IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received 13 December 2023, accepted 7 January 2024, date of publication 15 January 2024, date of current version 12 February 2024.

Digital Object Identifier 10.1109/ACCESS.2024.3354719

SURVEY

Visualization Analysis of Smart Classroom Research Based on CiteSpace

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ABSTRACT As technology continues to advance, the process of educational informationization is steadily progressing. This has made research on smart classrooms increasingly mainstream. However, understanding evolving trends in this field remains a complex challenge. This study explored the current status and future directions of smart classroom research. We conducted a visualization analysis using the CiteSpace software. First, we retrieved the research literature related to smart classrooms from the Web of Science Core Collection from 1990 to 2023. We then performed descriptive and visualization scientometric analyses, including the construction of co-citation, collaboration, and co-occurrence networks. From the co-citation network, we identified prominent journals, authors, and core literature on smart classroom research. Collaboration network analysis highlighted the patterns among researchers, institutions, and international collaborations. The co-occurrence network revealed the main categories and directions of research. By integrating descriptive and visualization-based scientometric methods, we delineate the developmental stages of smart classroom research, discuss current hot topics, and suggested future research avenues.

INDEX TERMS Smart classroom, visualization, CiteSpace.

I. INTRODUCTION

Advancements in science, technology, and educational paradigms have underscored the importance of smart classroom development. Despite the limited impact of information technology in education, the COVID-19 pandemic has accelerated the need for distance learning and technologically equipped classrooms [1]. Furthermore, the shift towards student-centered education necessitates the transformation of traditional classrooms [2].

Smart classrooms represent the convergence of intelligent learning environments utilizing the Internet of Things, cloud computing, and intelligent systems [3]. They blend physical and digital spaces to enhance instructional content delivery, resource accessibility, and interactive experiences. In addition, they have integrated situational awareness and environmental management.

The concept of a smart planet has spurred research on smart classroom design and technology. For example, Niemeyer's 'Hard Facts on Smart Classroom Design: Ideas, Guidelines, and Layouts' introduced different design schemes for smart classroom spaces [4], whereas Zhan [5] summarized the spatial layouts of existing smart classrooms. A notable difference from traditional classrooms is the seating arrangement in smart classrooms [6]. With the current emphasis on the Internet of Things, this technology is being applied to control different devices and systems in classrooms [7], [8]. In addition, ambient intelligence technology is used to enhance the environmental awareness of smart classrooms [9]. The incorporation of artificial intelligence and machine learning into the construction of smart classrooms enables the recognition of teacher and student behaviors, thereby facilitating the collection of instructional data [10].

Despite extensive research, understanding the trends in this field remains challenging. Kaur and Bhatia [11] analyzed smart classroom research using the Visualization of Similarities (VOS) viewer to summarize the research landscape and knowledge structure. Saini [3] also conducted an analysis of smart classroom research, categorizing the research through content analysis. Furthermore, some studies provide

The associate editor coordinating the review of this manuscript and approving it for publication was Laxmisha Rai.

TABLE 1. Retrieval strategies.

Criteria	Options
Databases	Science Citation Index Expanded (SCI-EXPANDED), Social Science Citation Index (SSCI), Arts & Humanities Citation Index (AHCI), Conference Proceedings Citation Index – Science (CPCI-S), Conference Proceedings Citation Index – Social Science & Humanities (CPCI-SSH), Emerging Sources Citation Index (ESCI), Index Chemicus (IC), Current Chemical Reactions (CCR-EXPANDED)
Search Terms	Smart classroom, intelligent classroom, future classroom, Technology enhanced classroom, Smart learning environment, intelligent learning environment, Smart learning space, intelligent learning space
Search Fields	title, abstract, or keywords
Other Limiting Criteria	publication date: 1990-01-01 to 2023-05-31
	document type: proceeding paper, article, or early access
	language: English

an overview of various aspects, such as the application of AI technologies in smart classrooms and the analysis of student attention [12], [13].

Since its introduction, CiteSpace has been widely used in various disciplines, including ecology and medicine [14], [15]. It has also been applied to the field of smart classroom research. Several scholars, such as Bai et al. [16] and Li and Zhang [17], have used CiteSpace to summarize the research on smart classrooms. However, these studies have primarily focused on analyzing research data from the China National Knowledge Infrastructure (CNKI) database. Owing to the certain requirements and limitations inherent in CiteSpace for data analysis, these studies may not fully exploit the functionality of the tool.

In this study, we used CiteSpace to analyze the literature on smart classrooms from the Web of Science Core Collection (WOS Core Collection). Our aim is to trace the history of development, identify research hotspots, and project future research directions in the field of smart classroom research. Through a systematic and in-depth analysis, this study aims to provide a comprehensive overview for researchers, educators, and policymakers, thereby promoting the development of smart classrooms and offering references for relevant policies and practices.

The next section will present the data sources and specific analytical methods used in this study. Section III presents a descriptive analysis of smart classroom research, detailing aspects such as the authors of publications and annual publication volume. Section IV presents a visualization scientometric analysis based on CiteSpace, covering co-citation networks, co-occurrence networks, and so on. Section V discusses the findings based on descriptive statistics and a visualization analysis. Finally, Section VI concludes the paper.

II. DATA SOURCE AND RESEARCH METHODS

A. DATA SOURCE

Utilizing CiteSpace for bibliometric analysis requires high-quality data. Established in 1964, the Web of Science is among the most authoritative databases, and its Web of Science Core Collection serves as a primary reference source for literature research. The data used in this study were retrieved from the WOS Core Collection. The following retrieval strategy was employed:

The WOS Core Collection includes various databases. The databases used in this research include the Science Citation Index Expanded (SCI-EXPANDED), Social Science Citation Index (SSCI), the Arts & Humanities Citation Index (AHCI), and etc. Using search terms such as ‘smart classroom’, ‘intelligent classroom’ and ‘future classroom,’ the search was carried out in the titles (TI), abstracts (AB) or keywords (AK) of the literature. Other limiting criteria for the retrieval of literature in this study included document type, language, and publication date. Specific retrieval strategies are presented in Table 1. The search date was 2023-06-05.

A total of 875 articles were identified. Two researchers analyzed the retrieved data to ensure the quality of the analysis. They identified literature related to smart classrooms by reading abstracts or full-texts articles. After two rounds of selection, 738 pieces of literature data were ultimately selected. These 738 papers were exported with the full content of their records to a plain text file in accordance with the requirements of CiteSpace.

B. RESEARCH METHODS AND FRAMEWORK

This study employs CiteSpace for a bibliometric analysis of smart classroom research literature. Developed by Professor Chen in 2004 [18], CiteSpace evolved through updates to provide functionalities, such as collaboration and co-occurrence analysis. It uniquely visualizes connections in the literature and offers insights into collaborative networks and trends in various research fields. In this study, CiteSpace 6.1. R6 Advanced was used to visualize and map the knowledge domain of smart classroom articles. The framework of this study is shown in Figure 1. The specific steps are as follows.

First, according to the retrieval strategy mentioned above, relevant studies on smart classrooms were collected from the

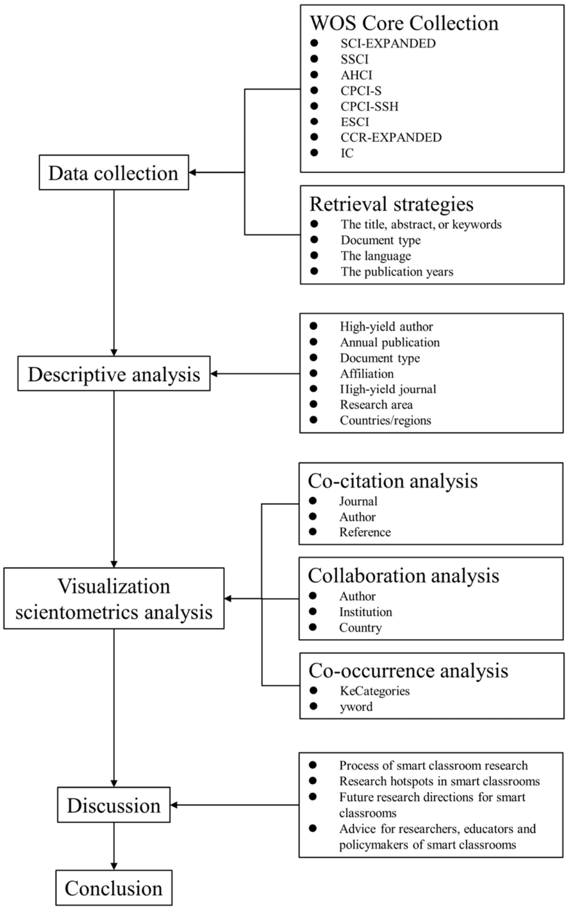


FIGURE 1. Research framework.

Web of Science Core Collection in order to create a literature database. This study mainly involved descriptive and visualization scientometric analyses. The descriptive analysis focused on seven aspects: high-yield authors, annual publications, document types, affiliations, high-yield journals, research areas, and countries/regions. Visualization scientometric analysis includes co-citation, collaboration, and co-occurrence network analysss. These studies explore the relationships among journals, authors, institutions, and countries, as well as literature categories and keywords. Based on the results, we discuss the development, current hotspots, and future directions of smart classroom research. Finally, the conclusions and limitations of this study are presented.

C. DATA PROCESSING

Scientometric analysis was performed using CiteSpace 6.1. R6 Advanced, including co-citation, collaboration, and co-occurrence analyses. The parameter settings in CiteSpace were set as follows: (i) based on the time span of the 738 retrieved literature, the timespan in CiteSpace was set from January 1990 to June 2023; and (ii) for the term source, the title, abstract, author keyword, and keyword plus were chosen for analysis. (iii) CiteSpace performs analysis based on different node selections. The nodes for the analysis of the collaboration network included the authors, institutions, and countries. The nodes for the co-occurrence network analysis included keywords, subject terms, and categories. The nodes for the co-citation network analysis include references, cited authors, and cited journals. In CiteSpace, the subject terms are primarily noun phrases from literature titles, abstracts, and keywords. Compared with keywords, subject terms cover a wider range of content. However, because keywords are more indicative of the main focus of the literature, this study only selected co-occurrence network analysis based on keywords. Node type included author, institution, country, keyword, category, reference, cited author, and cited journal; (iv) for the selection criteria, top N, we selected the top 50 levels of most cited or occurred items from each time slice; and (v) pruning methods, including minimum spanning tree (MST) and pruning sliced networks. The other settings were maintained at default. Figure 2 shows the parameter setting of the co-occurrence network of the keywords as an example.

III. DESCRIPTIVE ANALYSIS

A. HIGH-YIELD AUTHOR

Table 2 shows the top ten high-yield authors in smart classroom research. Aguilar leads with 14 papers, followed by Antona with 11 papers. Among them, five are from Greece, three of whom are affiliated with the Foundation for Research and Technology, Hellas, suggesting potential collaboration. Specific author-collaborating relationships will be elaborated later. The other five authors comprise three from China and one each from Mexico and Venezuela.

B. ANNUAL PUBLICATION

Figure 3 presents the annual publication trend in smart classroom research between 1990 and June 2023, which generally shows an upward trend. Based on this data, the development of smart classrooms can be roughly divided into three periods. From 1990 to 2001, publications were limited, with no more than five articles per year. A gradual increase began in 2002, with a modest growth rate, yielding an average of 15.79 publications per year until 2015. Since 2016, the annual number of publications has consistently exceeded 50, peaking at 92 publications in 2022.

C. DOCUMENT TYPE

Table 3 details the type of document in the collected data. There are 437 proceeding papers, 279 articles, and 22 early access papers. Proceeding papers make up about 60% of the total, with 13 of these presented at the International Conference on Smart Learning Environments (ICSLE).

D. AFFILIATION

Table 4 lists the top five affiliations contributing to the 738 papers on smart classroom research. Central China Normal University leads with 54 publications, the highest among these institutions. Among these institutions, three are from

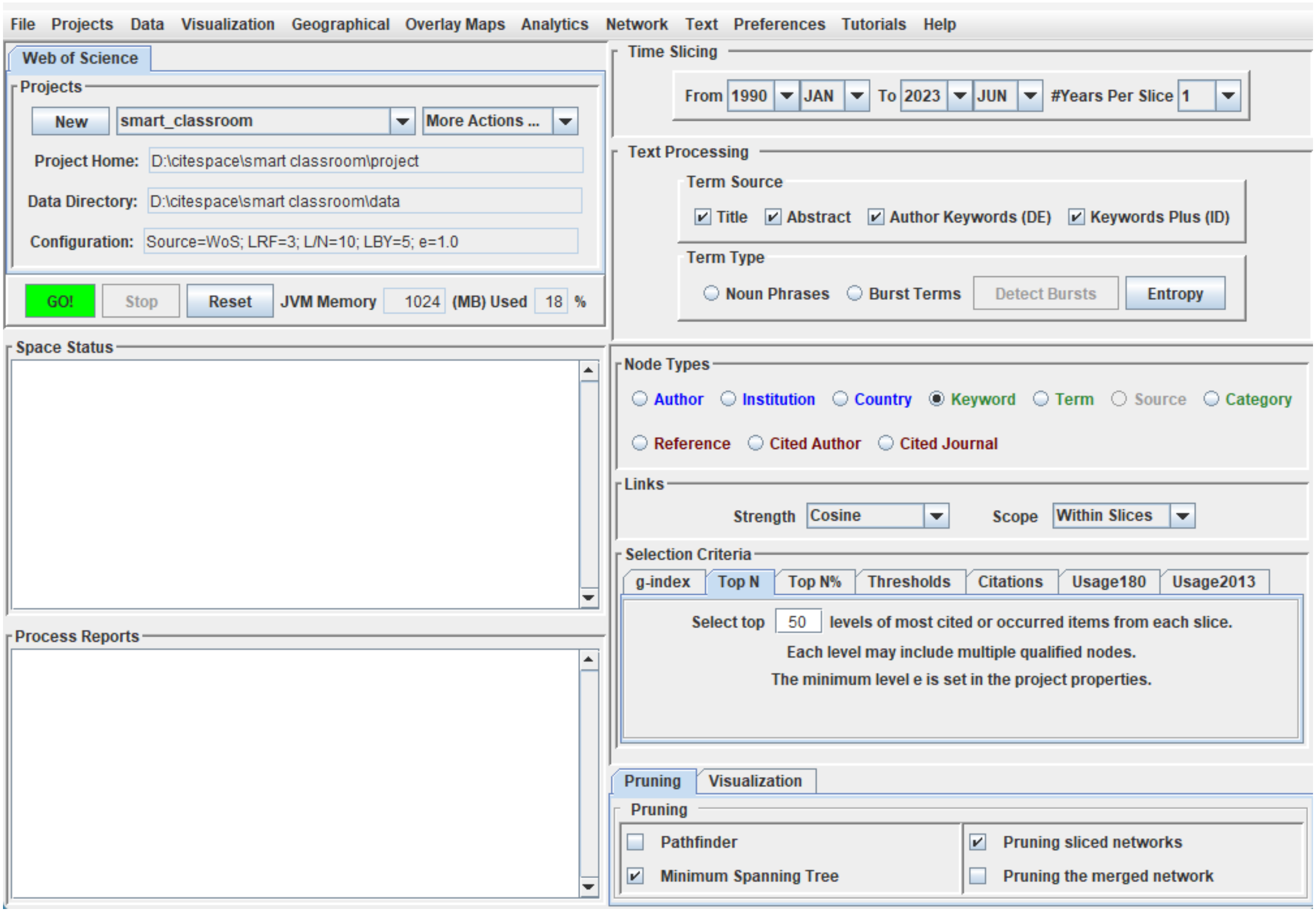


FIGURE 2. Setting of the CiteSpace software parameters (example: keyword co-occurrence).

TABLE 2. High-yield authors in the field of smart classroom.

Name	Country/region	Affiliation	Count
Jose Aguilar	Venezuela	Universidad de Los Andes	14
Margherita Antona	Greece	Foundation for Research and Technology - Hellas	11
Harrison Hao Yang	China	Central China Normal University	10
Asterios Leonidis	Greece	Foundation for Research and Technology - Hellas	10
Yuanchun Shi	China	Tsinghua University	10
Maria Korozi	Greece	Foundation for Research and Technology - Hellas	9
Guanyou Xu	China	Tsinghua University	9
Maria Lucia Barron Estrada	Mexico	Instituto Tecnológico de Culiacán	8
Maria Virvou	Greece	University Of Peraeus	8
Constantine Stephanidis	Greece	University Of Crete	8

China, while the others are from Venezuela, the United States, and Ecuador.

E. HIGH-YIELD JOURNAL

Table 5 shows the five journals with the highest number of publications. Mobile Information Systems leads with 14 articles, followed by the International Journal of Emerging Technologies in Learning with 13. These journals focus on the innovative development of technology, particularly in the realms of emerging technologies and intelligent systems, indicating a strong link between smart classroom development and technological advancement.

F. RESEARCH AREA

Table 6 presents the top five research areas in smart classroom studies. Among the 738 literature records, 443 were

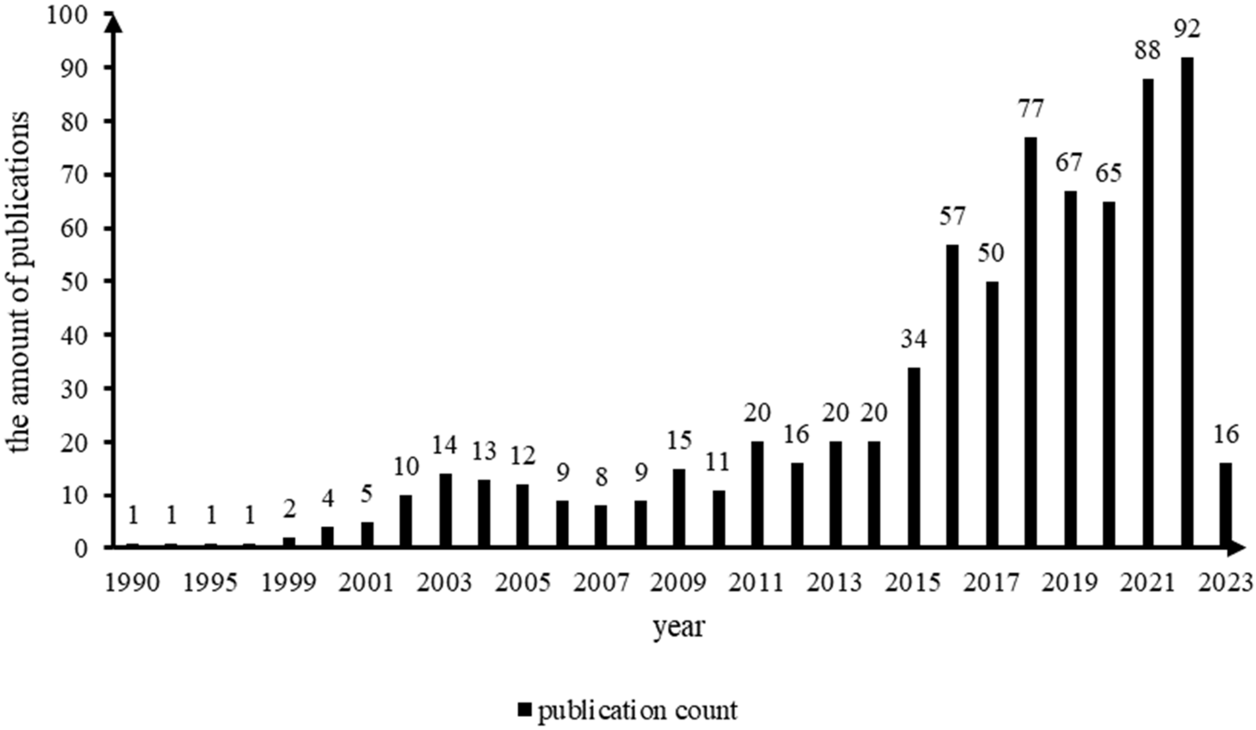


FIGURE 3. Temporal distribution of smart classroom research from 1990-2022.

TABLE 3. Document types of the collected data.

Document Types	Count (%)
Proceeding Paper	437(59.22)
Article	279(37.80)
Early Access	22(2.98)
Total	738

TABLE 4. Top five affiliations with the highest number of publications.

Affiliation	Count
Central China Normal University	54
University of Los Andes Venezuela	19
Beijing Normal University	18
Tsinghua University	17
Bradley University	14
Universidad Tecnica Particular de Loja	14

in computer science, 283 were in education and educational research, and 173 were in engineering. These areas highlight the strong connection between smart classroom research and computer science technology, engineering communication technology, and other related fields.

G. COUNTRIES/REGIONS

Table 7 shows the five countries/regions that led to smart classroom research publications. China was at the forefront of 259 articles, followed by the United States at 73. Geographically, Asia dominates these top countries/regions, contributing 328 articles, including those from China, India, and Taiwan.

TABLE 5. Top five journals with the highest number of publications.

Journal	count
Mobile Information Systems	14
International Journal of Emerging Technologies in Learning	13
IEEE ACCESS	9
Education And Information Technologies	9
Computers & Education	8

IV. VISUALIZATION SCIENTOMETRIC ANALYSIS

A. CO-CITATION ANALYSIS

CiteSpace's co-citation analysis, based on citation frequency within a research field, helps identify influential journals, key academic figures, and pivotal literature in specific knowledge domains [19]. This study intends to perform a co-citation analysis of 738 smart classroom articles, identify influential journals and authors, and explore key literature in this area.

1) JOURNAL CO-CITATION ANALYSIS

A journal co-citation analysis of these articles revealed a network of 2333 nodes and 2769 links, with a density of

TABLE 6. Top five research areas.

Research Area	Count
Computer Science	443
Education & Educational Research	283
Engineering	173
Telecommunications	74
Psychology	24

TABLE 7. Top five countries/regions with the highest number of publications.

Countries/Regions	Count
China	259
USA	73
India	40
Taiwan	38
Greece	31

0.001, as shown in Figure 4. In CiteSpace, the betweenness of centrality and frequency are important indicators for assessing the node significance [20]. Betweenness centrality is a measure that is assigned to each node within a network. This quantifies the likelihood that a given node will traverse the shortest path between any two nodes in the network. Nodes exhibiting high betweenness centrality typically act as bridges that connect large subnetworks or communities, reflecting their intermediary position. In CiteSpace, nodes demonstrating high betweenness centrality are visually indicated by the purple ring surrounding them. The breadth of this purple ring directly represents the extent of a node's betweenness centrality [21], [22]. Table 8 shows the five most-cited journals: Computer & Education, Lecture Notes in Computer Science, Computers in Human Behavior, Educational Technology & Society, British Journal of Educational Technology, and Smart Learning Environment. Computer & Education (0.11) and Lecture Notes in Computer Science (0.15), with betweenness of centrality scores above 0.1, occupy a central position in smart classroom research.

As shown in Table 5, Computer & Education published eight papers on smart classrooms between 1990 and 2023, and received 205 co-citations. This highlights the journal's significant impact in that Computers & Education focus primarily on research related to pedagogical uses of digital technology, suggesting that recent smart classroom research has focused on the application of technology in teaching [23]. Lecture Notes in Computer Science, mainly featuring conference proceedings, are key in computer science and information technology research. Notably, according to Table 3, approximately 60% of smart classroom research papers are conference proceedings, underscoring the importance of international academic conferences in smart classrooms, smart education, and educational informatization for disseminating research.

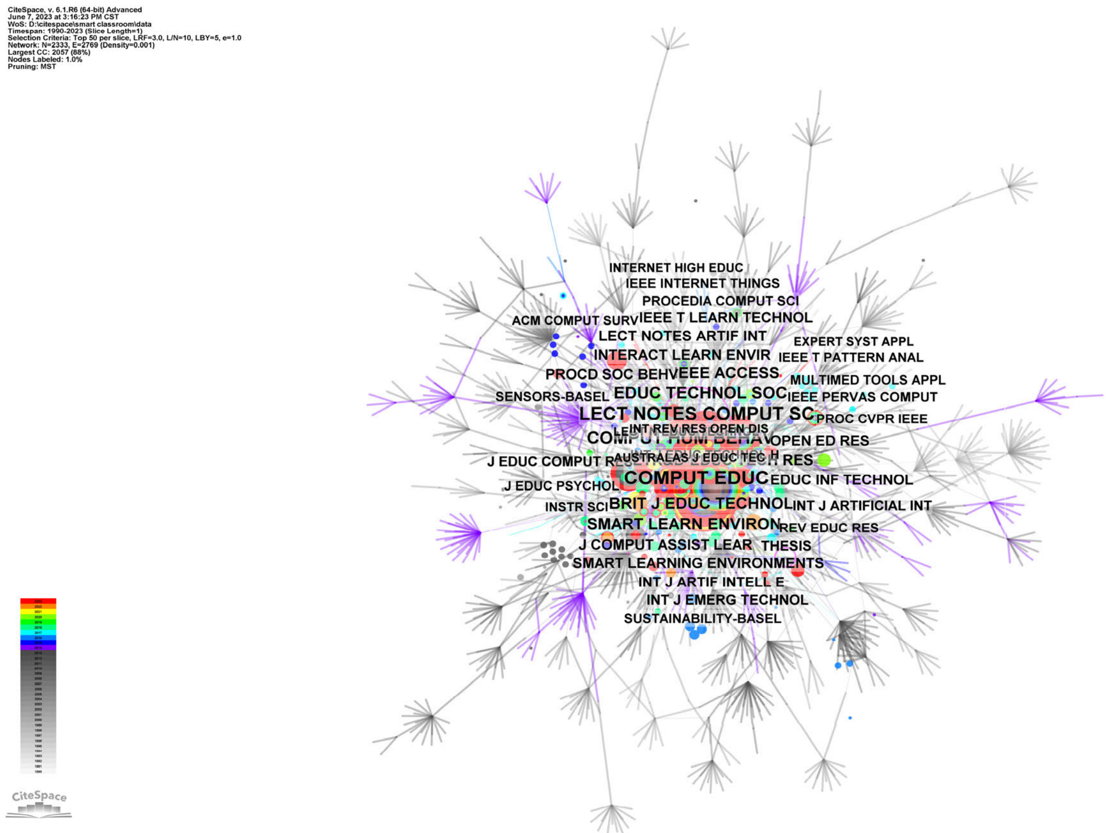
2) AUTHOR CO-CITATION ANALYSIS

To identify influential authors in the field of smart classrooms, author co-citation analysis was conducted on 738 papers, resulting in an author co-citation network, as shown in Figure 5. This network comprises 5307 nodes and 5202 links, with a density of 0.0004. Table 9 presents the top five co-cited authors with the highest betweenness centrality: Brusilovsky (0.13), Brown (0.12), Barab (0.12), AlMalki (0.12), Brewster (0.12), Bray (0.11), and Suo (0.10). Betweenness centrality measures the centrality of a node in a network. Nodes exhibiting high betweenness centrality play a central role in a network [24]. As indicated in Table 9, Brusilovsky's work garnered significant attention from smart classroom researchers, starting in 2004. Peter Brusilovsky, a professor at the School of Computing and Information at the University of Pittsburgh, specializes in areas such as learning technologies, information science, and artificial intelligence, which are crucial for the advancement of smart classrooms. Table 10 lists the five authors with the highest citation frequencies. The most cited author is Spector, whose research articles have been cited 38 times in various smart classroom research papers since 2015. Other highly cited authors included Macleod (38 citations), Shi (36 citations), Hwang (33 citations), and Zhu (30 citations). These authors, with their high citation frequency and betweenness centrality, have played a key role in driving advancements in smart classroom research.

3) REFERENCE CO-CITATION ANALYSIS

Reference co-citation analysis was carried out on 738 research articles on smart classrooms, resulting in a co-citation reference network, as illustrated in Figure 6. This reference co-citation network comprised 4233 nodes and 3188 links, and had a network density of 0.0004. The top five most-cited references were Macleod et al. [25], Zhu et al. [26], Spector [27], Hwang et al. [28], and Saini and Goel [3], reflecting their significant roles in the field of smart classroom research.

The top five most-cited articles played an important role in the development of smart classrooms. The details are listed in Table 11. Macleod [25] discussed a measurement scale for students' preferences towards smart classrooms in higher education, demonstrating the scale's validity and reliability through a survey. He also emphasized the importance of transforming existing classrooms into smart classrooms. Zhu [26] analyzed smart education, defined it, and summarized ten key characteristics of smart learning environments, including location and context awareness. Saini [3] summarized the different software and hardware technologies used in smart classrooms and proposed a framework that includes smart content, smart engagement, smart assessment, and a smart physical environment. Spector [27] used cognitive science, psychology, and emerging technologies to develop a foundational framework for smart learning environments, focusing on design principles that ensure effectiveness, efficiency, engagement, flexibility, adaptively, and reflectiveness. Hwang [28] provided a conceptual definition and



Note: Nodes: Each node corresponds to an academic journal. The size of a node is proportional to the number of times articles from the journal have been co-cited. Lines: These lines represent the co-citation links between journals.

FIGURE 4. Journal co-citation network.

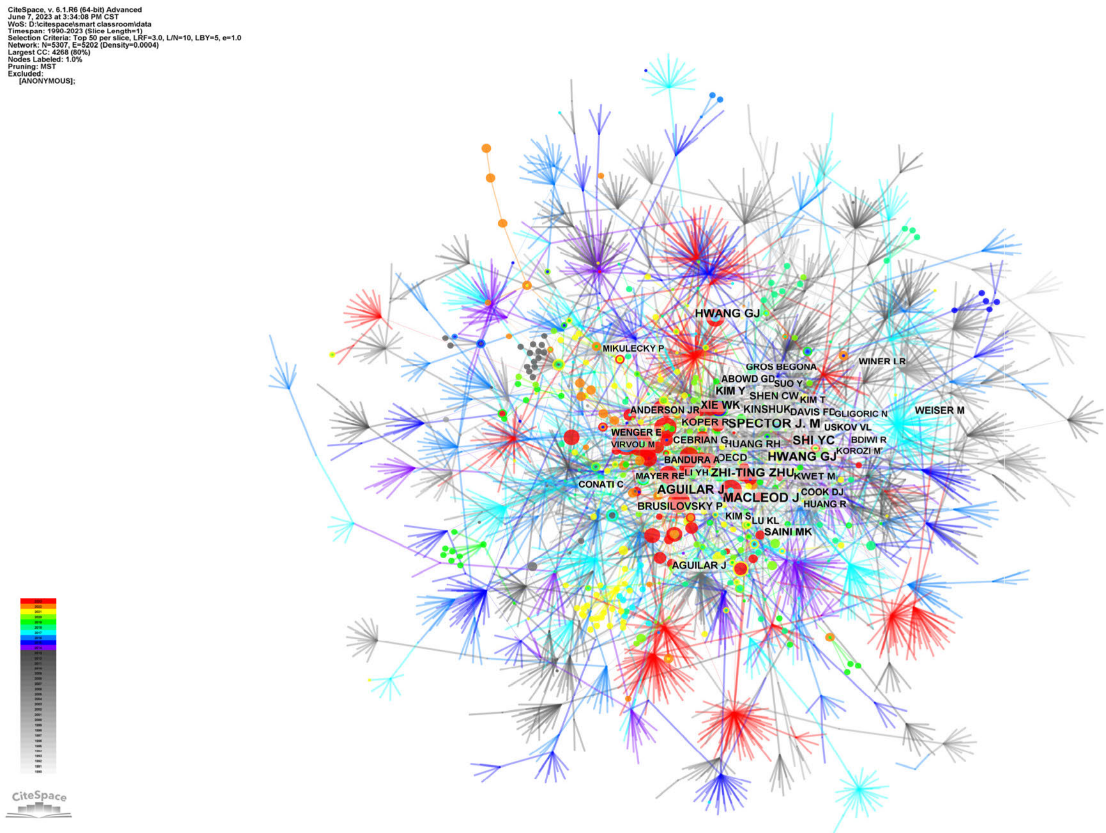
TABLE 8. Top five highly cited journals.

Rank	Count	Centrality	Year	Cited Journal
1	205	0.11	2002	*Computer & Education*
2	168	0.15	2001	*Lecture Notes in Computer Science*
3	120	0.05	2003	*Computers in Human Behavior*
4	96	0.06	2007	*Educational Technology & Society*
5	78	0.05	2009	*British Journal of Educational Technology*

framework for smart learning environments from the perspective of ubiquitous learning based on context awareness, suggesting that they should include seven modules: learning state detection, learning performance assessment, adaptive learning tasks, and others.

In addition to identifying the core literature in the field of smart classrooms through an analysis of highly cited references in the co-citation network, burst detection was used to identify references that experienced a sudden increase in citations between 1990 and 2023. This reflects the key literature on the different periods of smart classroom research, as shown in Figure 7. Among these, 21 references showed burst increases from 1990 to 2023, indicating a significant impact. The top three references with the highest burst strength are Macleod J's "Understanding Students' Preferences Toward the Smart Classroom Learning Environment: Development and Validation of An Instrument," Saini, MK's "How Smart Are Smart Classrooms? A Review of Smart Classroom Technologies," and Zhu Zhi-Ting's "A research framework of smart education." These references also have a high number of citations, underscoring their influence. Additionally, in the early stage of smart classroom research, Shi YC's "The smart classroom: merging technologies for seamless tele-education" was pivotal, discussing smart classrooms from the perspective of distance education, analyzing the importance of such systems, and proposing goals of smart classroom projects [29].

By analyzing key journals, authors, and references in the field of smart classrooms, a deeper understanding of the research can be gained. Through CiteSpace analysis of co-cited journals, important academic journals such as



Note: Nodes: Each node represents an author. The size of a node typically correlates with the frequency of the author being co-cited with others, indicating their impact or prominence in the field. Lines: These represent co-citation links.

FIGURE 5. Author co-citation network.

TABLE 9. High centrality cited authors (centrality over 0.1).

Rank	Centrality	Year	Cited Author
1	0.13	2004	Peter Brusilovsky
2	0.12	2002	John Seely Brown
3	0.12	2009	Sasha A. Barab
4	0.12	2023	Hameeda A. AlMalki
5	0.12	2009	Stephen Brewster
6	0.11	2017	Benjamin D Bray
7	0.10	2012	Yue Suo

"Computer & Education" and "Lecture Notes in Computer Science" have been identified. By analyzing co-cited authors and references, key figures such as Brusilovsky and Spector, and significant literature such as Macleod's "Understanding Students' Preferences Toward the Smart Classroom Learning Environment: Development and Validation of An Instrument" have been highlighted.

B. COLLABORATION ANALYSIS

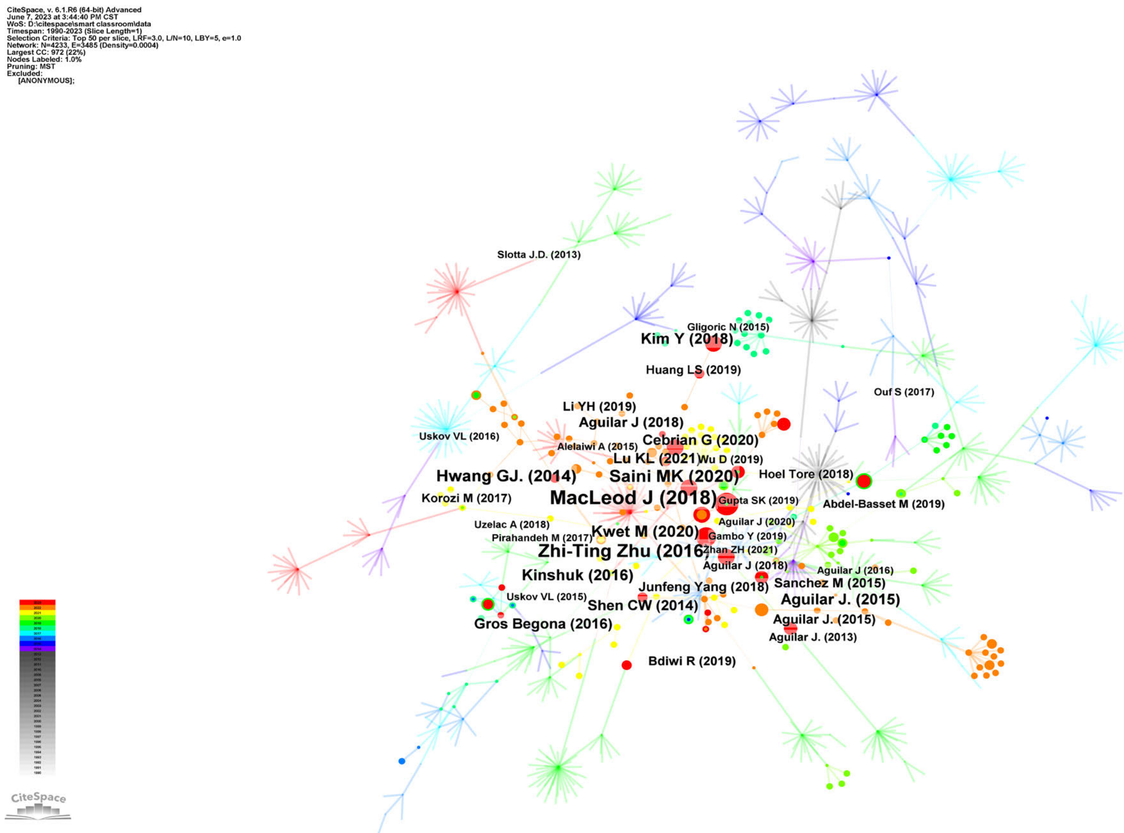
Collaboration network analysis in CiteSpace can be categorized into three dimensions: micro-level author collaboration, meso-level institutional collaboration, and macro-level country collaboration. By examining the diagrams of these collaboration networks, the strength of collaboration among various teams, institutions, or countries within a discipline can be revealed [30]. This analysis also helps to identify key researchers, institutions, or countries that are pivotal to the discipline. In this study, the author collaboration network, institution collaboration network, and country collaboration network were formed to identify the main collaboration teams, institutions, or countries currently active in the field of smart classroom research.

TABLE 10. Top five highly cited authors.

Rank	Frequency	Year	Cited Author
1	38	2015	Jonathan Michael Spector
2	38	2018	Jason MacLeod
3	36	2003	Yuanchun Shi
4	33	2015	Gwo Jen Hwang
5	30	2017	Zhiting Zhu

1) AUTHOR COLLABORATION ANALYSIS

After analyzing the author collaboration among all 738 studies on smart classroom research, the network formed a



Note: Nodes: Each node denotes a research paper. The size of a node corresponds to the frequency with which the paper is cited by others. Lines: These illustrate the co-citation relationships between papers.

FIGURE 6. Reference co-citation network.

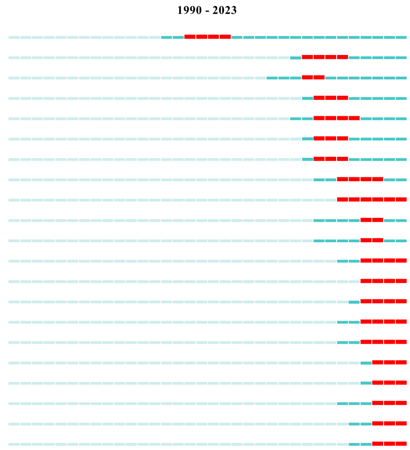
TABLE 11. Top five most cited references.

Rank	Count	Author	Title	Source Title	Year
1	35	Jason MacLeod	Understanding Students' Preferences Toward the Smart Classroom Learning Environment: Development and Validation of An Instrument	*Computers And Education*	2018
2	24	Zhiting Zhu	A Research Framework of Smart Education	*Smart Learning Environments*	2016
3	20	Mukesh Kumar Saini	How Smart Are Smart Classrooms? A Review of Smart Classroom Technologies	*ACM computing surveys*	2019
4	18	Jonathan Michael Spector	Conceptualizing The Emerging Field of Smart Learning Environments	*Smart Learning Environments*	2014
5	17	Gwo Jen Hwang	Definition, Framework and Research Issues of Smart Learning Environment - A Context-Aware Ubiquitous Learning Perspective	*Smart Learning Environments*	2014

graph with 1920 nodes, 1467 links, and a density of 0.0008, as depicted in Figure 8. The size of each node in the network represents the number of publications by the author, whereas the central color of each node represents the year in which the author first published an article in this field [31], [32]. Jose Aguilar was the most prolific author with 14 publications. Owing to the large number of nodes, Figure 8 shows only the top ten collaboration teams.

From the network, it is evident that the Largest Connected Component (largest CC) comprises 204 nodes, which is 10% of the total. The principal collaboration team within this network primarily consists of 23 authors, including Huang,

References	Year	Strength	Begin	End
Shi YC, The smart classroom: merging technologies for seamless tele-education	2003	4.45	2005	2008
Hwang GJ, Definition, framework and research issues of smart learning environments - a context-aware ubiquitous learning perspective	2014	4.39	2015	2018
Mikulecky P, smart environment for smart learning	2012	3.64	2015	2016
Aguilar J, Conceptual design of a smart classroom based on multi-agentsystems	2015	4.88	2016	2018
Spector J. M, Conceptualizing the emerging field of smart learning environments	2014	4.36	2016	2019
Sanchez M, Basic Features of a Reflective Middleware for Intelligent Learning Environment in the Cloud (IECL)	2015	3.64	2016	2018
Aguilar J, A Smart Learning Environment based on Cloud Learning	2015	3.64	2016	2018
Zhi-Ting Zhu, A research framework of smart education	2016	9.18	2018	2021
Kim Y, Towards Emotionally Aware AI Smart Classroom: Current Issues and Directions for Engineering and Education	2018	4.69	2018	2023
Kinshuk, 2016, Evolution Is not enough: Revolutionizing Current Learning Environments to Smart Learning Environments	2016	6.8	2020	2021
Gros Begona, The design of smart educational environments	2016	6.28	2020	2021
MacLeod J, Understanding students' preferences toward the smart classroom learning environment: Development and validation of an instrument	2018	15.71	2020	2023
Saini MK, How Smart Are Smart Classrooms? A Review of Smart Classroom Technologies	2020	9.92	2020	2023
Li YH, Preferences toward the constructivist smart classroom learning environment: examining pre-service teachers' connectedness	2019	3.95	2020	2023
Junfeng Yang, Evaluation of smart classroom from the perspective of infusing technology into pedagogy	2018	3.87	2020	2023
Aguilar J, Learning analytics tasks as services in smart classrooms	2018	3.76	2020	2023
Kwet M, The 'smart' classroom: a new frontier in the age of the smart university	2020	7.81	2021	2023
Cebrian G, The Smart Classroom as a Means to the Development of ESD Methodologies	2020	5.72	2021	2023
Hoel Tore, Standards for smart education – towards a development framework	2018	4.27	2021	2023
Bdiwi R, Smart learning environment: Teacher's role in assessing classroom attention	2019	4.19	2021	2023
Huang LS, A Context Aware Smart Classroom Architecture for Smart Campuses	2019	3.64	2021	2023



Note: Year: publication year of the study. Strength: The burst strength, which quantifies the intensity of the citation increase. Higher values indicate stronger bursts. Begin: The start year of the citation burst, marking when the paper began to gain considerable attention. End: The end year of the citation burst, indicating when the increased citation rate started to decline. Red Segment: Indicates the duration of the citation burst, during which there was a significant increase in the literature. Cyan Segment: Represents the years when the literature does not experience a burst.

FIGURE 7. Top 12 references with the strongest citation burst.

Yang, and Du, who collectively published 33 articles. The low density of the author collaboration network, at 0.0008, coupled with the fact that the largest connected component constitutes only 10% of the total nodes, suggests that author collaboration in the field of smart classroom research is still relatively dispersed.

2) INSTITUTIONAL COLLABORATION ANALYSIS

An analysis of the institutional collaboration network was conducted, resulting in a network comprising 816 nodes and 430 links, with a density of 0.0013. Owing to the large number of nodes, only the top ten institutional collaboration teams are shown in Figure 9. As previously mentioned, the three institutions with the highest number of publications were Central China Normal University (54 publications), the University of Los Andes Venezuela (19 publications) and Beijing Normal University (18 publications). Consequently, these institutions have larger nodes in the institutional collaboration network than others.

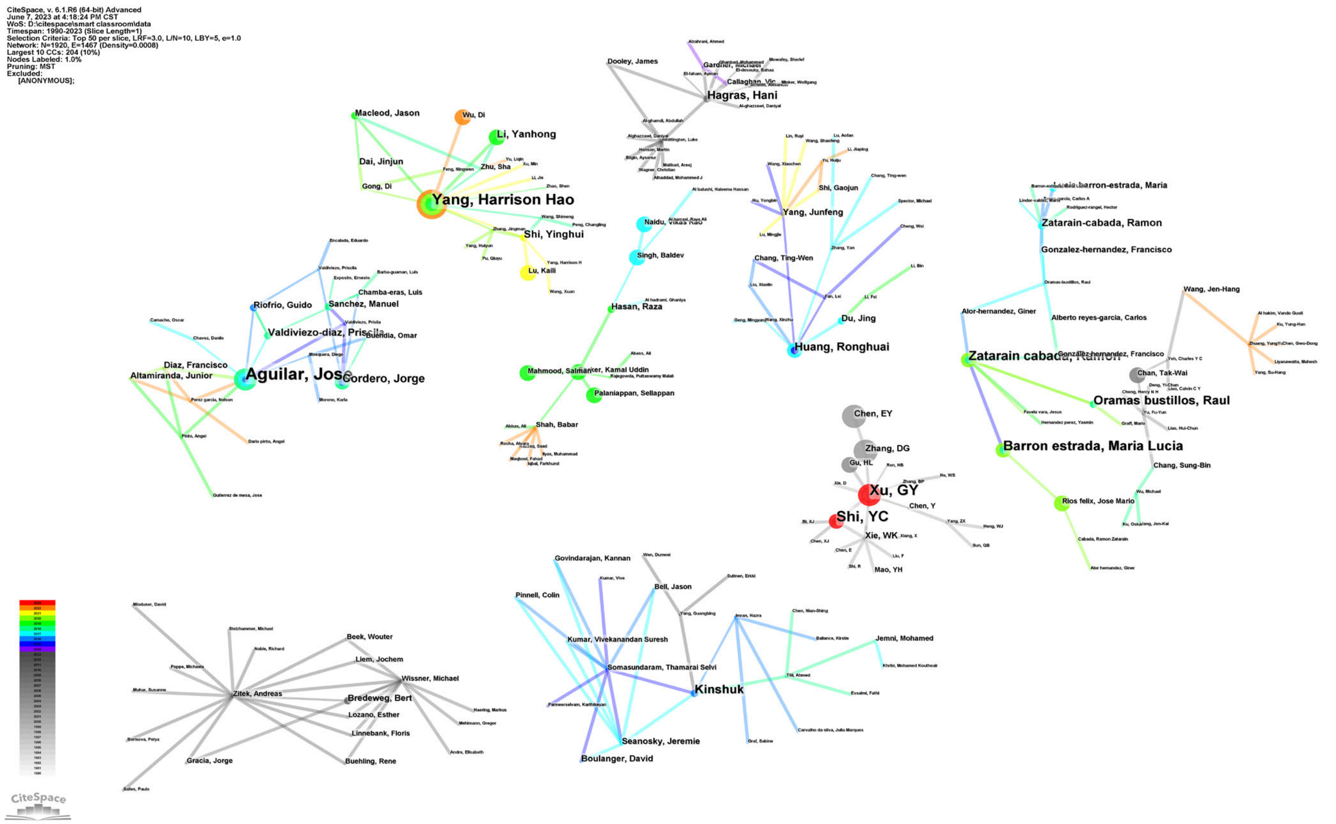
The largest connected component of the institutional collaboration network contains 157 nodes, accounting for 19% of the total nodes. A closer examination of the largest institutional collaboration team reveals that it is formed by Beijing Normal University in China, the University of North Texas in the United States, National Sun Yat-Sen University, and National Central University in Taiwan, which collectively have published over 40 papers. Overall, institutional collaboration in the field of smart classroom research is still relatively fragmented and no major core collaboration teams have emerged. However, institutions with high publication rates, such as Central China Normal University, the University of Los Andes Venezuela, and Beijing Normal University, are currently the central research institutions driving advancements in smart classroom research.

Moreover, the results of the author collaboration network analysis show that Huang, Yang, Du, and others form the main research teams that occupy a central position in smart classroom research. Upon analyzing the team members' affiliations, it was observed that they were affiliated with institutions, such as Beijing Normal University and Hangzhou Normal University. This indicates that collaboration among these scholars has fostered cooperation between different institutions in the field of smart classroom research.

3) COUNTRY COLLABORATION ANALYSIS

An analysis of the country/region collaboration network was performed based on the smart classroom literature. This analysis produced a network comprising 78 nodes and 102 links, with a network density of 0.034, as shown in Figure 10. As previously mentioned, the three countries/regions with the highest number of publications are China (259), the United States (73), and India (40), which are represented by larger nodes in the network. Additionally, the nodes from England, China, Spain, Canada, and the United States have purple outer rings, indicating higher betweenness centrality and reflecting the significant roles played by these countries/regions in smart classroom research. Moreover, the largest CC in the network included 59 nodes, accounting for 75% of the total. Overall, countries such as China, the United States, and England are the main contributors to smart classroom research, with high publication and betweenness centralities.

Conducting a CiteSpace collaboration network analysis of smart classroom research literature aids in identifying the primary research forces and analyzing the collaboration situation across different dimensions. The results reveal that Huang, Yang, and other authors in the micro-level author dimension; institutions like Beijing Normal University and China Central Normal University in the meso-level institution



Note: Nodes: Each node corresponds to an individual author. The node size reflects the number of publications by the author. Lines: The lines connecting nodes indicate the co-authorship between authors. Node Color: The color of a node indicates the time frame within which the author is prominent. Line Color: The color of the lines signifies the time when two nodes collaborate for the first time.

FIGURE 8. **Author collaboration network.**

dimension; and countries such as China, the United States in the macro-level country dimension, constitute the core forces in current smart classroom research. However, the density of collaboration network diagrams indicates that collaboration between researchers and institutions remains relatively sparse. Considering the current trend towards collaborative development, researchers in the field of smart classrooms should enhance their cooperation. This will promote greater cooperation between institutions and collectively advance the development of smart classroom research.

C. CO-OCCURRENCE ANALYSIS

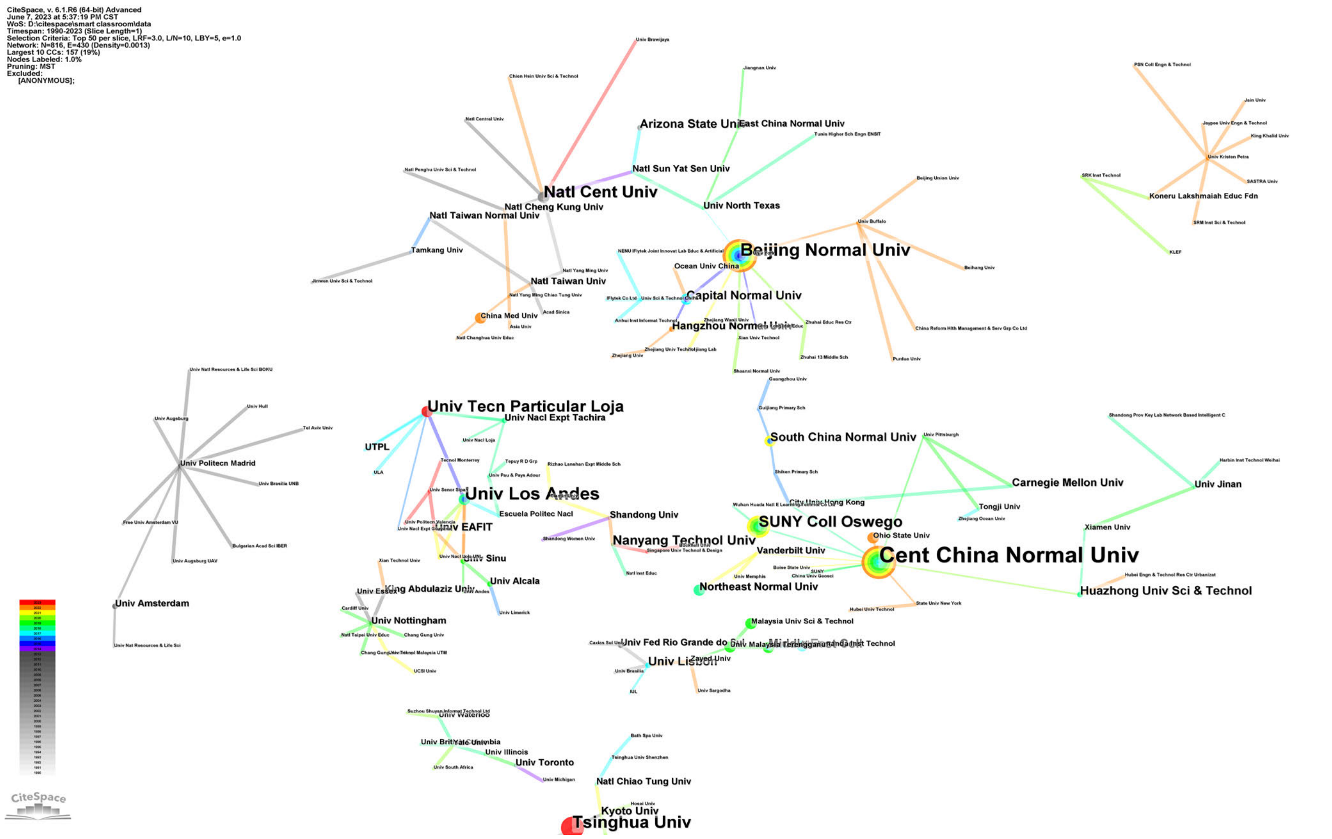
Co-occurrence analysis of CiteSpace can be performed across three dimensions: keywords, terms, and categories. ''Keywords'' refer to the author-assigned keywords of the articles, ''terms'' are the noun phrases extracted from the keywords, abstracts, and titles of the literature [33], while ''category'' pertains to the Web of Science categories. Co-occurrence analysis is instrumental in identifying research topics and major research categories within a specific field of study. Given that keywords can accurately reflect the research topics of authors, this study primarily used keywords in the literature for co-occurrence analysis to discern research themes in the field of smart classrooms. Concurrently, co-occurrence analysis was also carried out within the research categories of the literature to examine the main research categories in smart classroom research.

1) CATEGORY CO-OCCURRENCE ANALYSIS

Co-occurrence analysis of categories in literature data can reveal the main research categories within a specific research field. As illustrated in Figure 11, the category co-occurrence network consists of 78 nodes and 174 links, with a network density of 0.0579. The maximum connectivity involves 67 nodes, representing 85% of the total nodes. The diagram reveals that computer science, interdisciplinary applications (0.39), education and educational research (0.34), and computer science, artificial intelligence (0.21) have high betweenness centrality. This indicates that smart classroom research often requires a combination of computer science, education, and engineering, suggesting that it is interdisciplinary, to a certain extent.

2) KEYWORD CO-OCCURRENCE ANALYSIS

The keyword co-occurrence network in smart classroom research comprises 1576 nodes and 1919 links, with a



Note: Nodes: Each node corresponds to an academic institution. The size of a node is related to the number of publications in the institution. Lines: The connecting lines represent collaborative ties between institutions. Node Color: The color of a node indicates the time frame within which the institution is prominent. Line Color: The color of the lines signifies the time when two nodes collaborate for the first time.

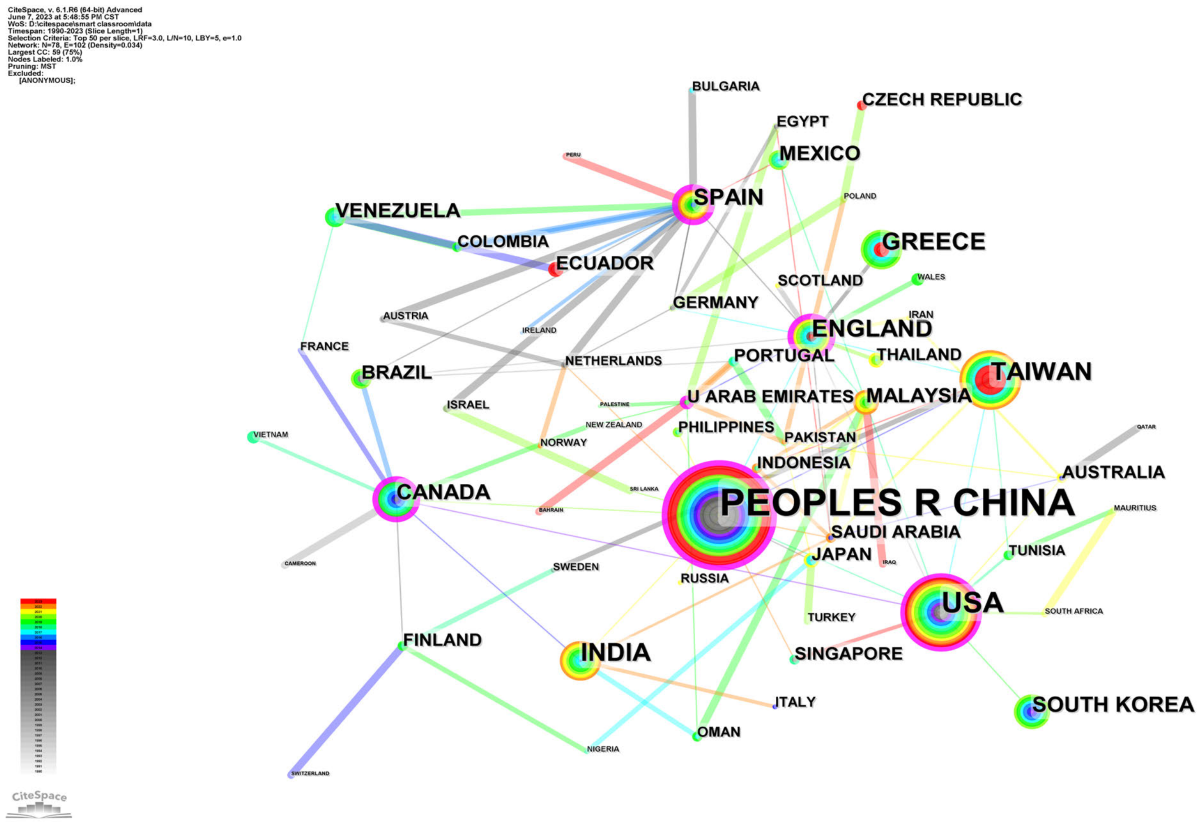
FIGURE 9. Institutional collaboration network.

network density of 0.0015, as shown in Figure 12. The largest connected component of this network included 1303 nodes, representing 82% of the total. As mentioned earlier, the betweenness centrality of the nodes reflects their key role within the network. Keywords with a betweenness centrality greater than 0.1 in this network include ''smart classroom,'' ''system,'' ''intelligent learning environment,'' ''intelligent tutoring system,'' ''technology,'' and ''smart learning environment,'' as shown in Table 12.

We then conducted cluster analysis using the log-likelihood ratio (LLR) algorithm. The resulting cluster graphics and reports are presented in Figure 13 and Table 13, respectively. The modularity Q value was 0.7817 and the Silhouette S value was 0.9595, indicating the high reliability of the clustering labels. Modularity in a network reflects its internal organization. A highly modular network is characterized by loosely interconnected components or sub-networks, pushing its modularity towards a maximum value of 1. Conversely, a network with tightly interconnected components will have a lower modularity, approaching at minimum value of 0. The silhouette score of a cluster evaluates its internal consistency by assessing whether the members of the cluster are grouped together owing to shared characteristics in certain aspects. Essentially, a cluster with a higher silhouette score is deemed more significant and coherent than a cluster with a lower silhouette score [34], [35]. Identified clusters includes ''smart classroom,'' ''intelligent learning environments,'' ''science education,'' ''smart university,'' ''teaching presence,'' etc., with details of the clusters having an S value greater than 0.9 presented in Table 13.

Research on smart classrooms, which has been ongoing for several years, has yielded a variety of research topics. Keywords play a crucial role in reflecting research themes. A cluster analysis of keywords helps summarize the research topics in smart classrooms over time. Generally, these topics can be divided into four categories: technological, instructional, conceptual, and environmental.

Technological research on smart classrooms forms the foundation for continual development. Cluster labels such as 2, 4, 6, and 10 are related to technology, covering various smart classroom technologies such as Bayesian networks [36], intelligent tutoring systems [37], ubiquitous computing [38], and emerging disruptive technologies such as virtual reality [39], machine learning [40], and ant colony optimization [41]. Instructional research focuses on teaching and pedagogical aspects of the smart classrooms. Keyword



Note: Nodes: Each node represents the country involved in research collaboration. The size of a node correlates with the number of publications to which the country has contributed. Lines: These represent the collaborative relationships between countries. Node Color: The color of a node indicates the time frame within which the country is prominent. Line Color: The color of the lines signifies the time when two nodes collaborate for the first time.

FIGURE 10. Country collaboration network.

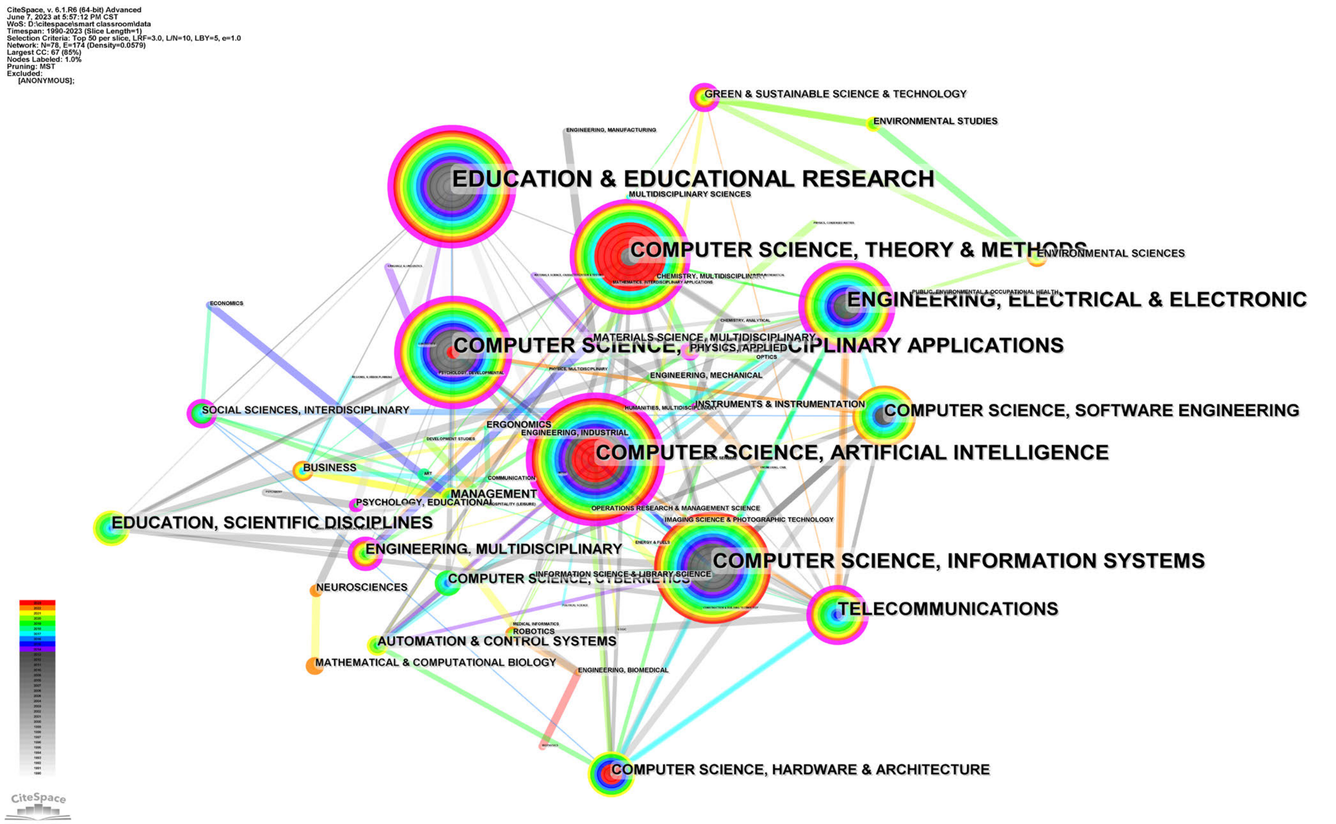
clusters such as "formative assessment," "gamification," "attention," and "teaching presence" are related to this area. Researchers have used smart technologies to enhance student evaluation and personalize instruction [42], with educational data supporting a more effective assessment of student attention and classroom environment control [43]. The conceptual aspect involves defining smart classrooms. Researchers differ in their interpretations but generally view them as classrooms equipped with smart technologies and devices [44], [45]. Research on the environmental aspect considers the physical setup of smart classrooms, including design [46], interaction between equipment and student use, and the impact on smart campuses development [47].

Burst detection, which is mainly used for trend identification [48], was applied in the literature on smart classrooms, and the results are shown in Figure 14. Burst refers to the intensity of the sudden appearance of keywords for a research topic in a specific field within a certain period [49]. The seven keywords with the strongest citation bursts were "intelligent learning environment," "intelligent tutoring system," "ubiquitous computing," "ambient intelligence," "smart learning environment," "technology-enhanced learning," and "performance," with "intelligent tutoring system" having the strongest strength (7.22), followed by "intelligent learning environment" (5.88) and "smart learning environment" (4.43).

Co-occurrence analysis of the literature on smart classrooms helps identify research categories and main topics. Based on the category co-occurrence analysis, the main research categories for smart classroom research were identified as computer science, interdisciplinary applications, education and educational research, computer science, and artificial intelligence. This analysis revealed that the research primarily focuses on four aspects: technology, pedagogy, concept, and environment.

V. DISCUSSION

An accurate understanding of smart classroom research is helpful for smart classrooms' development and for improving teachers' experiences, thereby advancing educational informatization. This discussion, informed by the CiteSpace visualization results, concentrates on three areas: the process of smart classroom research, recent research hotspots in smart classrooms, and future research directions for smart



Note: Nodes: Each node denotes a research category within the network. The size of the node reflects the volume of co-occurrence, suggesting the prominence of this category in the network. Lines: This illustrates the co-occurrence of categories within the literature. Node Color: The color of a node indicates the time frame within which the category is prominent. Line Color: The color of the lines signifies the time when two nodes co-occur for the first time.

FIGURE 11. Category co-occurrence network.

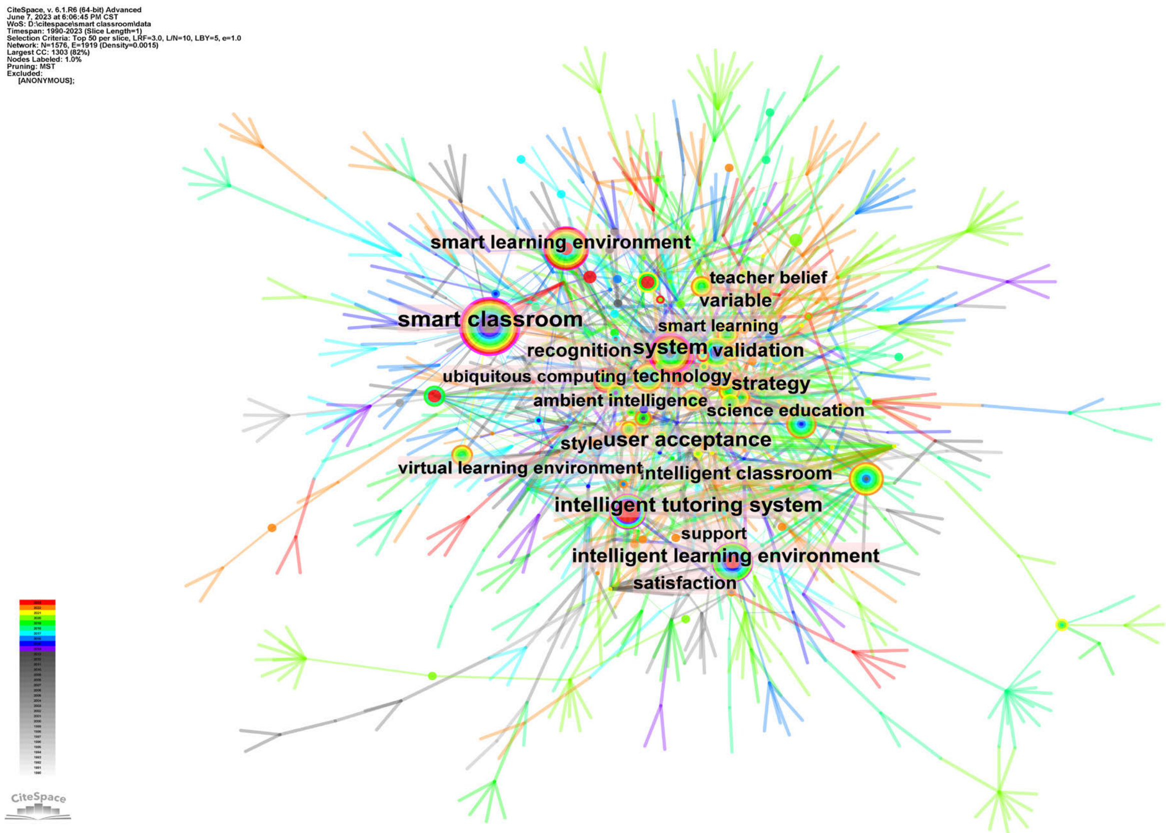
classrooms. Finally, this survey's assistance to researchers, educators, and policymakers will be analyzed.

A. PROCESS OF SMART CLASSROOM RESEARCH

This article categorizes the evolution of smart classroom research into three stages based on annual publication trends and keyword analysis.

The first stage spans from 1990 to 2001. During this period, the number of research articles on smart classrooms did not exceed five annually. As depicted in Figure 3, there was also a notable increase in the appearance of the key phrase "intelligent learning environment (ILE)," suggesting that researchers at that time predominantly understood smart classrooms through the lens of ILE. In that era, the PowerPoint slide teaching mode had just been introduced to the classroom, and AI development was in the machine learning stage. Callegari [50] introduced machine learning techniques from artificial intelligence into intelligent learning environments and proposed an intelligent-assisted learning system called the multi cooperative environment (MCOE). This indicates that researchers have focused on intelligent-assisted systems in their understanding of smart classrooms. Shi [51], from the perspective of distance education, proposed the concept of a "smart classroom." Although this still falls within the scope of intelligent-assisted instructional systems, it highlights the important role of smart classrooms in distance education.

The second stage covered the period from 2002 to 2015. As shown in Figure 3, the average volume of smart classroom research conducted during this period was 15.79 articles per year. Figure 14 also indicates a sudden increase in the appearance of keywords such as "ubiquitous computing" and "ambient intelligence," suggesting a deeper exploration of smart learning environments and an increasing demand for related technologies. The rising popularity of computers, advances in AI technology, and push for educational informatization have further propelled the development of smart classrooms. Yushendri [52] designed an intelligent whiteboard based on ubiquitous computing, integrating hardware, Raspberry Pi, cloud services, and user devices to enhance teaching interactions in smart learning environments. Hwang [28] discussed the definition and framework of smart learning environments from a context awareness perspective, and proposed a framework that includes modules



Note: Nodes: Each node represents a keyword extracted from the analyzed scientific literature. Larger nodes indicated a higher frequency of occurrence in the literature. Lines: The lines connecting the nodes represent the co-occurrence of two keywords within the same article. Node Color: The color of a node indicates the time frame within which the keyword is prominent. Line Color: The color of the lines signifies the time when two nodes co-occur for the first time.

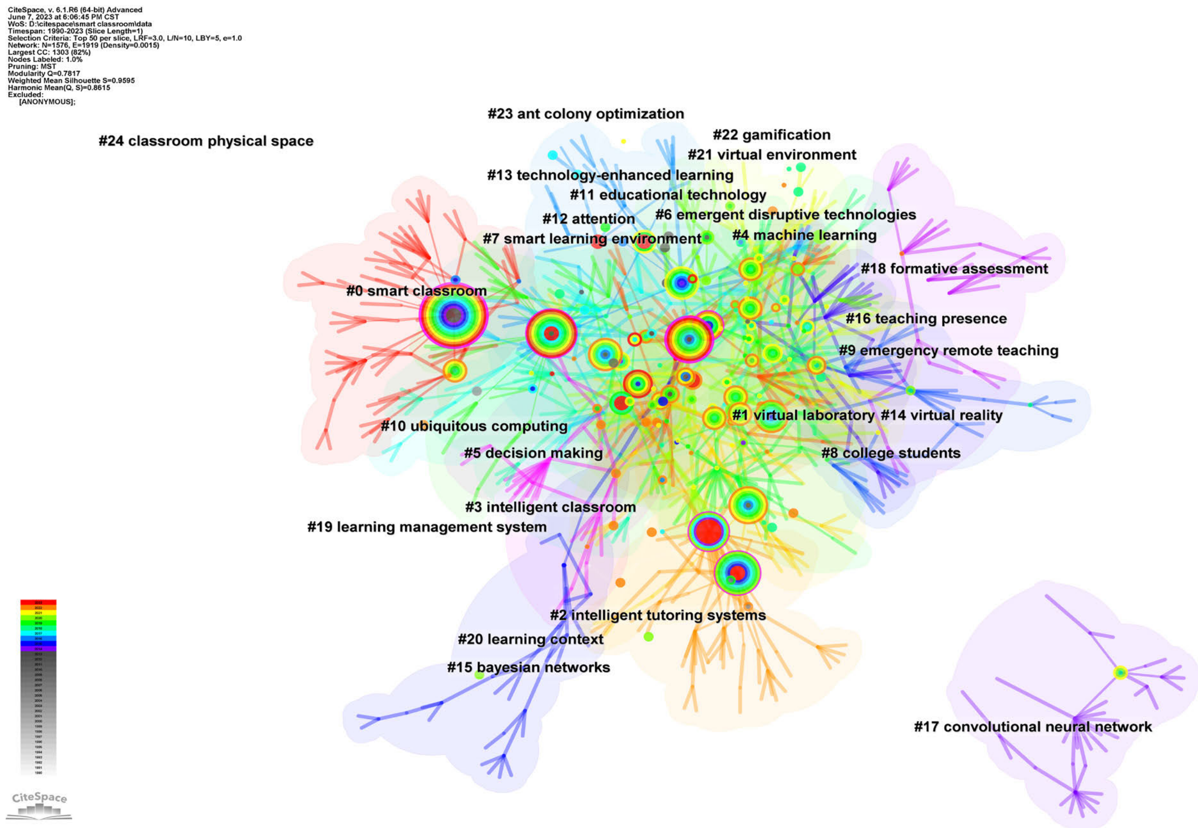
FIGURE 12. Keyword co-occurrence network.

for learning state detection and learning performance assessment. Margetis [53] explored education-oriented teaching approaches that incorporated environmental intelligence into the classroom, presenting a smart classroom solution based on this concept. Li [9] reviewed research on learning environments built with ambient intelligence, examined their characteristics, and presented a self-designed smart classroom case study based on context-aware technology.

The third stage, from 2016 to the present, has seen a significant evolution in smart classroom research. The concept of "smarter planet," proposed by the President of IBM in 2008 [54], led to the emergence of various "smart" concepts, including the smart classroom. Since then, research on smart classrooms has garnered increased attention. As Figure 3 shows, the average annual number of publications on smart classrooms exceeded 50 since 2016. After 2016, the citation count of research articles on different smart classroom-related topics increased significantly, indicating the growing prominence of this field. Figure 14 shows that from 2016 onwards, burst keywords in smart classroom research include "technology-enhanced learning," "learning analytics," and "performance." This shift indicates that researchers have gradually focused on how smart classrooms technology can enhance teaching and learning. Aguilar [55] proposed using technology in smart classrooms to observe the processes and behaviors of students, collect relevant learning data for analytics, and present a framework for this purpose. The performance of students in smart classrooms has been

TABLE 12. Keyword co-occurrence report (betweenness centrality over 0.1).

Rank	Betweenness Centrality	Year	Keyword
1	0.24	2002	smart classroom
2	0.21	2005	system
3	0.14	1999	intelligent learning environment
4	0.13	2001	intelligent tutoring system
5	0.12	2011	technology
6	0.11	2013	smart learning environment



Note: This visualization represents a keyword co-occurrence network analysis, with clusters indicating related groups of research topics. Numbered labels (e.g., #0, #1, etc.) represent distinct clusters of interrelated topics within the larger research field. Each cluster is formed by keywords that often appear together in literature, suggesting a shared focus or theme.

FIGURE 13. Keyword co-occurrence clustering network.

a focal point for scholars and teachers, with factors such as location [56] and lighting conditions [57] influencing learning outcomes. Over the years, the concept of smart classrooms has evolved from merely supporting teaching to embracing environmental intelligence and being driven by concepts such as the smart Earth. This evolution signifies a shift in smart classroom research from technological exploration to a more comprehensive examination of the role of technology in education.

B. RESEARCH HOTSPOTS IN SMART CLASSROOMS

Research hotspots are the main topics that have garnered attention from researchers [58]. By analyzing keyword co-occurrence, we found that the primary research themes in the field of smart classrooms include technology, instruction, concept, and environment. Recent trends, identified through burst detection of references and keyword clusters over the past five years, have focused on teaching, environment, and technology in smart classroom research.

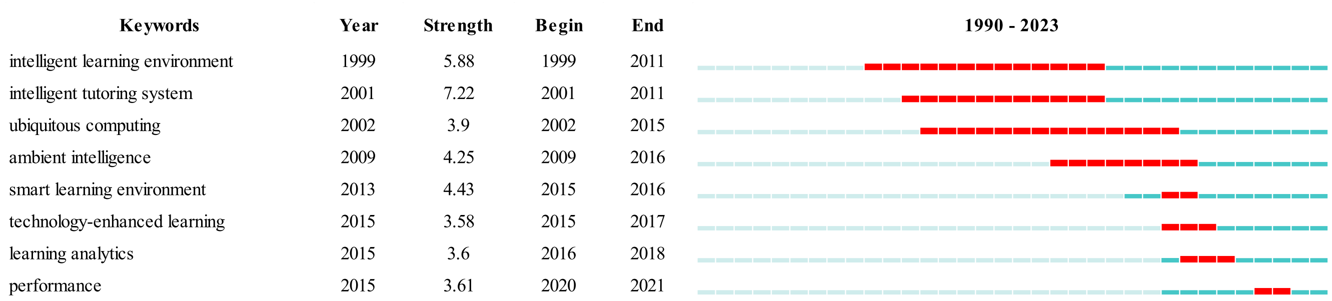
Smart classrooms play a pivotal role in enhancing teaching quality and innovating teaching methods, thereby advancing educational development. Research on teaching in smart classrooms, which includes analyzing student attentiveness and exploring teaching presence, significantly influences the perspectives of teachers and educational administrators in smart classrooms. The emergence of clustering keywords like ''attention'' in 2018 and ''teaching presence'' in 2019 highlights the academic community's recent focus on teaching in smart classrooms. Bdiwi's research [12] suggests that employing information and communication technologies (ICT) and Radio-Frequency Identification (RFID) positioning systems in smart classrooms can assess student attention, aiding teachers to better evaluate student participation and enhance teaching effectiveness. The rising interest in student attentiveness in smart classrooms is evident from the recent surge in the related research. The development of smart classrooms, especially multi-synchronous smart classroom (MSSC) [59], has been instrumental in sharing high-quality teaching resources. Using live-streaming devices, smart classrooms can synchronize high-quality teaching content with other classrooms, thereby greatly promoting educational equity. However, this led to a reduced sense of teaching. Di [60] analyzed teaching presence in smart classroom environments and examined its relationship with deep learning and the classroom atmosphere. This presence enhances students' deep learning and contributes

TABLE 13. Keyword co-occurrence clustering report.

Cluster Id	Size	Silhouette	Year	Keywords
0	96	0.979	2015	**Smart Classroom**; Learning Environment; Pedagogy; Traditional Classroom; Blended Learning
1	84	0.967	2012	**Virtual Laboratory**; Qualitative Reasoning; Smart Classroom; Assessment; Analytic Hierarchy Process
2	83	0.95	2011	**Intelligent Tutoring Systems**; Intelligent Learning Environments; Neural Networks; Fuzzy Logic; Affective Computing
3	79	0.95	2016	**Intelligent Classroom**; Information Technology; Distance Education; Multimedia; Educational Interventions
4	76	0.949	2017	**Machine Learning**; Cloud Computing; Fog Computing; Smart Classroom; Deep Learning
5	74	0.957	2013	**Decision Making**; Game-Based Learning; Optimisation Methods; School Design; Pattern Recognition
6	74	0.945	2019	**Emergent Disruptive Technologies**; Interactive Smart Board; UAE; Integrative Pedagogy; Higher Education
7	58	0.953	2016	**Smart Learning Environment**; Smart Learning Space; social media; Intelligent Learning Space; Facial Expression Recognition
8	58	0.96	2017	**College Students**; Different Form; Social Support; Perceived Learning; Career Relatedness
9	56	0.939	2017	**Emergency Remote Teaching**; User Experience; Self-Regulated Learning; Energy Saving; Smart Campus
10	55	0.915	2013	**Ubiquitous Computing**; Mixed Reality; Embedded Agents; Mobile Ad Hoc Networks; Ambient Intelligence
11	55	0.935	2017	**Educational Technology**; Artificial Intelligence; Object Detection; Computer Vision; Human-Computer Interaction
12	46	0.978	2018	**Attention**; Body Temperature; Health Care; Eye Movement; Spatio-Temporal Attention
13	46	0.95	2016	**Technology-Enhanced Learning**; Educational Data Mining; Smart Learning; Learning Analytics; Enhanced Teaching and Learning Practices
14	44	0.951	2016	**Virtual Reality**; Smart Teaching; Augmented Reality; Education Development; Computer Supported Collaborative Learning
15	39	0.965	2010	**Bayesian Networks**; Intelligent Learning; Learner Modelling; Decision Theory; Framework Gap
16	39	0.982	2019	**Teaching Presence**; Synchronous Teaching Model; Teacher Beliefs; Educational Application; Assessment Classification
17	38	0.979	2018	**Convolutional Neural Network**; FTIR Spectral Imaging; Static Image; Face Recognition; Optical Data Processing
18	36	0.966	2015	**Formative Assessment**; Mobile Learning; Integrated-Skills Approach; Intelligent Text Parser; Virtual E-Learning-IoT Tool
19	35	0.984	2017	**Learning Management System**; Information and Communication Technology; Virtual Learning Environment; Technology-Enabled Interaction System; Systematics

TABLE 13. *(Continued.)* Keyword co-occurrence clustering report.

20	34	0.984	2019	**Learning Context**; Ai-Assisted System; Contextual Analysis; Image Analytics; Language Learning
21	34	0.982	2019	**Virtual Environment**; Haptic Augmentation; Disturbance Observer; Sensorless Torque Control; Haptic Lever
22	25	0.98	2017	**Gamification**; Serious Games; Reinforcement Learning; Emotion Recognition; Student Facial Expression
23	21	0.976	2020	**Ant Colony Optimization (ACO)**; Internet of Things (IoT); Smart Learning Environment (SLE); Computer Architecture; Scratch
24	18	0.998	2018	**Classroom Physical Space**; Human-Building Interaction; Classroom Orchestration; Spatial Semiotics; Smart Learning Ecosystems



Note: Year: The year when the keyword first appeared in the literature. Strength: The burst strength, which indicates the intensity of the citation increase. Begin: The start year of the citation burst. End: The end year of the citation burst. Red Segment: Indicates the duration of the citation burst, during which there was a significant increase in the occurrence of keywords in the literature. Cyan Segment: Represents the years when the keyword was present in the literature but did not experience a burst.

FIGURE 14. Top 7 keywords with citation burst.

to future teaching strategies in synchronized smart classrooms.

The design and construction of a classroom environment is fundamental to the development of smart classrooms. Research focusing on the environment and construction of smart classrooms is vital for its progression. The clustering label "classroom physical space" indicates that the study of smart classroom environments is a scholarly hotspot. Sardinha highlighted that, propelled by information technology, new teaching methods such as collaborative and personalized learning necessitate a redesign of the physical classroom space [61]. Such redesigns and transformations have enabled student-centered teaching. MacLeod developed a scale with eight dimensions, including student negotiation and inquiry learning, to measure students' preferences for smart classrooms [25]. Similarly, Li analyzed teachers' preferences in a smart classroom environment [62].

Technology is central to smart classroom research. Smart classrooms represent the integration of technology into education. Advanced information and communication technologies form the backbone of smart classrooms and facilitate learning within them [63]. Disruptive technologies, including learning analytics, have propelled the development of smart classrooms. Learning analytics, a toolset derived from artificial intelligence, collects and analyzes classroom learning data [55]. Applying these techniques in smart classrooms allows for the recommendation of personalized learning resources tailored to student needs, aiding teachers in better assessing student learning activities. Artificial intelligence can also analyze the learning context in smart classrooms through data collection and analysis, enabling teachers to plan future teaching strategies and provide personalized guidance [13]. Additionally, emerging technologies such as ant clustering algorithms have improved the analysis of educational data in smart classrooms [41]. The results of such analyses will allow teachers to effectively group students, foster collaborative learning teams, and enhance collaboration in smart classrooms.

The development of smart classroom research has undergone three stages, during which the evolution of research focusing on teaching, space, and technology has been complex and mutually influential. In the initial stage of proposing smart classrooms (1990-2001), various researchers had rich ideas about smart classrooms yet were limited by the technological development of the time, focusing on the intelligent transformation of space design and teaching methods. From the perspective of overcoming the limitations of learning space, researchers have created multimedia classrooms capable of remote education and Internet-based learning communities, among others. With the continuous advancement of technology, the second stage of smart classroom research (2002-2015) saw the application of various technologies in construction. However, the impact of technology on the education industry was not significant, and many researchers continued to delve deeply in this period, focusing on technological development and application in smart classrooms, leading to a decline in research attention to teaching and space design. In the third stage (2016-present), research on smart classrooms was comprehensively developed. With the growing demands of students and teachers for educational reform, and researchers recognizing the mutual influence of space design, technology application, and teaching methods, the research focus has tended toward a balance, with teaching, space, and technology developing in coordination. Overall, research on teaching, space, and technology in smart classrooms has always been present, but the emphasis in different periods has shifted slightly. Only by integrating the development of these three aspects can smart classrooms be constructed and advanced.

C. FUTURE RESEARCH DIRECTIONS FOR SMART CLASSROOMS

In recent years, research on smart classrooms has predominantly focused on teaching, environment, and technology. This focus aligns with Radcliffe's principles for designing next-generation learning spaces encapsulated in the pedagogy-space-technology (PST) framework. Pedagogy typically refers the methods of teaching and learning that are applied to particular subjects within specific contexts. In an educational context, space usually refers to the location where teaching activities occur. Technology, when used in an educational sense, primarily signifies the integration of modern scientific and technological advancements into the educational process. Consequently, continuing research on these aspects is beneficial for the development of smart classrooms, and for teachers' and educational administrators' understanding and application of these innovative learning spaces.

Regarding teaching, future research should emphasize student-centered approaches, optimize teaching strategies, and analyze the effects of smart classrooms across different subject areas. The current trend in teaching is to shift from a teacher-dominated approach to a more student-centered one [64]. Accordingly, research on smart classrooms is increasingly focusing on students. Future research directions include collecting and analyzing various learning data from students in smart classrooms, providing precise and personalized teaching guidance, and developing corresponding smart classroom learning systems. Additionally, as smart classrooms contribute to the sharing of educational resources, there is an increasing trend in schools to deliver high-quality teaching through live-streaming and recorded sessions. This evolution necessitates a closer examination of both teacher and student strategies in these contexts as well as an analysis of how smart classrooms impact teaching in various subjects.

In terms of the environment, future research should aim to establish standards for smart classroom construction, design the physical environment of these classrooms, and construct virtual scenarios. Currently, there is no unified standard for smart classroom construction [65], leading to varying interpretations and implementations. Therefore, it is important to consider whether unified construction standards are required to and explore the impact of different standards on teaching effectiveness and knowledge delivery. Research should also focus on designing smart classroom environments, considering factors such as seating layout, lighting conditions, and air quality, which can influence both student learning outcomes and teaching effectiveness. With advancements in virtual reality (VR) and metaverse technologies, there has been an increasing focus on the construction of virtual smart classrooms. These technologies enable the creation of immersive environments, potentially revolutionizing distance education and promoting educational equity.

In terms of technology, future developments in smart classroom research should involve deepening the analysis of advanced communication and information technologies applied in these settings, incorporating diverse technologies, and thoroughly analyzing teachers' and students' preferences and needs concerning smart classroom technologies. The use of technologies such as the Internet of Things (IoT), machine learning, and artificial intelligence in smart classrooms is becoming increasingly sophisticated. Continuous analysis of the effectiveness and challenges of these technologies is crucial for their optimal use in smart classrooms. Furthermore, as the influence of science and technology on education increases with emerging technologies such as metaverse and magnetic resonance imaging gaining prominence, it is essential for researchers, teachers, and administrators to adopt an open mindset. They should actively explore different technologies, analyze and compare their applications, and identify appropriate technologies to advance smart classrooms. Introducing technology into classrooms should serve the needs of both teachers and students. Research should focus on understanding technological preferences and usage patterns of teachers' and students' in smart classrooms. By fully considering their needs, smart classrooms can effectively fulfill their intended functions.

In light of the PST framework, future research could more comprehensively integrate aspects of teaching methods, space, and technology within smart classrooms. The previous subsection also highlighted that the current research on smart classrooms predominantly focuses on teaching, space, and technology; however, there is a noticeable lack of comprehensive and integrated analysis. For example, integrating teaching and space would entail analyzing how spatial elements, such as the physical environment of the classroom, including air quality and noise control, impact the quality and effectiveness of teaching in smart classrooms. This is crucial for aiding in the development and construction of smart classrooms. In addition, there is potential for advancing the analysis of the conceptual connotations of smart classrooms. The current research tends to overlook the extension of smart classrooms. Although classrooms equipped with smart technology are commonly recognized as smart classrooms, the question remains whether classrooms that utilize smart teaching methods should be classified as such. This includes classrooms that implement Problem-based Learning (PBL) and student-centered active learning environment with upside-down pedagogies (SCALE-UP), both of which employ innovative teaching methods. SCALE-UP classrooms have been implemented in various universities worldwide. Determining whether these classrooms also qualify as smart classrooms is crucial to understanding the broader scope of the smart classroom concept.

D. ADVICE FOR RESEARCHERS, EDUCATORS AND POLICYMAKERS OF SMART CLASSROOMS

By conducting a detailed visual analysis of the smart classroom literature from the WOS Core Collection, this study aims to offer advice to researchers, educators, and policymakers in this field. The visualized results indicate a relatively low level of collaboration among scholars in the field of smart classroom research. This suggests that leaders at various universities could implement measures to improve collaboration, such as organizing research mobilization meetings, promoting the formation of core research teams, and driving field development. To develop smart classroom research further, researchers should adopt a more practical perspective. This involves focusing on students' performance in smart classrooms, understanding the needs of both students and teachers, and conducting research grounded in teaching reform.

Additionally, an analysis of the research hotspots in smart classrooms can aid teachers in designing more effective teaching strategies. For instance, they should capitalize on unique seating arrangements in smart classrooms to increase group learning and student engagement. Utilizing the capability of smart classrooms to access resources can also keep students updated with their latest knowledge during and after class. Moreover, analyzing the main research directions in the smart classroom literature helps educators understand the concept and scope of smart classrooms more clearly, distinguishing them from multimedia classrooms, and enabling more targeted instructional designs.

Finally, this study highlights that teaching, space, and technology are three key elements for future smart classroom policy formulation. Current policies tend to focus more on space and technology, with less emphasis on the teaching aspects. Therefore, future policy formulations should incorporate teaching factors such as methods and strategies specific to smart classrooms. For example, the existing guidelines for smart classroom construction in China emphasize the spatial environment, equipment, resources, and management platforms, but less so for smart teaching design and smart education. Policymakers should consider the impact of teaching elements on the construction and development of smart classrooms, and comprehensively address these three key elements (teaching, space, and technology).

VI. CONCLUSION

Research on smart classrooms is a significant tool for advancing educational informationization, optimizing teaching methods, and promoting student-centered education. This article analyzes the research literature on smart classrooms in the WOS core collection and presents the following conclusions.

A. OVERVIEW OF SMART CLASSROOM RESEARCH

A descriptive analysis of the data from smart classroom literature reveals that the most published author in the field is Jose Aguilar of the Universidad de Los Andes, with 14 publications, followed by Margherita Antona from the Foundation for Research and Technology – Hellas, with 11. Since 2016, the annual publication volume of smart classroom research has exhibited a fluctuating upward trend, averaging more than 50 articles per year. Among the collected literature, conference proceedings comprised the largest proportion, nearly 60%. Central China Normal University leads in institutional publications with 54 publications, while Mobile Information Systems is the most prolific journal, contributing 14 publications. The primary research areas in smart classroom studies were computer science (443) and education and educational research (283), with Mainland China having the highest number of publications (259).

B. VISUALIZATION SCIENTOMETRIC ANALYSIS

The co-citation network analysis of the collected data, using betweenness centrality measures in CiteSpace, identified influential journals, such as "Computer & Education" (0.11) and "Lecture Notes in Computer Science" (0.15). Key authors such as Brusilovsky and Brown were highlighted, along with significant papers, including MacLeod's "Understanding Students' Preferences toward the Smart Classroom Learning Environment: Development and Validation of an Instrument." Author collaboration analysis revealed relatively loose collaboration among the authors in this field, with the largest team led by Huang and Yang. Some collaborations were observed between Beijing Normal University and the University of North Texas. Co-occurrence network analysis showed that computer science is the main disciplinary category, and clustering analysis of keywords outlines research directions such as technological, instructional, conceptual, and environmental studies.

C. PROCESS OF SMART CLASSROOM RESEARCH

The process of smart classroom research is discussed in three stages based on annual publication volume and keyword detection. The first stage (1990-2001) focused on intelligent learning environments and support systems. The second stage (2002-2015) saw advancements in intelligent technologies and AI, with an increasing publication volume and focus on transforming classrooms with technology. The third stage, which began in 2016, was marked by the introduction of a series of smart concepts. During this phase, research on smart classrooms has attained an average annual publication volume of more than 50 articles. Accompanying educational reforms has led to a shift in the research focus back to students and the essence of teaching, emphasizing the analysis of the role and impact of smart classrooms on instructional methods.

D. RESEARCH HOTSPOTS IN SMART CLASSROOMS

Recent research hotspots, identified through burst detection and keyword cluster analysis, have concentrated on teaching, environment, and technology. Teaching-focused research examines student participation and the impact of teaching presence. Environmental research considers the redesign of physical smart classroom spaces and the preferences of different groups. Technological research has delved into the application of emerging technologies, such as artificial intelligence and learning analytics in smart classrooms. In reviewing the process of smart classroom research, the initial focus was on teaching and spatial design. This focus then shifted towards the application of technology, and ultimately, it progressed towards the integrated development of these three aspects. Although the focal points have varied at each stage, these three research hotspots have consistently been reflected in the development of smart classrooms.

E. FUTURE RESEARCH DIRECTIONS FOR SMART CLASSROOMS

Future research should continue to follow the pedagogy-space-technology (PST) framework, focusing on teaching, space, and technology. In terms of teaching, continued emphasis should be placed on student-centered approaches, the analysis of optimizing instructional strategies in smart classrooms, and the examination of the specific effects of smart classrooms across various subject areas. It is important to explore the need for standards in smart classroom construction. In addition, deepening the design of physical environments in smart classrooms and conducting research on virtual smart classroom environments are vital areas of focus. Ongoing research on the application of different ICTs in smart classrooms, the integration of emerging disruptive technologies, and the consideration of teachers' and students' needs in smart classroom technology will be crucial research issues in the near future. Additionally, a comprehensive consideration of the three elements of PST (Pedagogy, Space, and Technology) and their impacts on smart classrooms is essential. Continuously analyzing the expansion and scope of smart classrooms also forms a core direction for future development.

F. ADVICE FOR RESEARCHERS, EDUCATORS AND POLICYMAKERS OF SMART CLASSROOMS

For researchers studying smart classrooms, it is crucial to strengthen mutual cooperation. Additionally, they should pay more attention to student performance and the actual needs of teachers and students in smart classroom environments. For teachers, understanding the nature and functions of smart classrooms is essential, as is developing specialized teaching plans tailored to these environments. Policymakers in formulating smart classroom development strategies should comprehensively consider three key factors: teaching, space, and technology.

G. LIMITATIONS

Although this article provides a comprehensive overview of smart classroom research from the WOS Core Collection and employs CiteSpace software for visualization analysis, it has some limitations. First, CiteSpace software analyzes literature data using selected fields, such as authors, references, and keywords; however, it may not fully exploit all data available in the literature. Second, this study exclusively used data from the WOS Core Collection, which is particularly suitable for CiteSpace analysis, but did not include literature from other databases such as Scopus and Google Scholar. Moreover, the analysis focused solely on English-language literature, omitting research from Chinese databases, which imposes certain limitations on data sources.

To address these limitations, several improvements can be implemented to enhance the credibility of this survey study. First, continued learning and utilization of CiteSpace software for more comprehensive literature analyses, combined with content analysis and the use of additional tools such as the VOS viewer, can help to analyze and offset the shortcomings of CiteSpace from various perspectives. Second, including a broader range of databases and a more extensive collection of literature can increase the credibility of the analysis by ensuring data completeness. Finally, conducting expert consultations and discussions based on the analysis results is an effective method for further enhancing the credibility.

REFERENCES

[1] A. R. Masalimova, M. A. Khvatova, L. S. Chikileva, E. P. Zvyagintseva, V. V. Stepanova, and M. V. Melnik, "Distance learning in higher education during COVID-19," *Frontiers Educ.*, vol. 7, pp. 1–6, Mar. 2022, doi: 10.3389/feduc.2022.822958.

[2] P. S. Divaharan and P. Wong, "Promoting collaborative approaches through re-designing of classrooms," in *Proc. 7th INTED*, Valencia, Spain, 2013, pp. 2238–2242.

[3] M. K. Saini and N. Goel, "How smart are smart classrooms? A review of smart classroom technologies," *ACM Comput. Surv.*, vol. 52, no. 6, pp. 1–28, Dec. 2019, doi: 10.1145/3365757.

[4] D. Niemeyer, *Hard Facts on Smart Classroom Design: Ideas, Guidelines, and Layouts*. Lanham, MD, USA: Scarecrow Press, 2003.

[5] H. Zhan, Z. Liu, F. Lu, X. Ma, S. Zhang, and Y. Chen, "A construction framework design of smart classroom in universities based on pedagogy-space-technology framework," in *Innovative Computing*. Singapore: Springer, 2020, pp. 1647–1654, doi: 10.1007/978-981-15-5959-4_200.

[6] Q. Liu, G. Lu, L. Wu, and W. Deng, "Research on the correlation between location preference and learning motivation in smart classroom-take round table and seedling layouts as examples," *Mod. Educ. Technol.*, vol. 31, no. 8, pp. 67–75, Aug. 2021.

[7] D. Palma, J. Agudo, H. Sánchez, and M. Macías, "An Internet of Things example: Classrooms access control over near field communication," *Sensors*, vol. 14, no. 4, pp. 6998–7012, Apr. 2014, doi: 10.3390/s140406998.

[8] Z. M. Zhu, F. Q. Xu, and X. Gao, "Research on school intelligent classroom management system based on Internet of Things," in *Proc. 3rd ICMIR*, Kunming, China, 2020, pp. 144–149.

[9] X. Li, L. Feng, L. Zhou, and Y. Shi, "Learning in an ambient intelligent world: Enabling technologies and practices," *IEEE Trans. Knowl. Data Eng.*, vol. 21, no. 6, pp. 910–924, Jun. 2009, doi: 10.1109/TKDE.2008.143.

[10] S. Shapsough and I. Zualkernan, "Using machine learning to automate classroom observation for low-resource environments," in *Proc. IEEE Global Humanitarian Technol. Conf. (GHTC)*, San Jose, CA, USA, Oct. 2018, pp. 1–5.

[11] A. Kaur and M. Bhatia, "Smart classroom: A review and research agenda," *IEEE Trans. Eng. Manag.*, vol. 70, no. 3, pp. 1–17, Jun. 2022, doi: 10.1109/TEM.2022.3176477.

[12] R. Bdiwi, C. de Runz, S. Faiz, and A. A. Cherif, "Smart learning environment: Teacher's role in assessing classroom attention," *Res. Learn. Technol.*, vol. 27, p. 14, Jan. 2019, doi: 10.25304/rlt.v27.2072.

[13] E. Dimitriadou and A. Lanitis, "A critical evaluation, challenges, and future perspectives of using artificial intelligence and emerging technologies in smart classrooms," *Smart Learn. Environments*, vol. 10, no. 1, p. 26, Feb. 2023, doi: 10.1186/s40561-023-00231-3.

[14] C. Chen, Z. Hu, S. Liu, and H. Tseng, "Emerging trends in regenerative medicine: A scientometric analysis in CiteSpace," *Expert Opinion Biol. Therapy*, vol. 12, no. 5, pp. 593–608, May 2012, doi: 10.1517/14712598.2012.674507.

[15] X. T. Ma, J. A. Liao, and J. F. Zhao, "Knowledge mapping of alfalfa research—A visual analysis using CiteSpace," *Appl. Ecology Environ. Res.*, vol. 21, no. 3, pp. 1903–1916, Oct. 2023, doi: 10.15666/aeer/2103_19031916.

[16] S. Bai, F. Bao, and F. Zhao, "'Smart classroom' research hotspots and frontier analysis—Visual analysis based on CiteSpace," presented at the 3rd Int. Conf. Artif. Intell. Adv. Manuf., Oct. 2021, doi: 10.1145/3495018.3495385.

[17] L. Li and H. Zhang, "Research status and prospect of teaching evaluation in the context of big data: CiteSpace-based visual analysis," *J. Educ., Humanities Social Sci.*, vol. 14, pp. 134–143, May 2023, doi: 10.54097/ehss.v14i.8817.

[18] C. Chen, "CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature," *J. Amer. Soc. Inf. Sci. Technol.*, vol. 57, no. 3, pp. 359–377, Feb. 2006, doi: 10.1002/asi.20317.

[19] P. Xie, "Study of international anticancer research trends via co-word and document co-citation visualization analysis," *Scientometrics*, vol. 105, no. 1, pp. 611–622, Oct. 2015, doi: 10.1007/s11192-015-1689-0.

[20] Y. Li, Q. Gao, N. Chen, Y. Zhang, J. Wang, C. Li, X. He, Y. Jiao, and Z. Zhang, "Clinical studies of magnetic resonance elastography from 1995 to 2021: Scientometric and visualization analysis based on CiteSpace," *Quant. Imag. Med. Surgery*, vol. 12, no. 11, pp. 5080–5100, Nov. 2022, doi: 10.21037/qims-22-207.

[21] L. C. Freeman, "Centrality in social networks conceptual clarification," *Soc. Netw.*, vol. 1, no. 3, pp. 215–239, Jan. 1978, doi: 10.1016/0378-8733(78)90021-7.

[22] U. Brandes, "A faster algorithm for betweenness centrality*," *J. Math. Sociol.*, vol. 25, no. 2, pp. 163–177, Jun. 2001, doi: 10.1080/0022250X.2001.9990249.

[23] X. Chen, D. Zou, G. Cheng, and H. Xie, "Detecting latent topics and trends in educational technologies over four decades using structural topic modeling: A retrospective of all volumes of computers & education," *Comput. Educ.*, vol. 151, Jul. 2020, Art. no. 103855, doi: 10.1016/j.compedu.2020.103855.

[24] G. Qian, "Scientometric sorting by importance for literatures on life cycle assessments and some related methodological discussions," *Int. J. Life Cycle Assessment*, vol. 19, no. 7, pp. 1462–1467, Jul. 2014, doi: 10.1007/s11367-014-0747-9.

[25] J. MacLeod, H. H. Yang, S. Zhu, and Y. Li, "Understanding students' preferences toward the smart classroom learning environment: Development and validation of an instrument," *Comput Educ.*, vol. 122, pp. 80–91, Jul. 2018, doi: 10.1016/j.compedu.2018.03.015.

[26] Z. Zhu, M.-H. Yu, and P. Riezebos, "A research framework of smart education," *Smart Learn. Environ.*, vol. 3, p. 4, Mar. 2016, doi: 10.1186/s40561-016-0026-2.

[27] J. M. Spector, "Conceptualizing the emerging field of smart learning environments," *Smart Learn. Environments*, vol. 1, no. 1, p. 2, Oct. 2014, doi: 10.1186/s40561-014-0002-7.

[28] G.-J. Hwang, "Definition, framework and research issues of smart learning environments—A context-aware ubiquitous learning perspective," *Smart Learn. Environments*, vol. 1, no. 1, p. 4, Nov. 2014, doi: 10.1186/s40561-014-0004-5.

[29] Y. Shi, W. Xie, G. Xu, R. Shi, E. Chen, and Y. Mao, "The smart classroom: Merging technologies for seamless tele-education," *IEEE Pervasive Comput.*, vol. 2, no. 2, pp. 47–55, Apr. 2003, doi: 10.1109/MPRV.2003.1203753.

[30] L. Chenya, E. Aminudin, S. Mohd, and L. S. Yap, "Intelligent risk management in construction projects: Systematic literature review," *IEEE Access*, vol. 10, pp. 72936–72954, 2022, doi: 10.1109/ACCESS.2022.3189157.

[31] Q. Dang, Z. Luo, C. Ouyang, and L. Wang, "First systematic review on health communication using the CiteSpace software in China: Exploring its research hotspots and frontiers," *Int. J. Environ. Res. Public Health*, vol. 18, no. 24, p. 13008, Dec. 2021, doi: 10.3390/ijerph182413008.

[32] L. Guo and W. Zhang, "Knowledge mapping of population health: A bibliometric analysis," *Heliyon*, vol. 8, no. 12, Dec. 2022, Art. no. e12181, doi: 10.1016/j.heliyon.2022.e12181.

[33] S. Yang, S. Xu, and W. Huang, "3D point cloud for cultural heritage: A scientometric survey," *Remote Sens.*, vol. 14, no. 21, p. 5542, Nov. 2022, doi: 10.3390/rs14215542.

[34] M. E. J. Newman, "Modularity and community structure in networks," *Proc. Nat. Acad. Sci. USA*, vol. 103, no. 23, pp. 8577–8582, Jun. 2006, doi: 10.1073/pnas.0601602103.

[35] P. J. Rousseeuw, "Silhouettes: A graphical aid to the interpretation and validation of cluster analysis," *J. Comput. Appl. Math.*, vol. 20, no. 1, pp. 53–65, Nov. 1987, doi: 10.1016/0377-0427(87)90125-7.

[36] G. Kyriakaki, A. Doulamis, and N. Matsatsinis, "Evaluating a diagnostic model for intelligent learning," in *Proc. 3rd ICERI*, Madrid, Spain, Nov. 2010, pp. 5214–5222. [Online]. Available: https://www.webofscience.com/wos/woscc/full-record/WOS:000318797405009

[37] S. Narciss, S. Sosnovsky, L. Schnaubert, E. Andrès, A. Eichelmann, G. Goguadze, and E. Melis, "Exploring feedback and student characteristics relevant for personalizing feedback strategies," *Comput. Educ.*, vol. 71, pp. 56–76, Feb. 2014, doi: 10.1016/j.compedu.2013.09.011.

[38] H. Bargaoui and R. Bdiwi, "Smart classroom: Design of a gateway for ubiquitous classroom," in *Proc. Int. Conf. Web Open Access to Learn. (ICWOAL)*, Dubai, United Arab Emirates, Nov. 2014, pp. 1–4, doi: 10.1109/ICWOAL.2014.7009206.

[39] H. Elkoubaiti and R. Mrabet, "How are augmented and virtual reality used in smart classrooms?" presented at the 2nd Int. Conf. Smart Digit. Environ., Oct. 2018, doi: 10.1145/3289100.3289131.

[40] A. Uzelac, N. Gligoric, and S. Krco, "A comprehensive study of parameters in physical environment that impact students' focus during lecture using Internet of Things," *Comput. Hum. Behav.*, vol. 53, pp. 427–434, Dec. 2015, doi: 10.1016/j.chb.2015.07.023.

[41] I. Kallel and M. Chniter, "Building collaborative e-Learning teams in a smart education environment," in *Proc. IEEE Int. Smart Cities Conf. (ISC)*, Casablanca, Morocco, Oct. 2019, pp. 324–329, doi: 10.1109/isc246665.2019.9071716.

[42] E. Oliveira, P. G. de Barba, and L. Corrin, "Enabling adaptive, personalised and context-aware interaction in a smart learning environment: Piloting the iCollab system," *Australas. J. Educ. Technol.*, vol. 37, no. 2, pp. 1–23, May 2021, doi: 10.14742/ajet.6792.

[43] E. Stefanidi, M. Doulgeraki, M. Korozi, A. Leonidis, and M. Antona, "Designing a teacher-friendly editor for configuring the attention-aware smart classroom," in *Proc. Int. Conf. Hum.-Comput. Interact.*, Toronto, ON, Canada, Jun. 2016, pp. 266–270, doi: 10.1007/978-3-319-40542-1_43.

[44] S. Song, X. Zhong, H. Li, J. Du, and F. Nie, "Smart classroom: From conceptualization to construction," in *Proc. Int. Conf. Intell. Environments*, Shanghai, China, Jun. 2014, pp. 330–332, doi: 10.1109/IE.2014.56.

[45] R. H. Huang, J. Du, T. W. Chang, M. Spector, Y. Zhang, and A. F. Lu, "A conceptual framework for a smart learning engine," in *Proc. ICSLE*, Tunis, Tunisia, 2016, pp. 69–72, doi: 10.1007/978-981-10-2419-1_11.

[46] M. Antona, A. Leonidis, G. Margetis, M. Korozi, S. Ntoa, and C. Stephanidis, "A student-centric intelligent classroom," in *Proc. Int. Joint Conf. Ambient Intell.*, Amsterdam, The Netherlands, 2011, pp. 248–252.

[47] L.-S. Huang, J.-Y. Su, and T.-L. Pao, "A context aware smart classroom architecture for smart campuses," *Appl. Sci.*, vol. 9, no. 9, p. 1837, May 2019, doi: 10.3390/app9091837.

[48] D. Bicheng, N. Adnan, M. B. Harji, and L. Ravindran, "Evolution and hotspots of peer instruction: A visualized analysis using CiteSpace," *Educ. Inf. Technol.*, vol. 28, no. 2, pp. 2245–2262, Feb. 2023, doi: 10.1007/s10639-022-11218-x.

[49] M. Jian, D. Jin, and X. Wu, "Research hotspots and development trends of international learning cycle model: Bibliometric analysis based on CiteSpace," *Heliyon*, vol. 9, no. 11, Nov. 2023, Art. no. e22076, doi: 10.1016/j.heliyon.2023.e22076.

[50] D. A. Callegari and F. M. de Oliveira, "Applying reinforcement learning to improve MCOE, an intelligent learning environment for ecology," in *Proc. MICAI*, Acapulco, Mexico, 2000, pp. 284–293.

[51] W. K. Xie, Y. C. Shi, G. Y. Xu, and D. Xie, "Smart classroom—An intelligent environment for tele-education," in *Proc. Pacific-Rim Conf. Multimedia*, Beijing, China, 2001, pp. 662–668.

[52] J. Yushendri, F. Rindani, A. A. Cristhian, Rustamin, and R. D. Agushinta, "Design the smart board system in ubiquitous computing for teaching and learning process," in *Proc. Int. Conf. Sci. Inf. Technol. (ICSITech)*, Yogyakarta, Indonesia, Oct. 2015, pp. 89–94, doi: 10.1109/ICSITech.2015.7407783.

[53] G. Margetis, A. Leonidis, M. Antona, and C. Stephanidis, "Towards ambient intelligence in the classroom," in *Proc. 6th UAHCI/14th HCI*, Orlando, FL, USA, 2011, pp. 577–586.

[54] G. G. Lenssen and N. C. Smith, "IBM and sustainability: Creating a smarter planet," in *Managing Sustainable Business: An Executive Education Case and Textbook*. Dordrecht, The Netherlands: Springer, 2019, pp. 549–556, doi: 10.1007/978-94-024-1144-7_25.

[55] J. Aguilar, P. Valdiviezo, J. Cordero, G. Riofrio, and E. Encalada, "A general framework for learning analytic in a smart classroom," in *Proc. 2nd Int. Conf. Technol. Innov.*, Guayaquil, Ecuador, 2016, pp. 214–225, doi: 10.1007/978-3-319-48024-4_17.

[56] J. Wang, K. Xie, Q. Liu, T. Long, and G. Lu, "Examining the effect of seat location on students' real-time social interactions in a smart classroom using experience sampling method," *J. Comput. Educ.*, vol. 10, no. 2, pp. 217–235, Jun. 2023, doi: 10.1007/s40692-022-00229-9.

[57] B. Sun, Q. Zhang, and S. Cao, "Development and implementation of a self-optimizable smart lighting system based on learning context in classroom," *Int. J. Environ. Res. Public Health*, vol. 17, no. 4, p. 1217, Feb. 2020, doi: 10.3390/ijerph17041217.

[58] H. Chen, G. Zhao, and N. Xu, "The analysis of research hotspots and fronts of knowledge visualization based on CiteSpace II," presented at the ICHL, 2012, doi: 10.1007/978-3-642-32018-7_6.

[59] Y. Lee, H. H. Yang, J. MacLeod, and J. Dai, "Developing the rotational synchronous teaching (RST) model: Examination of the connected classroom climate," *Australas. J. Educ. Technol.*, vol. 35, no. 1, pp. 116–134, Mar. 2019, doi: 10.14742/ajet.4010.

[60] D. Gong, H. H. Yang, D. Wu, and J. Dai, "Relationships between teaching presence, connected classroom climate, and deep learning within the rotational synchronous teaching model," *Educ. Inf. Technol.*, vol. 28, no. 2, pp. 1715–1733, Aug. 2022, doi: 10.1007/s10639-022-11207-0.

[61] L. Sardinha, A. M. P. Almeida, and M. P. Barbas, "Digital future classroom: The physical space and the inclusion of the neet/refugee population—Conceptual and theoretical frameworks and methodology," in *Proc. 11th INTED*, Valencia, Spain, Mar. 2017, pp. 2396–2405.

[62] Y. Li, H. H. Yang, and J. MacLeod, "Preferences toward the constructivist smart classroom learning environment: Examining pre-service teachers' connectedness," *Interact. Learn. Environments*, vol. 27, no. 3, pp. 349–362, Apr. 2019, doi: 10.1080/10494820.2018.1474232.

[63] J. Yang, H. Pan, W. Zhou, and R. Huang, "Evaluation of smart classroom from the perspective of infusing technology into pedagogy," *Smart Learn. Environments*, vol. 5, no. 1, p. 20, Sep. 2018, doi: 10.1186/s40561-018-0070-1.

[64] Y. Matsuyama, M. Nakaya, H. Okazaki, A. J. Lebowitz, J. Leppink, and C. van der Vleuten, "Does changing from a teacher-centered to a learner-centered context promote self-regulated learning: A qualitative study in a Japanese undergraduate setting," *BMC Med. Educ.*, vol. 19, no. 1, p. 152, May 2019, doi: 10.1186/s12909-019-1550-x.

[65] L. Yanli, "Exploration on smart classroom construction based on educational ecology," *J. Educ. Culture Stud.*, vol. 4, no. 4, p. p112, Nov. 2020, doi: 10.22158/jecs.v4n4p112.

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