Article

Knowledge Map of Digital Learning and Sustainable Development (2004-2022): a Scientometric Analysis by Using Citespace

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Abstract: The objective of this research is to establish a better understanding of the current landscape of digital learning research and sustainable development by using CiteSpace. First, we retrieved published publications from the Web of Science (2004–2022). Following that, we examined the primary research strengths and important subjects of digital learning from two perspectives: collaboration networks (including collaborative networks across countries, institutions, and authors) and co-citation networks. We examined the co-citation network from three perspectives: cluster analysis, the most active citers, top references. Furthermore, referenced journals, popular themes, and rising trends were examined. These findings indicate the primary study subjects in the field of digital learning, the most intriguing research literature, and each period's emerging research hotspots. Finally, we proposed further study ideas for future paths.

Keywords: digital learning; CiteSpace; visualization; Web of Science

1. Introduction

The COVID-19 epidemic has put a strain on the global education system, forcing colleges and universities rethink their methods of instruction by removing face-to-face interaction from the classroom [1]. As a result of the widespread use of information and communication technology (ICT), higher education has shifted to digital platforms and adapted virtual teaching to deliver online courses [2-3]. In the COVID-19 epidemic, where social distance is seen as the next degree of normalcy, there is an increasing urge to substitute physical engagement with virtual interaction. To meet the situation of educational institution closures prompted by COVID-19, UNESCO suggested that educational institutions equip themselves with digital learning resources [4]. Because of COVID-19, digital learning has grown in popularity throughout the world, as seen by the increasing funding for education-related digital learning initiatives and the use of newer technologies and techniques in the field to encourage student-teacher interaction.

Digital learning is thought to have a significant impact on students' academic achievement [5]. It has developed as a potent learning medium, particularly when applying internet as a delivery method. Learner satisfaction has skyrocketed following the successful adoption of digital learning platforms [6]. It is possible for professors and teachers to design out their lessons, implement them, and keep track of the progress of their students using digital learning tools. Consequently, it is critical for educational institutions to provide a learning environment that motivates students to succeed while also allowing them to grow.

In light of this, a number of research have achieved advancements in the profiling of literature on digital learning. In these studies, a variety of perspectives have been explored, including the contribution of MOOCs to students' equity and social inclusion [7]; self-regulated learning in MOOCs [8]; the impacts of flipped classrooms on students [9-12]; learning strategies in flipped classrooms [13-14]; the indicators of acceptance of e-learning [15]; and the extended model of the Technology Acceptance Model [16]. There is a dearth of bibliometric quantitative analysis in this discipline because of the reliance on expert opinion in the majority of cases (e.g. analysis of the frequency of words, the authors, the citations, the co-citations, the co-occurrences). Despite the fact that there are a lot of books and articles about digital learning, its overall structure is unknown to the best of our knowledge.

To overcome the subjectivity of research, knowledge mapping—a new multidisciplinary field of study that aims to track, mine, analyze, sort, and present information—is introduced into the field of digital learning. CiteSpace, a software that incorporates bibliometric analysis, data mining tools, and visualization techniques, is better at making visualizations clear and easy to understand than other tools. This makes it easier for users to identify the most essential trends and critical points without having to think too hard about it [17].

So far, only a small amount of research had been done with CiteSpace to analyse the rapidly expanding digital learning literature. Based on the China National Knowledge Infrastructure (CNKI) (2000–2020), CiteSpace was used by Huang & Zhou (2021) to assess the knowledge map of digital resources in the 21st century and examine the changes and development of digital learning resource research [18]. Based on data from the Web of Science (WoS), Park and Shea (2020) conducted a co-citation study of digital research trends over the past ten years and discovered features and changes in research trends in digital learning as well as the most cited publications in the field [19]. Based on the WoS database from 1995 to 2018, Negahban and Zarifsanaiey (2020) investigated the research trends in the field of digital learning by assessing relevant studies employing network analysis and scientific mapping techniques and identified the most frequently used terminology, the greatest impact studies, and some topics that served as bridges to connect different topics [20]. Based on the CNKI database from 2000 to 2021, Chi (2021) analyzed the number distribution of blended learning literature, core authors, and research institutions, and further conducted keyword co-occurrence analysis, emergence detection analysis, and cluster time domain mapping analysis by using the knowledge mapping tool CiteSpace [21]. Based on the WoS dataset from 2012 to 2018, Zheng et al. (2019) charted the knowledge mapping of MOOCs research and revealed the most important individuals and organizations, as well as well-known terms and periodicals in this field's scholarly literature [22].The existing literature had laid a foundation for understanding and in-depth research in the field of digital learning. However, there are still certain drawbacks, such as a lack of rigorous bibliometric analysis, limiting literature sources, and low sample sizes.

To give a holistic and impartial overview of research on online learning, this study utilizes a scientometric analysis based on CiteSpace to identify bibliometric traits and show relationships among publications on this subject published in WoS journals between 2004 and 2022. More precisely, the research is governed by four overarching objectives: (1) to gain an understanding of the characteristics of cooperation in the field of digital learning; (2) determine who are the most highly referenced researchers and journals in the field; (3) to demonstrate the primary areas of knowledge and how they have changed over time; and (4) to identify new subjects in digital learning research that have emerged over the years.

The rest of the document is structured as follows: The section under "Materials and Methods" describes data collecting as well as CiteSpace. The "Results" section includes a complete study of research outputs and their categories: the cooperation network (e.g., nation, institution, and author), the cocitation network (e.g., article, author, and journal), and developing trends. Finally, the "Discussion" section sums up the most important findings and suggests new directions for future research, which shows how this work can be used by a wide range of scientists.

2. Materials and Methods

2.1. Research Tools

Scientometric analysis is an important tool for dealing with data and information visualization, and it may be used to identify research frontiers and hotspots, as well as track key developments in one field. To prevent subjectivity, scientometric analysis primarily uses statistical methodologies to assess, analyze, and evaluate the quality and characteristics of research materials. According to a massive collection of publications in the database of scholarly literature, this approach is recognized as a popular tool for learning about a single topic, summarizing the development route, and forecasting the future trend. Many literature analysis programs, notably CiteSpace, are employed in scientometric analysis.

CiteSpace is a Java-based program developed by Chaomei Chen, a well-known academic whose research interests include information visualization, knowledge mapping, and scientific frontier atlases. CiteSpace is an effective tool for swiftly acquiring knowledge on a certain topic. CiteSpace's underlying approach is to designate co-citation clusters and then create timeliness and critical spots using time-sliced snapshots. CiteSpace 6.1.R1 (64-bit) was utilized in this study, which runs on the Java 8 environment. Kleinberg's burst detection, Freeman's betweenness centrality (BC) measure, and heterogeneous networks are all included in the latest edition. This means that three critical issues may be addressed more effectively: (1) establishing research frontiers, (2) categorizing specializations, and (3) spotting developing trends and abrupt points. Moreover, recently, the number of publications employing CiteSpace has expanded dramatically, and the software can be obtained from http://cluster.ischool.drexel.edu/cchen.CiteSpace.download.html (Retrieved on April 20th, 2022).

2.2. Data Collection

As the most important component of a review article, data gathering plays a pivotal role in determining the quality and effectiveness of a review article. The WoS is among the most famous citation indexes. Scientists can use the Science Citation Index (SCI), the Social Science Citation Index (SSCI), as well as the Arts and Humanities Citation Index (AHCI) to do their research. In order to discover the most relevant and appropriate articles, this article employed a certain procedure for collecting and selecting information: (1) Select the WoS Core Collection; (2) Choose the advanced search option; (3) abide by Table 1's search requirements; and (4) finalize the collection of data. After removing duplicates, a total of 25382 qualified records were retained.

Table 1. Detailed search setting parameters.

Source	WoS Core Collection
Citation	SCI-EXPANDED,SSCI,AHCI
Search conditions	ts=("digital education" OR "online learning" OR "digital learning" OR "electronic learning" OR "online-merge-offline" OR "distance teaching" OR "remote instruction" OR "distance learning" OR "remote education" OR "online teaching" OR "online education" OR "blended learning" OR "online reading" OR "smart learning" OR "e-learning" OR "massive open online courses" OR "online course" OR "computer supported collaborative learning" OR "immersive Learning" OR "smart education" OR "moodle" OR "small private online course" OR "massive private online course" OR "flipped classroom" OR "ubiquitous learning" OR "online course") AND language:(English) Type:Article,Published Online,Review
Time span	2004-2022
Qualified records	25382

2.3. Research Framework

In this paper, we provide an integrated framework for interpreting the trends and sustainable development in digital learning for a total of 25382 publications from 2004 to 2022 (Figure 1). Stable results can be achieved by tweaking the parameters over and over again. During this investigation, the following tasks were accomplished: (1) descriptive statistical analysis, including the distribution of publications, with the goal of gaining a comprehensive picture of this field; (2) collaboration network analysis, including three levels, namely nation, institution, and author, is intended to describe the main contributions of digital learning from the macro, medium, and micro levels; (3) cited reference analysis, including cluster of cited references, most active citer of clusters, and top references, intended to identify primary research topics, and the classic literature; (4) cited journal analysis, including top citation of journals, and top citation burst; (5) research hotspots, analyzing the current research hotspots of digital learning through keyword co-occurrence network analysis and keyword clustering, dividing hotspot keywords into three types, and analyzing the evolution of the research topic. Researchers have discovered five potential future research trajectories using burst detection.

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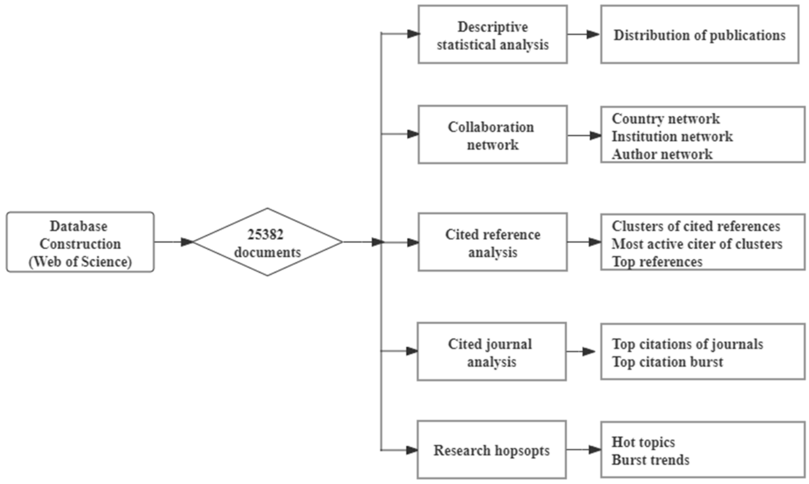

Figure 1. General framework of this study.

3. Results

3.1. Research Outputs

The progression of papers published related to digital learning during the 19-year period 2004–2022 is shown in Figure 2. There is a definite growing trend in the use of scientific research in digital learning throughout the years. According to the growth curve of digital learning research, three stages can be identified as follows:

(1) Stage of slow development (2004–2010). Prior to 2008, the number of papers published each year averaged around 500. Although researchers had recognized that digital learning could be a useful complement to traditional learning, the main research content at this stage was mostly more general theoretical and practical explorations, such as barriers to digital learning for students [23], students' experiences of digital learning [24], learner characteristics and their approaches to managing learning (Rodrigo et al., 2009), and combining digital learning with traditional methods [26].

(2) Stage of rapid development (2011–2016). By this stage, some empirical studies on digital learning had been produced. The research in this period mainly includes two categories: one is the influence of digital learning on students [27-30]; the second is the factors affecting students' digital learning participation, performance, and satisfaction [31-33]. In comparison to previous years, the volume of articles has increased significantly faster now. The annual number of articles published exceeded 1000 during this period.

(3) Stage of explosion (2017- 2022). Since 2017, A growing number of policymakers, academics and international organizations are taking a closer look at digital learning difficulties. During this period, there were more than 1500 articles published annually. The main reasons behind this may include two aspects: first, the rapid development of information and communication technology provides a foundation for the popularization of digital learning [3]; second, during the COVID-19 pandemic, in order to avoid large-scale transmission of the virus, schools temporarily stopped face-to-face offline teaching and switched to digital learning [4]. According to incomplete statistics, about 1.2 bifllion students have used digital learning so far. At the same time, research on digital learning has grown explosively.

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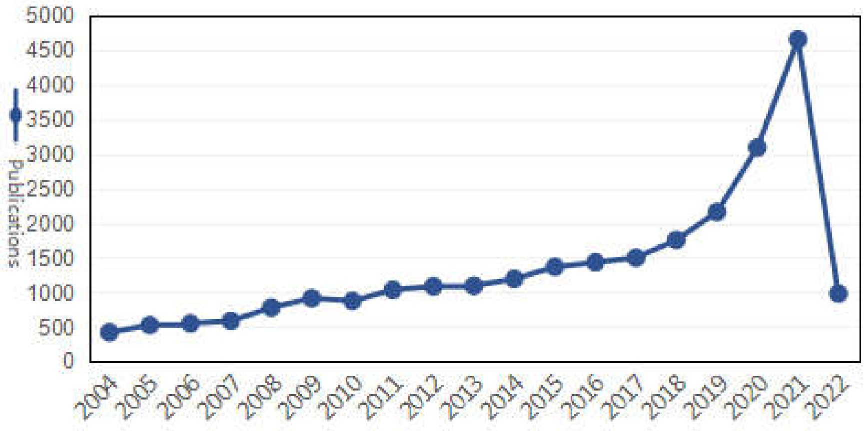

Figure 2. Publications from 2004 to 2022.

3.2. Collaboration Network

3.2.1. Country Collaboration Network

Figure 3 depicts the collaboration network, which had 243 nodes and 3452 linkages between 2004 and 2022, and Table 2 lists the 10 nations that contributed the most to the overall outputs. The United States publishes the most papers (6948), followed by China (4978, including the Taiwan district (1582)) as the second greatest provider. England ranked third, as its number of publications was 1986. In general, the number of outputs is proportional to the number of research institutes and the amount of funds available for research. Another clear explanation for increased research outputs is that the unique coronavirus epidemic has prompted educational institutions in the great majority of nations to shift from conventional face-to-face instruction to digital teaching. As a node's BC indicates how many shortest routes flow through it, the node's relevance grows. CiteSpace uses this statistic to assess a node's importance to the network. An essential reference for the field is judged to have a betweenness value of 0.1 or more. It is clear that European countries play a big part in making connections with other countries because of their high BC, including Switzerland (0.12), Finland (0.12), and France (0.1).

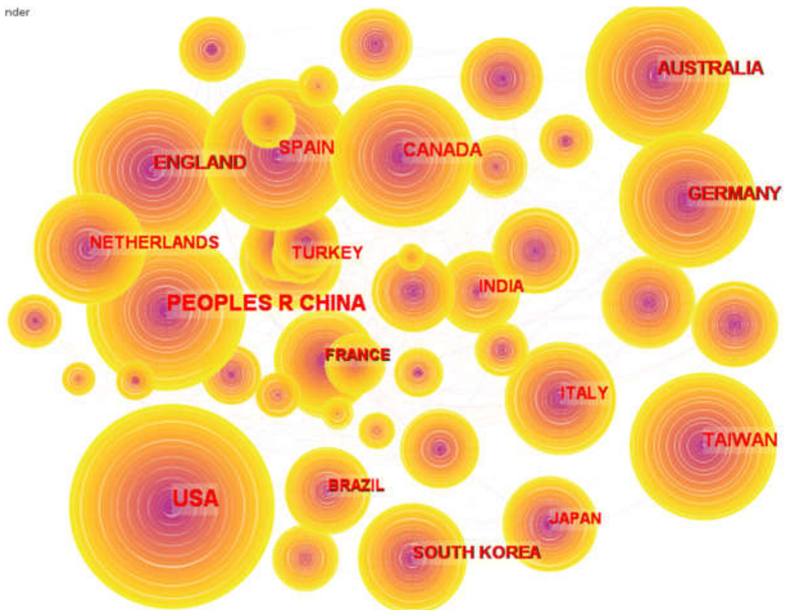

Figure 3. Visualization of the country collaboration network.

Table 2. Top 10 countries based on frequency and BC.

Country	Frequency	Country	BC
USA	6948	England	0.38
China	3396	Canada	0.22
England	1986	Sweden	0.22
Spain	1921	France	0.18
Australia	1685	India	0.13
Canada	1262	Saudi Arabia	0.13
Germany	1197	Scotland	0.13
Turkey	762	USA	0.12
Netherlands	686	Portugal	0.12
Portugal	632	Australia	0.11

3.2.2. Institution Collaboration Network

Figure 4 depicts the collaboration network of universities between 2004 and 2022, which included 1652 institutions and 3985 linkages. Even if there are some connections between the nodes, the colors are lighter, indicating that although there is some collaboration between the nations, the degree of cooperation is not profound at this time. Because of this, there is greater room for growth in the area of digital education in the future. Table 3 lists the top 20 institutions in terms of overall outputs and the percentage of their outputs that they contributed to. With 231 publications, the Open University takes the top spot on the list and Nanyang Technological University (202), Monash University (186), the University of Toronto (180), and the University of Sydney (180) are additional institutions with a substantial number of publications (174). Clearly, institutional contributions to digital learning line up with countries.

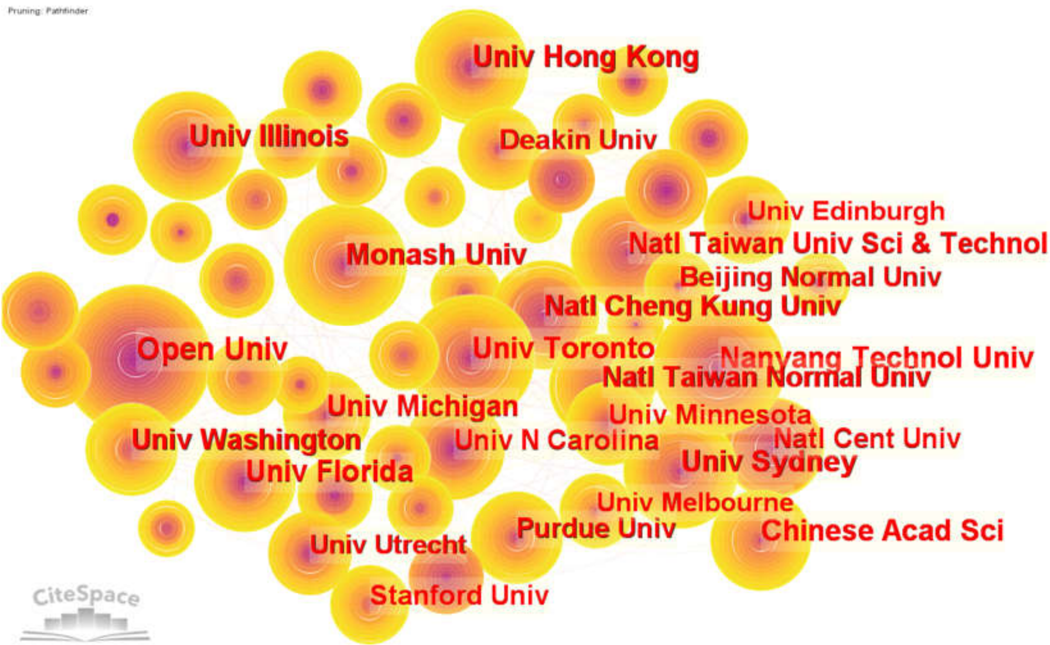

Figure 4. Visualization of the institution collaboration network.

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Table 3. A list of the top 20 most frequently visited institutions.

Institution	Frequency	Country
Open Universiy	231	United Kingdom
Nanyang Technology University	202	Singapore
Monash University	186	Australia
University Toronto	180	Canada
University Sydney	174	Australia
University Hong Kong	169	China
University Illinois	155	America
Chinese Academic Science	153	China
University Florida	149	America
Natl Cheng Kung University	143	Singapore
Natl Taiwan Normal University	142	China
Natl Taiwan University Science & Technology	142	China
University Michigan	129	America
University Washington	126	America
Natl Cent University	124	China
University N Carolina	119	America
Beijing Normal University	117	China
Purdue University	115	America
Deakin University	113	Australia
University Minnesota	108	Australia

3.2.3. Author Collaboration Network

There were 3765 authors and 9142 cooperation ties in the author collaboration network for digital learning research depicted in Figure 5. Research in digital learning is multidisciplinary because of the network's size and scope and the variety of collaborations among its members. HWANG GWO-JEN appears to be the most prolific author in the area of digital learning; he has worked on the U-learning environment and learning strategy, intelligent online learning, and game-based learning strategy for over 15 years. Furthermore, three major authors (HWANG GWO-JEN， HUANG YUEH-MIN, CHEN NIAN-SHING) developed a closer relationship since 2008. Table 4 shows that the majority of the writers in the top 10 list are associated with a department or faculty that specializes in digital learning, engineering, information, or electronics.

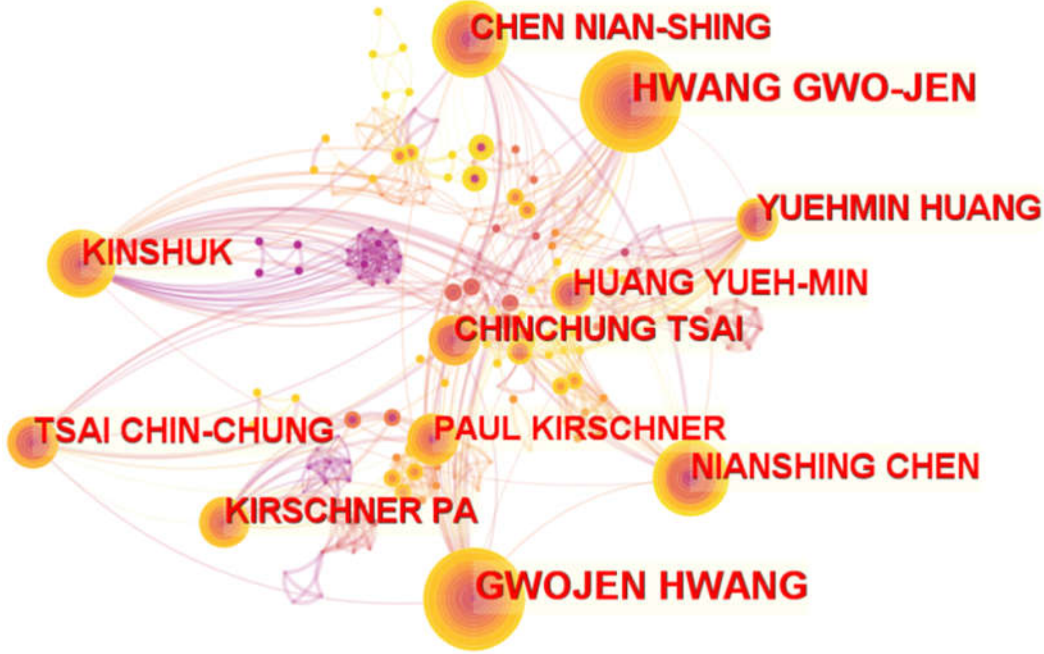

Figure 5. Visualization of the author network.

Table 4. Top 10 authors based on frequency.

Frequency	Author	Institution
57	HWANG GWO-JEN (2008) [34]	Graduate Institute of Digital Learning and Education,National Taiwan University of Science & Technology
39	HUANG YUEH-MIN (2006) [35]	Department of Engineering Science,National Cheng Kung University
35	CHEN NIAN-SHING (2007) [36]	Department of Information Management,National Sun Yat Sen University
35	KIRSCHNER PA (2004) [37]	Research Centre for Learning ,Teaching and Technology,Open University Netherlands
34	KINSHUK (2004) [38]	College of Information,University of North Texas System
34	TSAI CHIN-CHUNG (2008) [39]	Graduate Institute of Digital Learning and Education,National Taiwan University of Science & Technology
34	VAN DER SCHAAR MIHAELA (2010) [40]	Department of Electrical and Computer Engineering,University of California Los Angeles
31	PAUL KIRSCHNER (2007)[41]	Research Centre for Learning ,Teaching and Techology,Open University Netherlands

3.3. Knowledge Structure Map

The development of a new subject necessitates the accumulation of knowledge in related fields. Research papers cannot be generated purely based on their own content. The article should draw on previous research and literature in the field or in related fields. Journal articles are generally considered to represent the cutting edge of specific areas, and references in these articles are often used as a basis for further research. We were able to detect co-citation clusters using a computer application that let us locate common citations in digital learning. Using journal articles to visualize digital learning research's foundational knowledge is a critical first step in identifying such information.

CiteSpace was configured with the parameters listed below: (1) Time slicing: from 2004 to 2022 ,and years per slice: 1; (2) Term source: title, abstract, descriptors, identifiers; (3) Node type: cited reference; (4) Pruning: pathfinder and pruning the merged network; (5) Top N per slice: Select top 50 most cited articles per slice. CiteSpace generated a map depicted in Figure 6. For the clustering, this study employed log-likelihood ratios and the

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labeling source of 'T'. According to co-citation cluster statistics, there are 27 knowledge clusters, seven of which are large clusters (Figure 7).

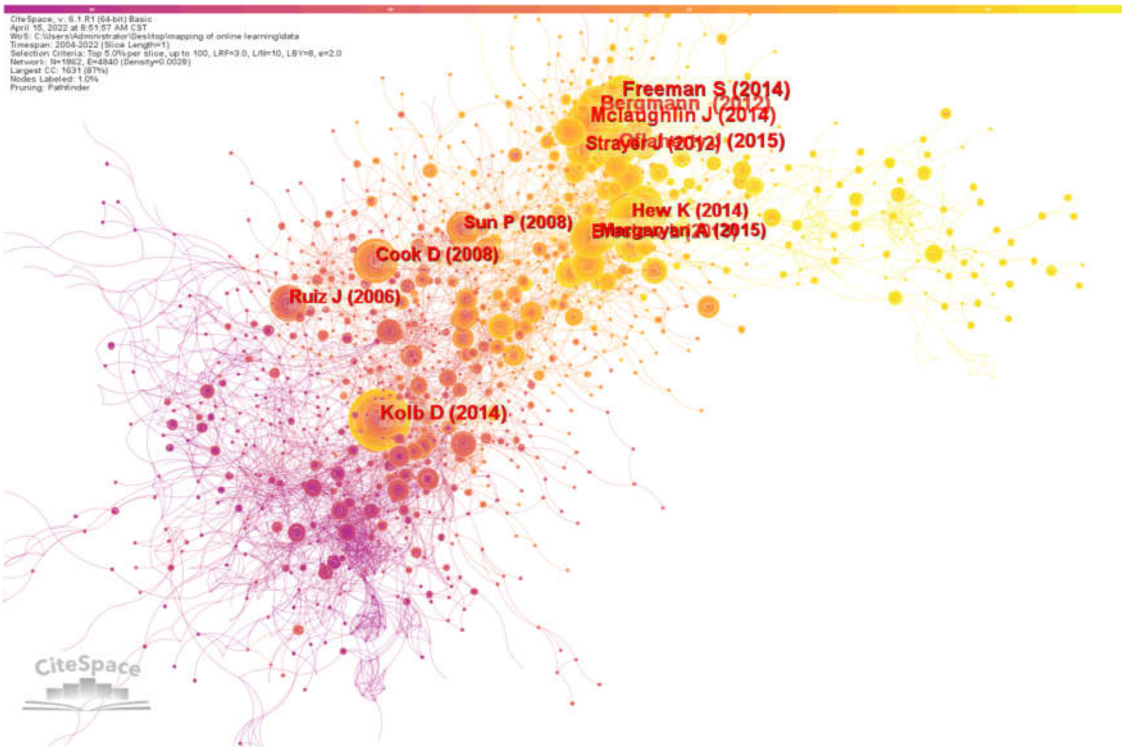

Figure 6. Mapping of cited reference.

Modularity Q ranges from 0 to 1, with values closer to 1 indicating tighter relationships and connections within the cluster. As a general rule, Modularity Q levels between 0.4 and 0.8 can be deemed appropriate [42]. The range for the Mean Silhouette is -1 to -1. Content consistency or similarity is high when a cluster's value is close to 1 [42]. According to Figure 7 and Table 5, Modularity Q is 0.7948, and the Mean Silhouette is 0.9058. The Silhouette values for each of the 27 clusters are more than 0.8. This means that the digital learning research mapping has undergone a high-quality cluster analysis.

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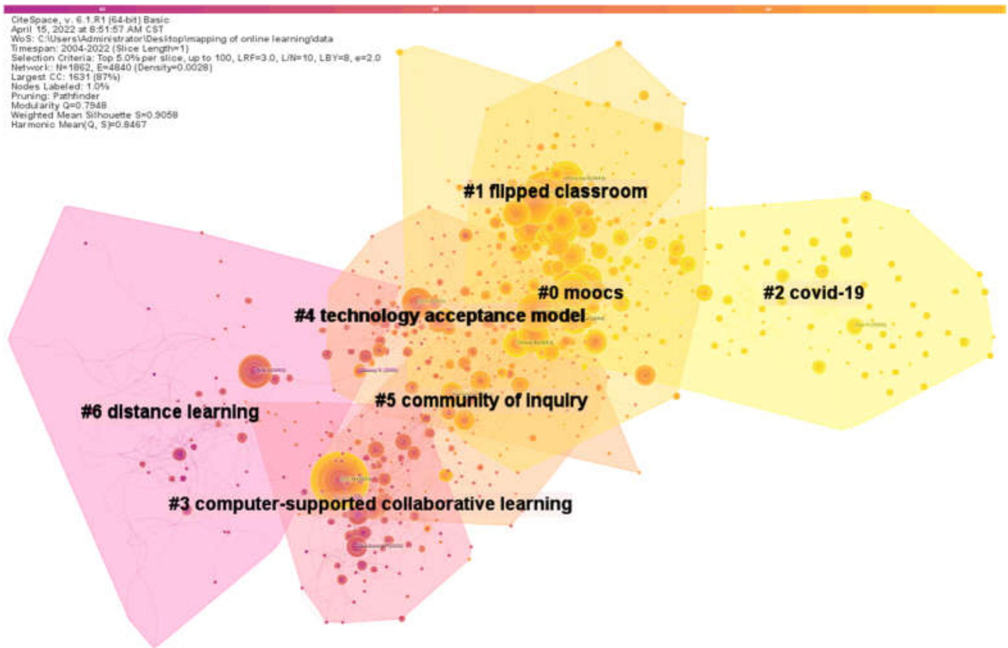

Figure 7. Co-citation Clusters of Cited references.

Table 5. Details of knowledge clusters.

ID	Size	Silhouette	Year	Label(LLR)
0	136	0.888	2017	**MOOCs** (100.05, 1.0E-4); mooc (91.27, 1.0E-4); massive open online courses (69.47, 1.0E-4); massive open online course (mooc) (30.15, 1.0E-4);
1	131	0.95	2017	**flipped classroom** (302.26, 1.0E-4); active learning (66.96, 1.0E-4); flipped learning (56.35, 1.0E-4);
2	129	0.969	2021	**covid-19** (266.26, 1.0E-4); covid-19 pandemic (47.92, 1.0E-4); pandemic (39.18, 1.0E-4);
3	121	0.858	2009	**computer-supported collaborative learning** (59.73, 1.0E-4); collaborative learning (32.65, 1.0E-4);
4	114	0.858	2013	**technology acceptance model** (22.88, 1.0E-4); e-learning (18.51, 1.0E-4); flipped classroom (16.28, 1.0E-4);
5	109	0.852	2013	**community of inquiry** (49.5, 1.0E-4); social presence (38.98, 1.0E-4); teaching presence (29.6, 1.0E-4);
6	108	0.922	2005	**distance learning** (25.48, 1.0E-4); internet (20.91, 1.0E-4); medical education (18.04, 1.0E-4); e-learning (13.74, 0.001);

Specifically, from Table 5, it can be seen that the biggest and most important cluster was MOOCS (#0). This cluster of studies focuses on motivations and challenges, instructional quality, enrolment and completion, and so on. A total of 136 items were found in this cluster, most of which were published in 2017. This cluster has a silhouette value of 0.888, indicating that the 136 cited literatures in the cluster had a high consistency, with Hew's (2014) article on motivation and challenges of MOOCs use being referenced to most frequently (among this cluster,42% of the articles cited Hew's article, which was published in the Educational Research Review) [43]. The second most-cited article was Margaryan's (2015) on instructional quality [44], published in the Computers and Education and cited by 37 percent of the articles in the cluster. The essay by Liyanagunawardena (2013) came in third place in terms of citations [45], which is a systematic literature review between 2008 and 2012. A 2014 study by Jordan published in the International Review of Research in Open and Distributed Learning [46], which investigated initial tendencies in enrolment and completion, was the article with the fourth-highest number of citations.

The second largest cluster, labelled "flipped classroom" (#1), contains 131 articles with a silhouette value of 0.95. Oflaherty's (2015) paper on students' satisfaction with blended instructional design was the most cited [47], with 41 percent of the 131 articles.

The third largest cluster (#2) contains 129 articles with a silhouette value of 0.969, which indicates the high consistency of this cluster. The most-cited article within the cluster was Dhawan's (2020) article on a systematic literature review on the definition of digital learning [48]. Details about these clusters are shown in Table 6.

Table 6. Most active citer of the clusters.

Coverage	Author(Year)	Articles
Cluster #0		
42%	Hew (2014) [43]	Students' and instructors' use of massive open online courses (MOOCs): Motivations and challenges
37%	Margaryan (2015) [44]	Instructional quality of Massive Open Online Courses
32%	Liyanagunawardena (2013) [45]	MOOCs: A systematic study of the published literature 2008-2012
32%	Jordan (2014) [46]	Initial trends in enrolment and completion of massive open online courses
Cluster #1		
51%	Oflaherty (2015) [47]	Students' Satisfaction with a Blended Instructional Design: The Potential of" Flipped Classroom" in Higher Education.
41%	Strayer (2012) [49]	How learning in an inverted classroom influences cooperation, innovation and task orientation
Cluster #2		
23%	Dhawan (2020) [48]	How many ways can we define online learning? A systematic literature review of definitions of online learning (1988-2018)
22%	Rose (2020) [50]	Medical student education in the time of COVID-19
21%	Bao (2020) [51]	COVID-19 and online teaching in higher education: A case study of Peking University
21%	Henseler (2015) [52]	A new criterion for assessing discriminant validity in variance-based structural equation modeling
Cluster #3		
25%	De (2006) [53]	Content analysis schemes to analyse transcripts of online asynchronous discussion groups: a review
18%	Kirschner (2006) [54]	An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching
17%	Weinberger (2005) [55]	Epistemic and social scripts in computer-supported collaborative learning
17%	Fischer (2013) [56]	Toward a script theory of guidance in computer-supported collaborative learning
Cluster #4		
45%	Sun (2008) [39]	What drives a successful e-Learning? An empirical investigation of the critical factors influencing learner satisfaction
22%	Liaw (2008) [57]	Investigating students' perceived satisfaction, behavioral intention, and effectiveness of e-learning: A case study of the Blackboard system
21%	Alraimi (2015) [58]	Understanding the MOOCs continuance: The role of openness and reputation

Analysis was also carried out to determine the most widely cited papers based on the amount of citations (Table 7). Top 5(citation above 600) most-cited studies include: Oflaherty (2015)'s study on the impact of flipped classroom on students' learning satisfaction and involvement (citation 1295) [47]; Sun (2008)'s study on the influencing factors of students' satisfaction with e-learning (citation 1033) [39]; Hew (2014)'s study on motivation, challenges, and unresolved issues in MOOCs use (citation 879) [43]; Strayer (2012)'s study comparing flipped classroom and traditional classroom (citation 790) [49]; Margaryan (2015)'s study on the quality of MOOCs instructional design (citation 655)[44].

Table 7. Top 5 References with cited frequency.

Authors	Articles	Cited Frequency	Year
Oflaherty	Students' Satisfaction with a Blended Instructional Design: The Potential of" Flipped Classroom" in Higher Education.	1295	2015
Sun	What drives a successful e-Learning? An empirical investigation of the critical factors influencing learner satisfaction	1033	2008
Hew	Students' and instructors' use of massive open online courses (MOOCs): Motivations and challenges	879	2014
Strayer	How learning in an inverted classroom influences cooperation, innovation and task orientation	790	2012
Margaryan	Instructional quality of massive open online courses (MOOCs).	655	2015

A surge in citations is a sign that a certain field of study is becoming more and more well-known. Evidence of a citation spike might be seen in the form of citation bursts [42]. With a citation burst value of 23.96, Bergmann's (2012) paper from cluster #6 came out on top [59]. Indicators such as an increase in citations to a single article during a period of strong activity in a particular field of study are known as a "citation burst" [42]. Table 8 lists the top 20 burst-based authors and research.

Table 8. Top 20 References with strongest citation bursts.

References	Year	Strength	Begin	End
Palloff R, 1999, *Jossey-Bass*, CO, V0 [60]	1999	14.15	2004	2007
Ruiz J, 2006, *Academic Medicine*, V81, P207 [61]	2006	22.37	2007	2014
Garrison D, 2004, *The Internet and Higher Education*, V7, P95 [62]	2004	15.9	2007	2012
Bernard R, 2004, *Review of Educational Research*, V74, P379 [63]	2004	13.74	2007	2012
Cook D, 2008, *The Journal of the American Medical Association*, V300, P1181 [64]	2008	20.38	2009	2016
Sun P, 2008, *Computers & Education*, V50, P1183 [39]	2008	17.97	2010	2016
Bergmann , 2012, *International Society for Technology in Education*, V0 [59]	2012	23.96	2015	2019
Mclaughlin J, 2014, *Academic Medicine*, V89, P236 [65]	2014	18.71	2015	2020
Margaryan A, 2015, *Computers & Education*, V80, P77 [44]	2015	13.53	2015	2020
Strayer J, 2012, *Learning Environments Research*, V15, P171 [49]	2012	14.77	2016	2020
Davies R, 2013, *Educational Technology Research and Development*, V61, P563 [66]	2013	13.41	2016	2020
Freeman S, 2014, *Proceedings of the National Academy of Sciences*, V111, P8410 [67]	2014	20.8	2017	2022
Hew K, 2014, *Educational Research and Reviews*, V12, P45 [43]	2014	15.45	2017	2022
Oflaherty J, 2015, *The Internet and Higher Education*, V25, P85 [47]	2015	18.78	2018	2020
Abeysekera L, 2015, *Higher Education Research & Development*, V34, P1 [68]	2015	18.7	2018	2020
Mason G, 2013, *IEEE Transactions on Education*, V56, P430 [69]	2013	14.26	2018	2020
Hone K, 2016, *Computers & Education*, V98, P157 [70]	2016	13.64	2019	2022
Kizilcec R, 2017, *Computers & Education*, V104, P18 [71]	2017	13.5	2019	2022
Cao W, 2020, *Psychiatry Research*, V287, P0 [72]	2020	18.24	2020	2022
Rose S, 2020,*The Journal of the American Medical Association*, V323, P2131 [50]	2020	14.58	2020	2022

Purple rings indicate significant research with a high BC. A larger circle signifies a greater degree of importance for betweenness. A research with a centrality rating of equal to or more than 0.1 is generally regarded an important study. For example, Means (1988)'s study on meta-analysis of online learning had a centrality value of 0.18 [73]. Rourke (2007)'s study had a centrality value of 0.11 [74]. Table 9 specifies the top 9 key pieces of literature in the digital learning knowledge map.

Table 9. Top 9 references by centrality.

Centrality	References
0.18	Means B, 2009, *Evaluation Evidence,* V0, P0 [73]
0.11	Rourke L, 2007,*The Journal of Distance Education*, V14, P50 [74]
0.11	Pena-shaff J, 2004, *Computers & Education*, V42, P243 [75]
0.1	Kolb D, 2014, *FT Press*, V0, P0 [76]
0.09	Broadbent J, 2015, *The Internet and Higher Education*, V27, P1 [77]
0.08	Schellens T, 2006, *Computers & Education*, V46, P349 [78]
0.08	Tucker B, 2012, *Education Next*, V12, P82 [79]
0.08	Schrire S, 2006, *Computers& Education*, V46, P49 [80]
0.08	Anderson T, 2001, *American Journal of distance education*, V15, P7 [81]

3.4. Distribution of Cited Journals

To systematically learn about the publication status, the cited journal network is shown in Figure 8 and Table 10. Articles from the Computer and Education have a total citation of 2684. Articles from Educational Technology Research and Development have a total citation of 1958, and articles from the Internet and Higher Education have a total citation of 1628. Computers in Human Behavior has a total citation of 1540. It is clear that these journals are an important source of knowledge in the field of online learning.

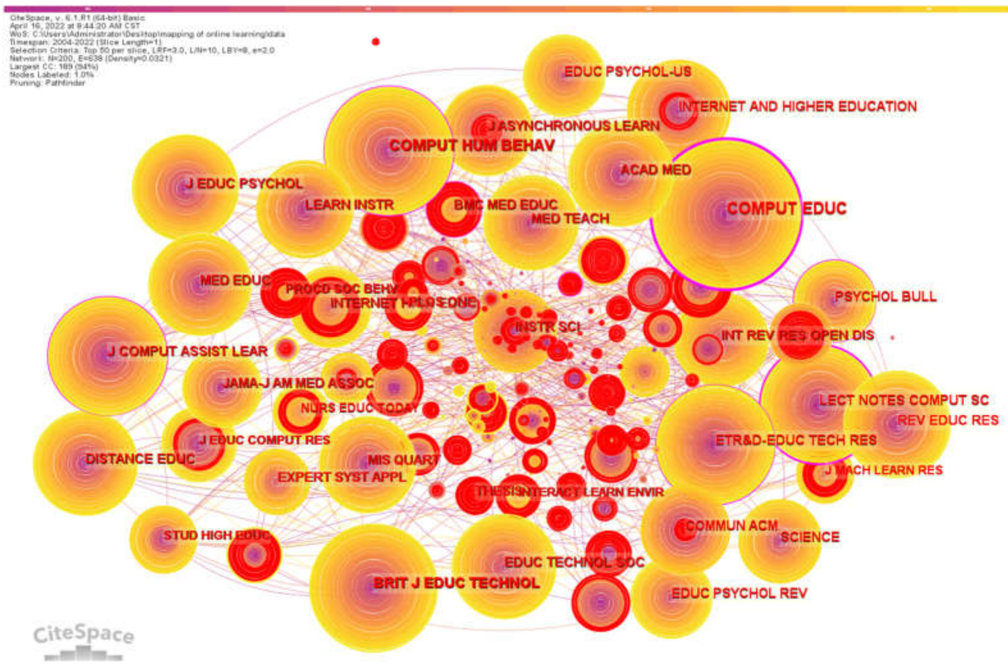

Figure 8. Cited journal network.

Table 10. Journals with 600+ citations.

Source	Frequency	Year
Computers & Education	2684	2004
Educational Technology Research and Development	1958	2004
The Internet and Higher Education	1628	2008
Computers in Human Behavior	1540	2004
British Journal of Educational Technology	1371	2004
Lecture Notes in Computer Science	1063	2004
Educational Technology & Society	1060	2006
Journal of Computer Assisted Learning	932	2004
Review of Educational Research	812	2004
Journal of Educational Psychology	700	2004
Distance Education	688	2004
Academic medicine	672	2004

Nevertheless, for the period (2004-2022), from the perspective of the burst values (Table 11), with a burst value of 126.45, Thesis ranked first. Frontiers in Psychology has a burst value of 82.13. Additional journals with quite high burst values include Education and Information Technologies (77.36), IEEE Access (73.02), American Journal of Distance Education (67.83), PLOS One (63.02), International Journal of Educational Technology in Higher Education (58.35), and Educational Research Review (56.19), which are mainly related to information technology and education. It is clear that these journals are the most active in the field of digital learning.

Table 11. Top cited journals by citation burst.

Journals	Strength
Thesis	126.45
Frontiers in Psychology	82.13
Education and Information Technologies	77.36
IEEE Access	73.02
American Journal of Distance Education	67.83
PLOS One	63.02
International Journal of Educational Technology in Higher Education	58.35
Educational Research Review	56.19
Neurocomputing	50.55
Innovations in Education and Teaching International	50.46

3.5. Popular Topics and Emerging Trends

The findings of the keyword visualization provide insight into popular topics and developing tendencies. Keywords with high frequency are shown in Figure 9 and Table 12, including "student," "higher education," "model," "performance," "technology," "impact," "system," "design," "knowledge," and so on. Table 12 provides a list of the top 24 most frequently used terms in the visualization results to aid in understanding and the highest BC that appeared in the 25382 articles, and more than 400 occurrences of each term have been indexed. To a significant degree, these keywords might represent current research tendencies and popular subjects.

Table 12 shows keywords with both high frequency and high BC, mainly including three types of keywords: student-related, system-related, and teacher-related. First of all, keywords related to students include: "student", "higher education", "model," "performance," "impact," "motivation," "satisfaction," and "experience." Most of these studies focus on the construction of models of learning performance, learning motivation, learning satisfaction, learning experience, and other influencing factors of digital learning for students in higher education institutions. Rahman (2021) adapted PLS-SEM to study the effects of direct instruction, teacher-learner interaction, learner-learner interaction, and self-efficacy on digital learning motivation and satisfaction. The results show that digital learning motivation has a significant mediating effect between independent variables and learning satisfaction. In addition, direct instruction, learner-learner interaction, and online self-efficacy significantly predicted students' digital learning satisfaction [82]. Yang (2022) studied students' online self-evaluation task behavior and its impact on academic performance [83]. Online evaluations after class appear to have a positive impact on students' exam scores, according to the findings. Nevertheless, despite taking the exams, the learning performance of learners who displayed nonstandard conduct did not necessarily improve.

Secondly, keywords related to learning systems include "system," "design," "environment," "framework," "algorithm" and "information". The research related to learning systems mainly focuses on how to design an online learning system to improve the digital learning environment and enhance information quality. For example, Buabeng-andoh (2022) studied the influencing factors of learners' operations of their teaching and learning systems during COVID-19 [84]. The results show that nine factors, namely performance expectancy, effort expectancy, attitude, social influence, facilitating condition, self-efficacy, behavioral intention, perceived enjoyment, and system quality, have a significant positive impact on learners' teaching system operation.

Finally, keywords related to teachers include "strategy," "quality," "instruction," and "knowledge." Focus on how teachers adopt effective teaching strategies to improve teaching quality and optimize the knowledge transfer process. Hongsuchon (2022) studies the factors influencing the effectiveness of digital learning, including students' self-efficacy, teachers' self-efficacy, attitudes, technological confidence, educational strategies, and positivity [85]. Learning objectives, according to the findings of this study, might help universities improve the efficacy of students' digital learning by persuading them to enroll in digital courses and designing learning techniques that are tailored to their specific requirements.

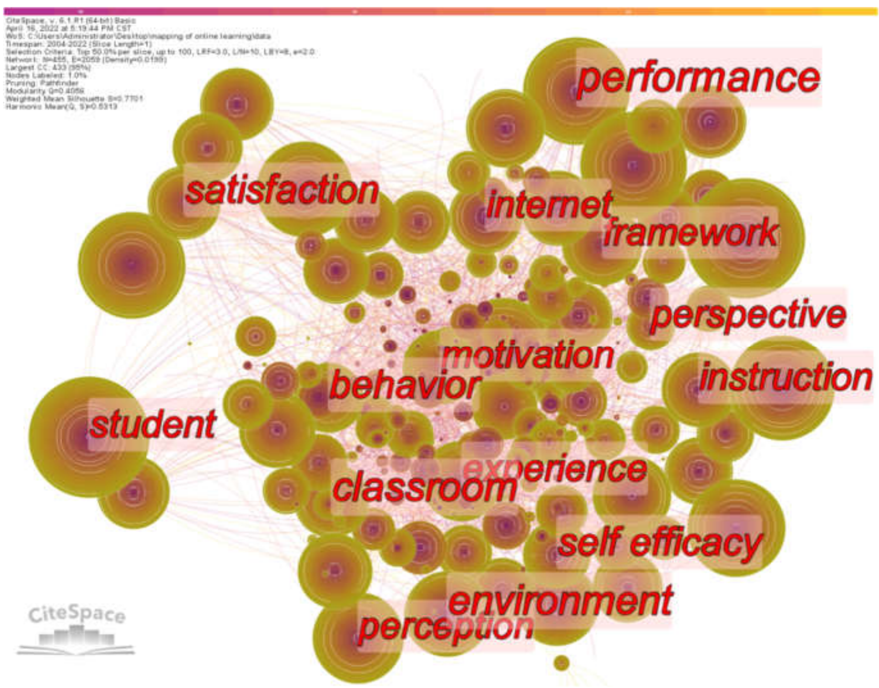

Figure 9. Hot topics.

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Table 12. Top 24 research keywords by frequency and centrality.

Keywords	Frequency	Keywords	Centrality
student	1895	performance	0.1
higher education	1417	algorithm	0.07
model	1400	student	0.06
performance	1359	experience	0.06
technology	1106	professional development	0.06
impact	1040	higher education	0.05
system	1017	model	0.05
design	919	system	0.05
knowledge	807	satisfaction	0.05
perception	776	environment	0.05
motivation	685	framework	0.05
satisfaction	572	strategy	0.05
experience	561	information	0.05
environment	555	knowledge	0.05
framework	534	perspective	0.05
strategy	526	web	0.05
skill	469	implementation	0.05
achievement	466	continuing education	0.05
engagement	463	impact	0.04
algorithm	461	quality	0.04
information	456	instruction	0.04
attitude	430	behavior	0.04
quality	422	support	0.04
instruction	403	motivation	0.03

These keyword networks might also be quite useful in identifying revolutionary tendencies in this industry, which would be extremely beneficial. In order to evaluate the developmental route in digital learning, a timeline perspective was utilized to assess the tendency of research over the past 20 years, and Figure 10 depicts the changing trend in this field.

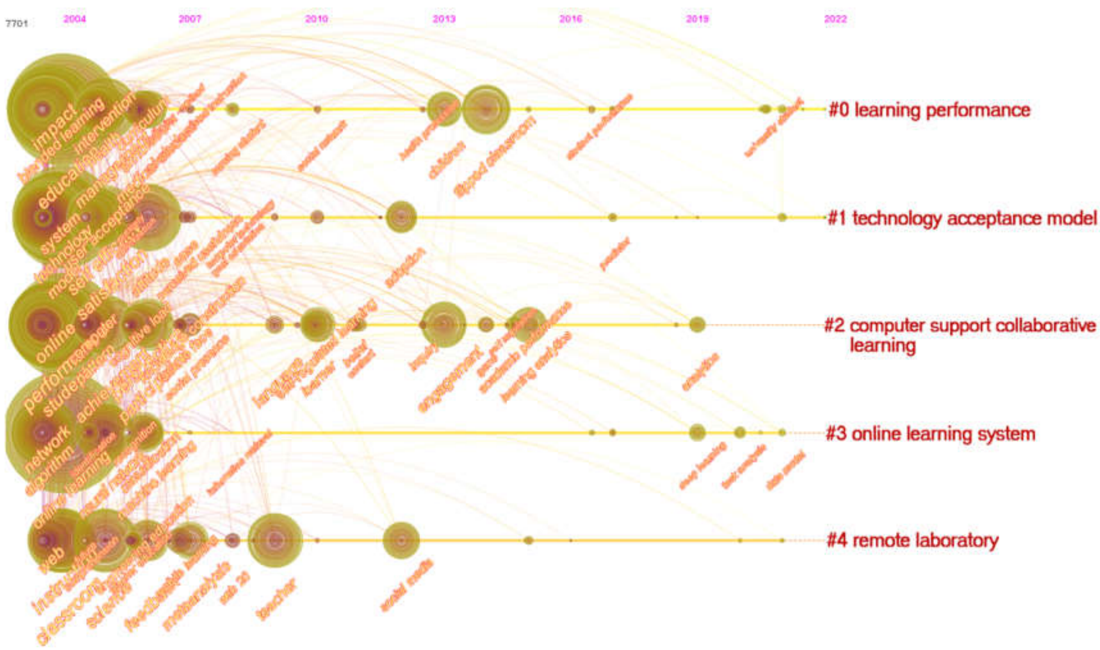

Figure 10. Burst trends of research keywords.

Firstly, learning performance, computer support collaborative learning (#2) and digital learning system are recently research hotspots. Figure 10 shows that the three clusters have been extensively studied since 2004. Learning performance has been an ongoing research topic in the field of digital learning since 2004. As an illustration, for the purpose of categorizing students and making predictions about their future learning outcomes based on characteristics extracted from the recorded data of an online educational system, Minaei-Bidgoli (2004) developed a method known as feature importance mining [87]. A study by Nakayama (2012) examined the causal correlations that existed between student traits, note-taking abilities, learning experience, note evaluation, and test results [87]. Meanwhile, Structural Equation Modeling (SEM) was used to track students' learning processes while they took notes. From an integrated perspective of individuals, environment/technology, and behavior, Wang (2021) examined the constructs of compatibility, personal innovativeness, convenience, perceived usefulness, continued intention, and healthcare students' learning performance in digital learning system use contexts [88]. This study concluded that personal innovativeness, convenience, and perceived usefulness were the key determinants of students' learning performance and adoption of an digital learning system. Meanwhile, perceived usefulness was the critical mediator between the influences of personal and environmental factors on students' learning performance. However, this topic received less attention in 2019. With the emergence and spread of COVID-19, countries have had to adopt quarantine measures in order to effectively stop the spread of the virus. As a consequence, a huge amount of pupils have to choose digital learning. The topic of learning performance gets researchers' attention again. For example, Hsiao (2021) investigated the effects of course type and gender on distant learning performance by examining baseline data from the three academic years before COVID-19 (2016–2018) and COVID-19 (2017–2018). The findings indicated that obligatory courses are better suited for distant learning courses, but optional and general education courses are better suited for face-to-face instruction. Males do better in face-to-face courses than females, and there was no discernible difference in their performance between the two teaching approaches. Meanwhile, research on computer support collaborative learning and online learning system are still influencing in the past 10 years. On the one hand, in recent years, computer-supported collaborative learning has mainly focused on inquiry learning, self-regulation learning, and learning analysis. For example, Pietarinen (2021) addressed the real-time shifts in focus and distribution of teachers' guidance and support of different student groups during in-person computer-supported collaborative inquiry learning in science classrooms [90]. The study concluded that it was discovered that the prior science competency of groups had no influence on teacher supervision and support; rather, instructors guided the groups they regarded to be motivated and eager to collaborate, according to the findings. Wetcho (2021) embedded CSCL into the self-regulating learning process, and explored the predictive effect of self-assessment on task and goal definition [91]. Results indicated that self-evaluation and self-reflection were shown to be somewhat mediated by cooperation. On the other hand, digital learning systems mainly focus on system algorithms, neural networks, machine learning, deep learning, task analysis, data models, and so on. For example, based on the neural network algorithm, Peng (2022) developed a method for intelligently teaching English, based on the new algorithm, and the effectiveness of the system for English digital learning has been verified [92]. Suparwito (2021) adopted five criteria, namely self-management, personal effort, technology use, self-role recognition, and lecturer role recognition, to analyze students' views on digital learning, and used a random forest algorithm to examine the data [93]. The results showed that the factors affecting students' satisfaction with digital learning included relationships between students and teachers, the adaptation of learning materials to digital learning methods, and the use of technology for digital learning.

Secondly, Technology Acceptance Model (#1) is still influencing in the past 10 years. Technology acceptance model proposed by Davis (1989) is an important theoretical model to evaluate the use of new technology, including students' digital learning use behavior and satisfactory [94]. This topic mainly discusses the influencing factors of students' digital learning success, use intention, and satisfaction. Figure 10 shows that the external influencing factors of TAM mainly include anxiety, self-efficacy, perceived usefulness, perceived ease of use, etc. For example, based on the technology acceptance model, Hoang (2021) studied the determinants of Vietnamese people's willingness to borrow and consume credit [95]. Results showed that perceived usefulness played a mediating role in the influence of subjective norms on consumer credit lending intention. Meanwhile, subjective norms also had a significant impact on borrowing intentions. It was worth noting that borrowing intention is unaffected by anxiety or perceived ease of use. On the basis of the technology acceptance model, Hanham (2021) investigated the factors influencing the technology acceptance of preschool teachers [96]. Instructors' behavioral intentions are high according to the findings, which also demonstrate that perceived usefulness and reported ease of use are significantly predictive of instructors' behavioral intentions when measured directly. Perceived ease of use and job relevance have a significant effect on perceived usefulness. The impression of external control and computer self-efficacy are the two most important aspects influencing perceived ease of use.

Lastly, of the 25382 papers and references examined, "remote laboratories" (#4) was the fifth most often cited direction. There is no doubt that the major content areas of this field are engineering education, science, teacher education, mobile learning, and social media. Although there are few studies on remote laboratories in recent years, it is often mentioned in engineering education, science, teacher education, mobile learning, social media and other fields. For example, Lee (2021) studied science education experts' perceptions of remote lab sessions during the COVID-19 pandemic by conducting 10 semi-structured interviews with experts in the fields of physics, chemistry, biology, and earth sciences [97]. Those who participated in the Remote Laboratory Sessions were found to have reexamined the purpose and goals of traditional laboratory instruction in light of what they learned. In addition, the study found that students were unable to learn because of a lack of hands-on experience, less contacts between instructors and students, and an increased workload for instructors.

4. Discussion

4.1. Discussion

The purpose of this study was to provide a systemic and objective overview of research on digital learning. Based on 25382 documents from 2004 to 2022, collected from the WoS database, CiteSpace 6.1.R1 (64-bit) was used to undertake an in-depth examination of the research of digital learning based on five different perspectives: annual publications, collaboration network (country network, institution network, and author network), co-cited references, cited journals, and co-occurrence analysis of keywords.

With regard to annual publication from 2004 to 2022, the duration of research development is divided into three stages: the slow development stage (2004–2010), the rapid development stage (2011–2016), and the explosion stage (2017–2022). This research result is basically consistent with previous study [22]. Zheng(2019) took 20679 MooCs-related studies in the WoS database from 2012 to 2018 as data sources and concluded that MooCs studies during this period continued to rise, and the growth rate increased year by year. In this study, Due to the COVID-19 pandemic, digital learning has become an important learning mode for educational institutions and learners worldwide. Digital learning research are developing at an exponential rate as a result.

Cooperative network mainly includes three types: national cooperative network, institutional cooperative network and author cooperative network. The most frequently posted countries were the USA (6948), PEOPLES R CHINA (3396), ENGLAND (1986), SPAN (1921) and AUSTRALIA (1685). The institutions with the highest publications were Open University (231), Nanyang Technology University (202), Monash University (186), the University of Toronto (180), and the University of Sydney (174). HWANG Gwa-Jen (57), HUANG Yueh-min (39), Chen Nian-shing (35), KIRSCHNER PA (34), and KINSHUK (34) have published the most papers. This result is basically consistent with previous studies, but there are some differences, such as the rankings of countries [98]. With WoS and CNKI as data sources (2002–2021) and "digital education" and "instructional design" as search keywords, Li searched a total of 670 instructional papers. The results show that the top three core countries are the United States, China, and Canada. According to this study, the reason for the different results lies in the small amount of data in Li's study. Although it can reflect the major research countries, the statistics on the number of publications in each country are not accurate enough.

Through the cluster analysis of cited references, it is found that digital learning research mainly includes seven themes: MOOCs, flipped classroom, COVID-19, computer-supported collaborative learning, technology acceptance model, community of inquiry, and distance learning. The classic literature for each topic is listed in Table 6. In addition, the literature cited frequently in the field of digital learning is listed in Table 7. Table 9 specifies the top 9 key pieces of literature in the digital learning knowledge map. For cited journals, the most cited journals were: Computer and Education (2684), Educational Technology Research and Development (1958), The Internet and Higher Education (1628), Computer in Human Behavior (1540), and British Journal of Educational Technology (1371). Through keyword co-occurrence analysis, high-frequency keywords and high mediating centrality keywords are listed in Table 12. The higher of the above two is the hot spot in digital learning research. After in-depth analysis, digital learning research hotspots mainly include three categories: student-related, system-related, and teacher-related. Drawing the aforementioned timeline allowed us to group five different subjects together while also revealing the stages at which each topic's theory and body of knowledge evolved. The results of this study are both identical [22,98] and different from previous studies [99], including highly cited journals, some research hotspots, and some classical literature. Differences include research topics and future research trends. The main reasons for the difference may be as follows: social environment change, research scope, research time span, CiteSpace parameter setting, etc.

4.2. Implication

As for the theoretical implications, based on the bibliometric analysis of literature in the field of digital learning from 2004 to 2022, this study generates a comprehensive, clear, and systematic overview of the field, including annual publications, major contributions, research topics and classic literature, current research hotspots, and future research trends.

In addition, the practical implications of this study mainly include three aspects: Firstly, generating seven research subfields of digital learning according to literature co-citation and identifying the classic literature in each subfield can help future researchers identify the classic literature in their respective fields, save literature retrieval time and improve research efficiency. Secondly, according to keyword co-occurrence analysis, the research hot spots and future research trends in digital learning are determined. It provides guidance for future researchers to engage in related research. Third, figuring out who are the most important and active people in the field of digital learning based on the co-occurrence of their names can help future researchers pay attention to and keep track of their research updates and understand the research trends in this field.

4.3. Limitation and Future Works

CiteSpace was utilized to assess digital learning articles from 2004 to 2022, based on the WoS database, in this research. However, despite its excellent accuracy, this method has certain drawbacks. Firstly, due to the limitation of data resources, the earliest data used in this study was in 2004. Therefore, many studies are not included in the collected data set. Furthermore, there are a number of policy and social publications not included in the database, including those from governments or organizations, editorials, and book reviews. This has a great impact on a comprehensive and systematic understanding of the origin and development of digital learning. Thus, in future studies, researchers should combine various data sources and develop and extend the research data channels (e.g., SCOPUS, Google Scholar) in order to discuss and evaluate the research issue more extensively and comprehensively. Secondly, this study did not delve into the differences in the development of digital learning before and after COVID-19. In the future, a study should be systematically designed, such as a time frame before and after COVID-19, database, retrieval strategies, etc., to compare the laws of change and development trends of digital learning between two time frames. Finally, although abundant keywords related to digital learning have been selected for retrieval in this study, it is inevitable that some keywords may be omitted. In the future, researchers should enrich retrieval strategies as much as possible and collect more comprehensive and accurate literature to grasp the complete situation of digital learning field.

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Conflicts of Interest: The authors declare no conflict of interest.

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