thematic network, the more centrality and the higher the importance. Node is in an important position in the network [10], and this section presents the motor theme data. The analysis shows that the top 3 topics are Smart Education, Artificial Intelligence, and Internet of Things. The development degree (density) between Q1 and Q4 lies on the horizontal axis, so it can be interpreted that the theme will be developed further and remain the dominant topic in this research field. They are basic knowledge for topics such as Smart Learning, Smart Learning Environment, and E-Learning shown in Q4. It also shows the other top 3 topics, namely Blended Learning, Online Learning, and Technology Enhanced Learning, which are on the vertical axis as relevance degree (centrality). It can be interpreted that the themes will be developed more and become specific topics in this research field related to smart learning content linked to each other.

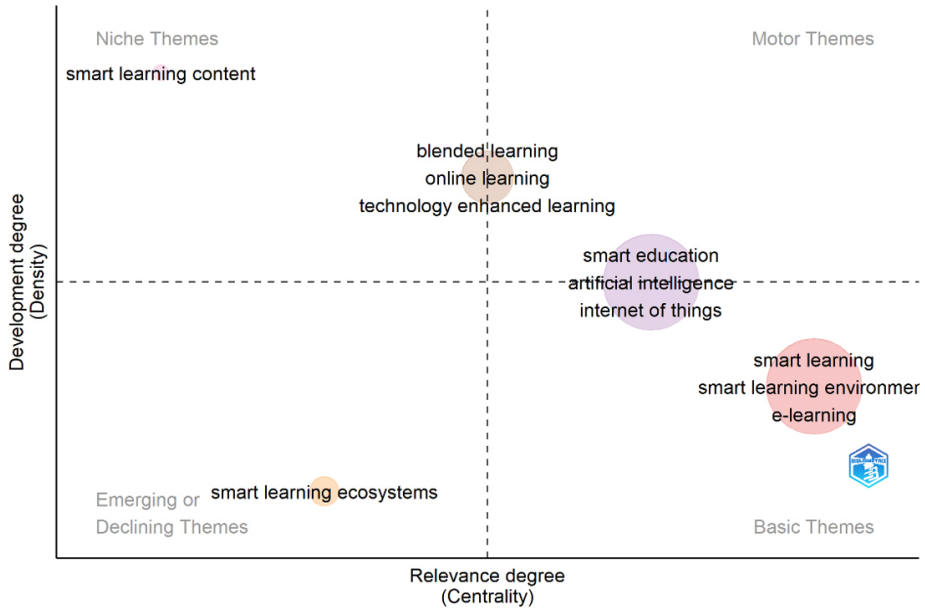

Fig. 6. Thematic map

Factorial Analysis. Abstracts with bigrams characterize multiple correspondence analysis (MCA), which displays a research field that is organized into two clusters. Figure 7 shows the MCA of high-frequency abstracts is those that are closer to the center of the graph. The most words attention in this study. However, the words that are distributed closely area contain similar linked concepts. The first cluster is on the left side of the x-axis (the red cluster) and contains words about the concepts of nature Switzerland, smart city, artificial intelligence, cloud computing, and educational process. And other words in this cluster study are smart education, machine learning, education system, information technology, smart pedagogy, etc. The next second cluster is the right side of the x-axis (the blue cluster). There are three words including exclusive license, nature Singapore, Singapore pte ltd (private limited company).

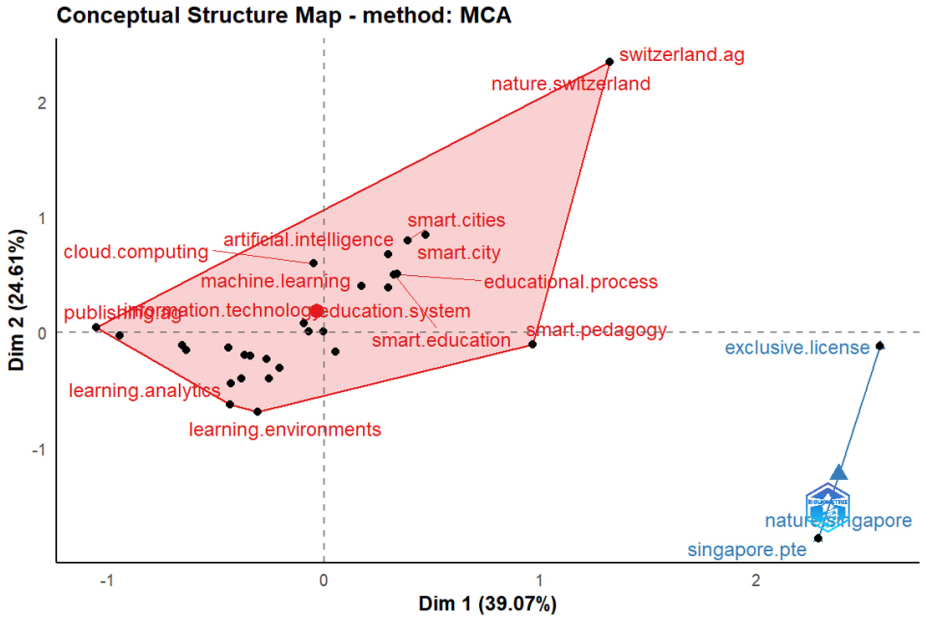

Fig. 7. Multiple correspondence analysis of high-frequency abstract

3.3 Structure of smart education research

Co-citation analysis of sources and documents. This section analyzed a network of publications that co-citations. There were 118 out of 24,239 sources, with at least 20 citations determined according to the available criteria. From Figure 8, six clusters were created from the co-citation analysis of these 118 sources. The first cluster (39 sources) is the largest, such as Smart Learning Environments, IEEE Access, Sustainability. The second cluster (37 sources) is the second largest, such as Computers & Education, Computers in Human Behavior, and British Journal of Educational Technology. The third cluster (19 sources) is Future Generation Computer System, Sustainable Cities and Society, and IEEE Internet of things Journal. For example, Interactive Learning Environments, the International Journal of Artificial Intelligence in Education, and the International Journal of Mobile and Blended Learning are part of the fourth group of 18 sources. The fifth cluster (3 sources) is Nature, Physical Review Letters, and Science. The sixth cluster (2 sources) is Computer Assisted Language Learning and ReCALL.

From the analysis, there were six outstanding journals with total link strength > 2200 and Citations ≥ 150, namely Computers & Education (TLS=5952, Citations=376), Smart Learning Environments (TLS=5383, Citations=460), IEEE. Access (TLS=4381, Citations=326), Computers in Human Behavior (TLS=2921, Citations=232), Sustainability (TLS=2297, Citations=204) and British Journal of Educational Technology (TLS=2234, Citations=150).

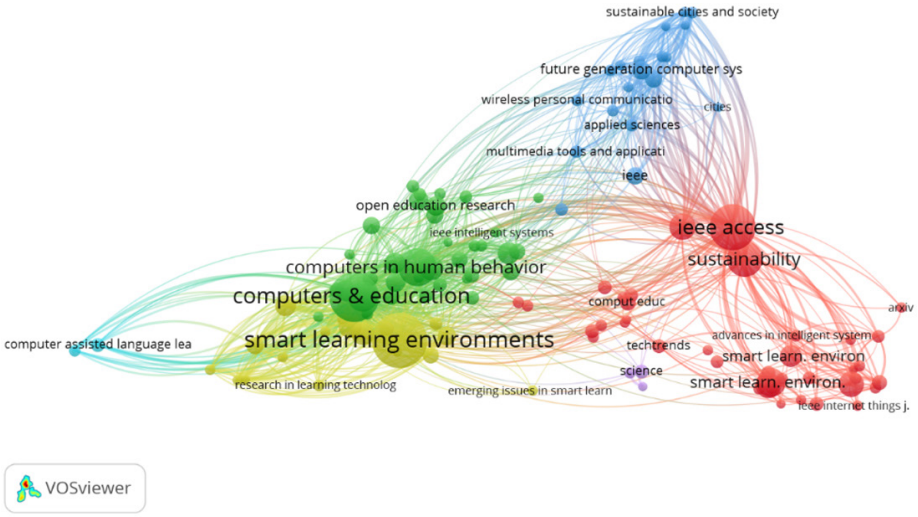

Fig. 8. Co-citation network of sources

Bibliographic Coupling among authors writing on Smart Education Research. Bibliographic coupling is a bibliometric technique that uses citation analysis to establish a meaningful relationship between documents [24]. Coupling is measured by the number of co-citations. The strength of the relationship will increase as a document or article gets more citations. It presents the similarity of the content of the two works in terms of document, source, author, organization, and country [25]. Figures 9 and 10 show two types of bibliographic network formation using author and document names for analysis.

Figure 9 shows the results network with 91 authors with the highest number of contributions. There are 11 clusters with 1,853 Links. The total link strength among these 11 clusters is 23,867. The first cluster located on node 1 (the red node in the center of the network) has 19 authors, with Ronghuai Huang [21] as the most prominent (Links=73, TLS=954, Document=21). The second cluster (the green node on the left of the network) has 15 authors, with Linda Daniela [26] as the most prominent (Links=53, TLS=200, Document=8). The third cluster (the blue node on the right of the network) has 12 authors, with Miguel L. Bote-Lorenzo [27] as the most prominent (Links=60, TLS=2029, Document=14). The fourth cluster (the yellow node at the bottom of the network) has nine authors, with Heui Seok Lim [28] as the most prominent (Links=14, TLS=243, Document=6). The fifth cluster (the purple node on the bottom of the network) has 9 authors with Chen, Xieling [11] as the most prominent (Links=70, TLS=920, Document=8). The sixth cluster (the light blue node at the top of the network) has six authors, with Vladimir L. Uskov [15] as the most prominent (Links=58, TLS=1951, Document=21). The seventh cluster (the orange node on the right of the network) has five authors, with Peter Brusilovsky [29] as the most prominent (Links=22, TLS=133, Document=7). The eighth cluster (the brown node in the middle of the network) has five authors, with Solomon S. Oyelere [10] as the most prominent (Links=75, TLS=1320, Document=10). The ninth cluster (the light purple

node on the right of the network) has five authors, with Rafael Molina-Carmona [30] as the most prominent (Links=48, TLS=731, Document=9). The tenth cluster (the pink node on the bottom of the network) has four authors, with Carlo Giovannella [31] as the most prominent (Links=18, TLS=137, Document=17). The last cluster (the light green node in the middle of the network) has two authors with the same value (Links=50, TLS=316, Document=5).

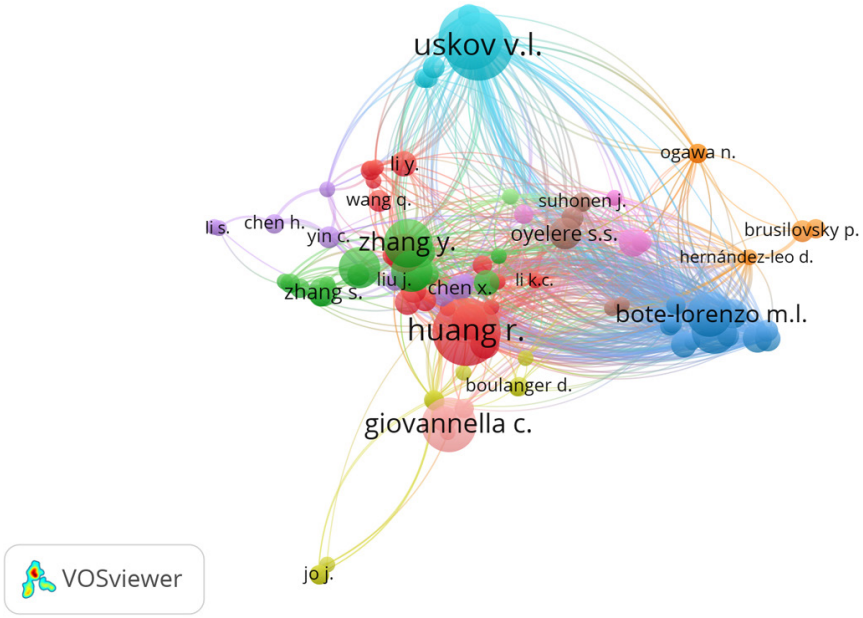

Fig. 9. Bibliographic author coupling

In addition, for the bibliometric network analysis with the top 100 papers with the highest link strength, each paper must contain at least ten citations from 1,580 publications. Figure 10 shows a network of 9 clusters with a link strength of 736 and a total link strength of 1,105. The first cluster is the largest (the red node at the bottom of the network) and has the highest link strength, 17 items [1] were the most prominent in this cluster (Links=49, TLS=91, Citations=268), which presented the research framework of smart education. The second cluster (the green node on the right of the network) had the second-highest link strength. There were 16 items [32] most prominent in this cluster (Links=18, TLS=25, Citations=49), which is the study of the bibliometric perspective of the learning analytics research landscape. The third cluster (the blue node on the network's right) had the third-highest link strength. There were 15 items [33] most prominent in this cluster (Links=19, TLS=39, Citations=15)) which is the study of factors affecting smart learning adoption in the workplace by comparing large to small organizations.

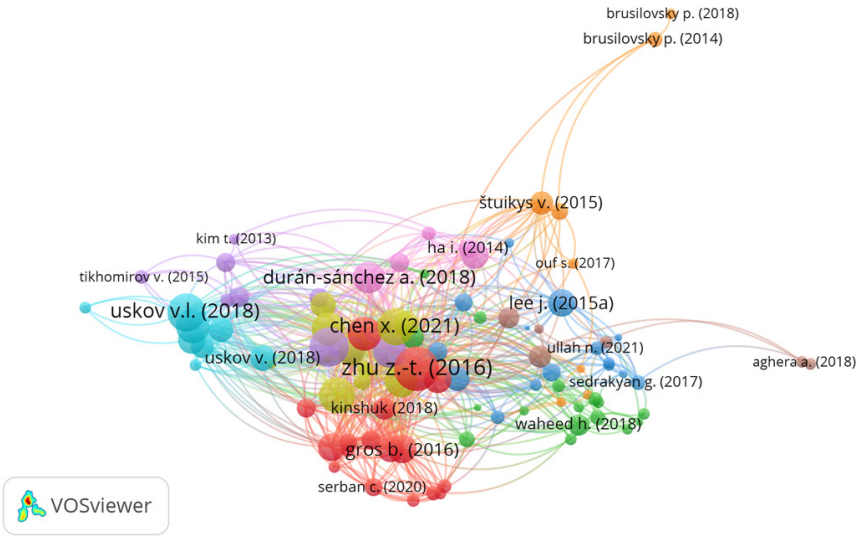

Fig. 10. Bibliographic document coupling of top 100 document

Smart Education publications structure. This section uses co-authorship analysis in smart education. The collaborations are among 297 authors when considering 1,000 authors. Figure 11 shows a total of 21 clusters. The researcher presents only 10 clusters, and the first cluster is the largest, with 24 authors. The main author in this cluster is Limin Zhang [34] (Links=31, TLS=31, Citations=126), who focused on technology education in smart education. The second cluster has 24 authors. The main author in this cluster is Yuchen Zhang [35] (Links=21, TLS=27 Citations=68), who focused on topic themes related to the teaching of teachers from primary to higher education. There are 19 authors in the third cluster. The main author in this cluster is Huanan [36] (Links=13, TLS=17 Citations=16), who focused on online education. There are 19 authors in the fourth cluster (Links=26, TLS=27 Citations=61). There are 17 authors in the fifth cluster (Links=25, TLS=26 Citations=141). There are 17 authors in the sixth cluster (Links=14, TLS=18 Citations=25). There are 17 authors in the seventh cluster (Links=17, TLS=41 Citations=190). The most prominent author is Ronghuai Huang [37]. The eighth cluster has 16 authors (links = 10, TLS = 13, citations = 4). There are 15 authors in the ninth cluster (Links=23, TLS=39 Citations=126). The most prominent author is Solomon S. Oyelere [10]. There are 12 authors in the tenth cluster (Links=29, TLS=32 Citations=107). Dan Wang [38] focused on education through knowledge graph analysis.

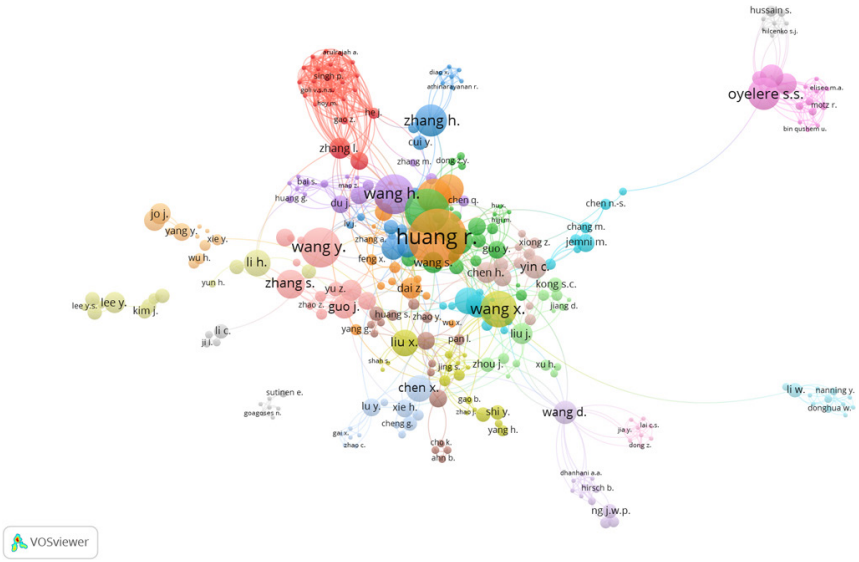

Fig. 11. Smart education publications structure in map view

Figure 12 shows a network of international cooperation. The analytical results can be divided into 6 clusters by using the top 40 with the highest link strength. Each country must have at least ten citations out of a total of 108 countries around the world. It was found that the largest cluster (the red node at the top of the network) has 13 countries. Turkey is the most prominent country in this cluster (Links=22, TLS=34, Citations=161, Documents=23). The next cluster (the green node at the bottom of the network) has seven countries. Spain is the most prominent country in this cluster (Links=18, TLS=45, Citations=601, Documents=84). The third cluster (the blue node on the right of the network) has six countries in it. India is the most prominent in this cluster (Links=21, TLS=44, Citations=864, Documents=144). The fourth cluster (the yellow node in the middle of the network) has five countries. United States is the most prominent in this cluster (Links=27, TLS=107, Citations=1521, Documents=145). The fifth (the purple node on the right side of the network) has five countries. Canada is the most prominent in this cluster (Links=20, TLS=46, Citations=46, Documents=37). There are four countries for the last cluster (blue bottom node of the network). China is the most prominent in this cluster and has the highest international cooperation among all clusters (Links=26, TLS=114, Citations=1611, Documents=347).

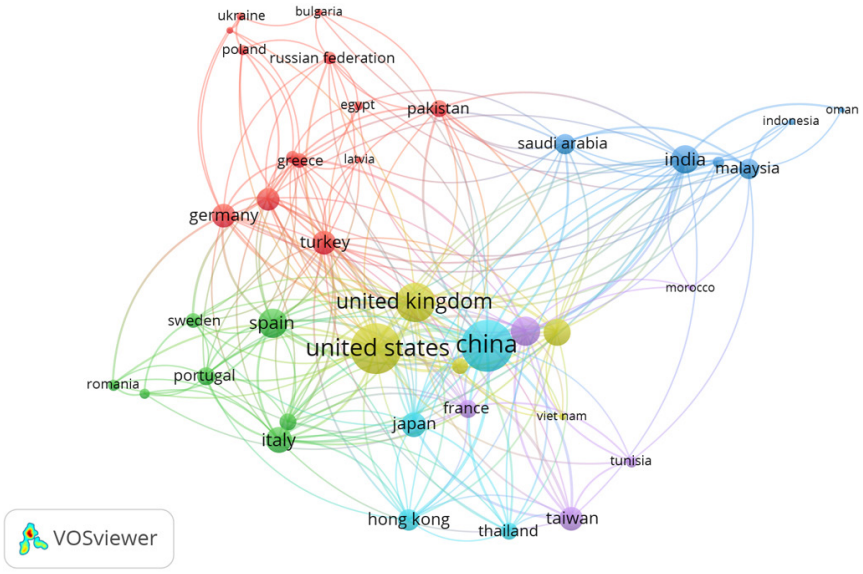

Fig. 12. Country collaboration map of smart education publications

Figure 13 shows the inter-institutional cooperation network, divided into four top 35 clusters with the highest link strength. Each institution must have at least one citation. From 2,751 institutions, it was found that the largest cluster (the red node) has 15 institutions (Links=20, TLS=20, Citations=15, Documents=1). The second cluster has nine institutions (the green node). The European Society of Residents in Urology (ESRU), Arnherm, Netherlands, and the Department of Experimental and Clinical Medicine, University of Florence, Florence, Italy (Links=31, TLS=34, Citations=174, Documents=3) are two of the most prominent. The third cluster (the blue node) has six institutions: the Departments of Urology from 5 countries: United Kingdom, Germany, Italy, France, Spain by Italy, France and Spain (Links=23, TLS=25, Citations=67, Documents=2). The last cluster (the yellow node) had five institutions. The Department of Urology, Careggi Hospital, University of Florence, Florence, Italy, are the most prominent in this cluster (Links=24, TLS=26, Citations=27, Documents=2).

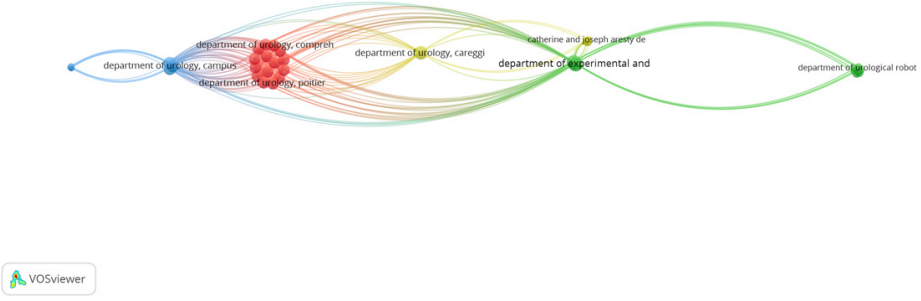

Fig. 13. Collaboration network of institutions

4 Conclusions

This article analyzes the publications of 1,661 international journals published in indexed journals in the Scopus database. They are the research related to smart education published from past to present (1986–2022). Using the biblioshiny package in the R-Studio program, the quantitative data analysis technique was applied to study the knowledge structure, characteristics, and research trends of smart education research. This study found that publications had the most citations in 1989. The most significant number of citations per article was 40, with an average of 1.21 per year in smart education. The most influential article was on Definition, framework, and research issues of smart learning environments – a context-aware ubiquitous learning perspective by Hwang, G.J. [14] with 293 citations, average citation per year of 32.56, and he is also the most influential author. Vladimir L. Uskov has the highest number of published papers, with 21 papers and the highest h-index of 9. In addition, the most published journal is Smart Innovation, Systems, and Technologies, with 127 articles. In 2021, the most published year was 296 out of 1,580 articles, likely increasing the attention in smart education research publications. The most common research topics are Smart Education, Smart Learning, Smart Learning Environment, E-Learning, Artificial Intelligence, Internet of Things, Machine Learning, Education, Mobile Learning and Augmented Reality. There are three important topics, namely Artificial Intelligence, Machine Learning and COVID-19 which have still received attention until today and likely to increase more and more. In addition, the researcher created a network map by using the VOSviewer program to analyze and display the knowledge structure by analyzing the network of publications with the most co-citations among the journals, authors, and papers. The documents with the most co-author citations belong to Vladimir L. Uskov (Links=58, TLS=1951, Document=21, Citations=234), Ronghuai Huang (Links=73, TLS=954, Document=21, Citations=190) and Jeffrey P. Bakken (Links=56, TLS=2012, Document=20, Citations=231). The top three journals with the most co-citations were Computers & Education (TLS=5952, Citations=376), Smart Learning Environments (TLS=5383, Citations=460), and IEEE Access (TLS=4381, Citations=326). The top three countries with the most international cooperation are China (Links=26, TLS=114, Citations=1611, Documents=347), the United States (Links=27, TLS=107, Citations=1521, Documents=145), and the United Kingdom (Links=26, TLS=73, Citations=757, Documents=60). The two institutions that collaborated the most on the research are the European Society of Residents in Urology (ESRU), Arnherm, Netherlands, and the Department of Experimental and Clinical Medicine, University of Florence, Florence, Italy (Links=31, TLS=34, Citations= 174, Documents=3).

This article presents a global research overview of smart education through detailed bibliometric analysis, which provides suggestions for researchers and educational practitioners and explains the situation of knowledge or knowledge structure, characteristics, and global research trends of smart education research, that has been accepted for publication from the past to the present. However, only bibliographic data from an internationally accepted database was analyzed. Hence, the researcher did not analyze the contents of those articles.

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