

Virtual Learning During the COVID-19 Pandemic: A Bibliometric Review and Future Research Agenda

Bilal¹, Eglantina Hysa², Ahsan Akbar³, Fakhra Yasmin⁴, Atteeq ur Rahman⁵, Shengbing Li^{4,6}

¹School of Accounting, Hubei University of Economics, Wuhan, People's Republic of China; ²Department of Economics, Epoka University, Tirana, Albania; ³International Business School, Guangzhou City University of Technology, Guangzhou, 510080, People's Republic of China; ⁴School of Education, South China Normal University, Guangzhou, 510631, People's Republic of China; ⁵Department of Management Sciences, University of Gujrat, Gujrat, Pakistan; ⁶Center of Cross Border Education, School of International Business, South China Normal University, Guangzhou, 510631, People's Republic of China

Correspondence: Ahsan Akbar, Tel +86 13802400964, Email akbar@gcu.edu.cn

Abstract: Virtual learning has emerged as a powerful platform for students and academicians in the “new normal” owing to the availability of advanced technological tools and platforms. Recently, considerable literature has grown up around the role of digital and remote technologies in learning and teaching during the ongoing COVID-19 pandemic. However, the research evidence on this topic is still fragmented, requiring a synthesis of this rapidly growing literature. This study aims to assess the key research trends in virtual learning during the COVID-19 pandemic through a bibliometric analysis of 1595 studies from 589 journals during 2020–21. Our study highlights the influential aspects, such as the most contributing countries, journals, authors, and keywords in this research field. We identified the following four main research trends: 1) challenges in online learning and blended learning strategies; 2) student-centered, collaborative learning, and curriculum design; 3) home-based laboratory learning; and 4) teachers’ professional competence and interdisciplinary learning. We conclude this research by discussing the implications for regulators and educational institutions, and directions for future research.

Keywords: COVID-19 pandemic, educational technologies, virtual learning, online learning, remote learning, students, teachers

Introduction

The adoption of technology has diverse applications, such as online shopping, e-banking, remote education, and telehealth, for users. The focus of research has now shifted to evaluating the influence of social variables, such as gender, age, environment, and cultural settings, on people’s adoption of technology.¹ The unexpected eruption of the novel coronavirus disease 2019 (COVID-19) pandemic has begun a new era of social change, especially in the education system. The abrupt disruption in the social order caused by the COVID-19 pandemic has brought into the spotlight the challenge of instantly switching from proximate learning to remote learning platforms.²

Against the backdrop of strong technological capabilities, universities in the developed world have successfully transitioned to virtual learning.³ Pushed by the conditions created by lockdown, educators have adopted various digital methods and technological tools, such as Zoom, Microsoft Teams, and Tencent Meetings, appropriate for distance learning. Currently, most educational institutes are increasingly involved in online activities, courses, and degrees related to teaching and research.^{4–8} However, because of a lack of technological infrastructure and educational platforms, as well as network constraints, educational institutions in the developing world have struggled with this forced transition to online learning.⁹

Several studies have examined the role of virtual platforms in teaching and learning during the pandemic.^{10,11} These studies have provided various educational pedagogies for learners and educators for effective learning. For example, Lapitan et al¹² presented an online strategy that facilitated the transition from traditional face-to-face learning to complete online instruction, called Discover, Learn, Practice, Collaborate, and Assess (DLPCA). The DLPCA pedagogy consists of two parts. In the first (asynchronous) part, course content is taught via the broadcasting of prerecorded lectures such as

YouTube videos for students to self-study at their own pace. In the second (synchronous) part, teachers teach online via Zoom or Google Meet. Before the actual implementation, the DLPCA pedagogy was presented and conveyed to the students. Lapitan et al¹² documented a positive impact of DLPCA on students' learning and teachers' online teaching experience. Another pedagogy strategy, the Demonstrate–Engage–Assess framework for Practical online teaching of Preclinical subjects (DEAPP), includes three components.¹³ The first component is the demonstration, where teachers interact with the students through live or recorded videos. The second is engagement, where teachers provoke the students' thinking and questioning behavior via critical analysis of the contents. Finally, the third component is assessment, and this framework allows students to undertake self-assessment through quizzes or online multiple-choice questions. Khan et al¹³ found that DEAPP was engaging and enjoyable, and motivated learning by the students and teachers.

Several studies have documented the conflicting views regarding virtual learning and implementing the online teaching pedagogies. For example, a few studies found virtual learning to be beneficial and convenient.^{14–16} Menon et al¹⁷ found that medical students perceived moderate satisfaction and usefulness with the ongoing online classes. Some students opined that the flexibility and convenience of online classes make them an attractive option; online learning was seen as a real challenge.¹⁸ Rahiem¹⁹ found that the students were motivated and committed to their studies despite the challenges of the COVID-19 pandemic.

However, other studies have found virtual learning to be challenging and stressful.^{20,21} For example, Daumiller et al²² claimed that the performance and work avoidance (e.g. spending the day with little effort) goals were perceived as threats caused by the shift from traditional to online teaching and learning. Scherer et al²³ concluded that teachers in higher education are not a homogeneous group, indicating that their innovative potential in education may be a struggle for online teaching and learning. Moreover, according to Srivastava et al,²⁴ students faced anxiety issues during the emerging remote learning period. In particular, mental health scores that indicate depression are high among students disrupted by COVID-19.²⁵ Given the diversity of studies and viewpoints of the researchers, in this study, to find out more about the implications of COVID-19 on online teaching and learning, we decided to conduct a bibliometric analysis to find answers to the following research questions:

RQ1. Which authors, journals, and countries have the highest bibliometric impact on virtual learning and COVID-19 pandemic literature?

RQ2. What are the key trends for research on virtual learning and COVID-19 pandemic literature?

This is the first investigative study using bibliometric analysis to scrutinize the distance-learning activities and trends amid the COVID-19 pandemic. Bibliometric analysis is used in many studies as it helps scholars to identify the literature trends and influential studies related to a specific discipline.^{26–28} Thus, this scientometric review contributes to the rapidly growing body of literature on the impact of the COVID-19 pandemic and online learning in several ways.

First, it offers a holistic view of the fragmented literature scattered around the COVID-19 outbreak and remote learning by analyzing the countries, journals, and authors with the most contributions, and exploring research trends through keyword analysis. Second, the synthesis of the extant literature highlights some pertinent research gaps that should capture researchers' attention. Our study finds the following four research trends in this field, with studies exploring: 1) the challenges in online learning and blended learning strategies,^{11–15,29–32} 2) course design, and student-centered and collaborative learning,^{3,33–38} 3) home-based laboratory learning,^{39–43} and 4) the effects of the professional competence of teachers and interdisciplinary learning.^{44,45} Our study finds a dearth of studies on post-pandemic strategies to adjust the existing educational policies regarding instructional design, pedagogical strategies, and assessment methods to sustain learning in a dynamic environment that is pivoted by digital education. Finally, based on the emergent research themes and influential aspects of the literature, we discuss significant policy implications for educational institutions, regulators, educational leaders, and academicians.

This pandemic has most severely hit the education system in developing countries, which do not have the educational technologies and online learning platforms required to shift to online learning.⁹ Moreover, there is a scarcity of studies on how the educational system in underdeveloped and impoverished countries has responded to this pandemic. This phenomenon is also reflected in the negligible collaboration score of researchers from developing regions. Hence, future research could benefit from this bibliometric study by filling these gaps in the literature.

The study is organized as follows. The **Methods** section describes the applied methodology and the related context. In **Results and Discussion**, the findings and discussion of the bibliometric analysis are presented. The subsequent section explores the main implications of the work and provides directions for future research. Finally, conclusions are presented in the last section.

Methods

We retrieved the relevant publications on the COVID-19 pandemic and online education from the Scopus database on May 24, 2021, using the following query “(TITLE-ABS-KEY (‘COVID-19’ OR coronavirus OR ‘Corona virus’ OR coronaviruses OR ‘2019-nCoV’ OR ‘SARS-CoV’ OR ‘MERS-CoV’) AND TITLE-ABS-KEY (‘online education’ OR ‘online learning’ OR ‘online teaching’ OR ‘virtual learning’ OR ‘virtual teaching’ OR ‘e-learning’ OR ‘on-line education’ OR ‘on-line learning’ OR ‘on-line teaching’ OR ‘distance learning’) AND TITLE-ABS-KEY (‘student*’ OR teacher*)) AND (LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2020)) AND (LIMIT-TO (LANGUAGE, ‘English’)) AND (LIMIT-TO (DOCTYPE, ‘ar’) OR LIMIT-TO. (DOCTYPE, ‘re’)).” Following PRISMA guidelines (Figure 1), we recruited 1595 studies from 2680 based on our inclusion criteria. Our inclusion criteria include: 1) the study’s main objective is to analyze the impact of the COVID-19 pandemic on online teaching and learning; 2) the study is published in the English language; and 3) the study is a peer-reviewed article.

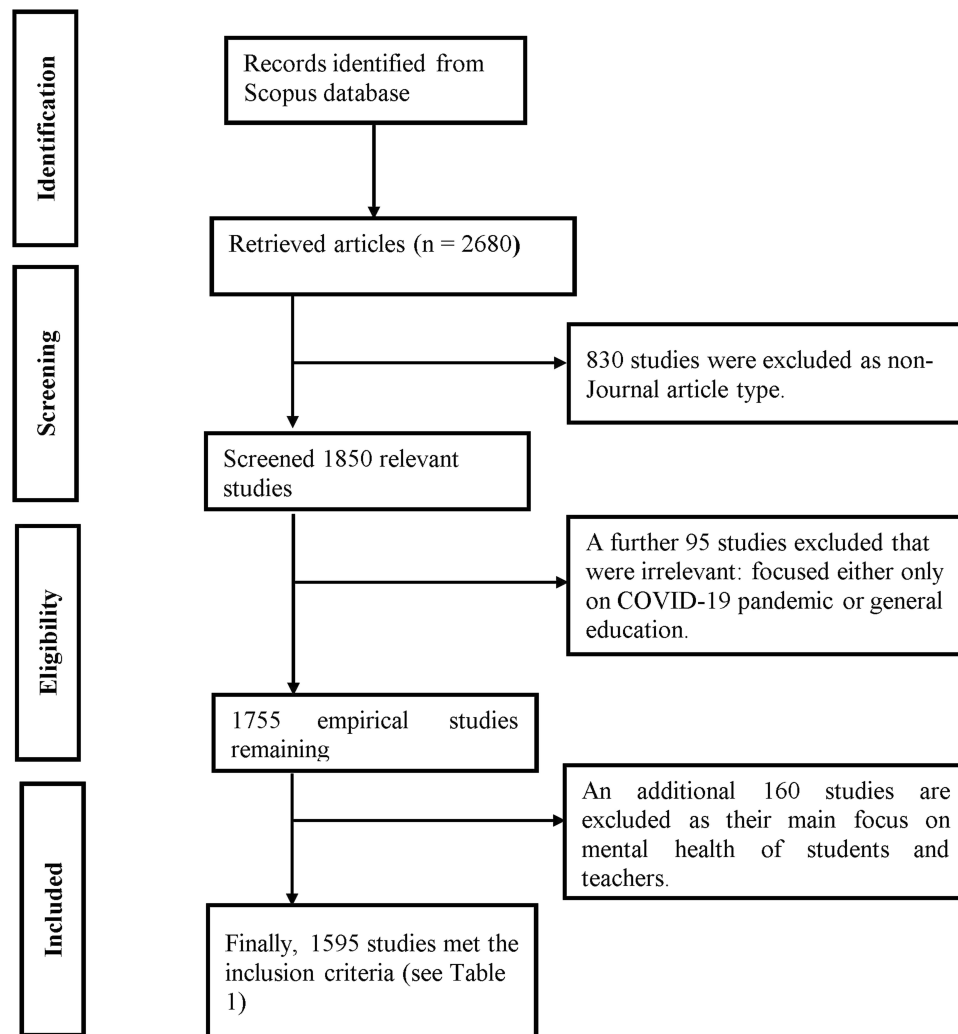


Figure 1 Flow diagram of the study selection process.

Table 1 provides the detail of the selected studies on COVID-19 and online learning. Our study recruited 1595 articles published in this research domain from 2020 to 2021, published in 589 academic journals. Studies were predominantly in the form of research articles, and only 66 were review studies. We identified 3014 authors' keywords in our selected studies. The authors' statistics reveal that 5557 appeared in the selected documents, out of which 256 were single-authored documents and 5301 were multi-authored documents. There were 3.7 co-authors per document, representing a high degree of collaboration in this research domain.

Bibliometrix software R was used to analyze the bibliometric research trends.⁴⁶ Against the backdrop of the rapid proliferation of literature on COVID-19 and online learning, it is imperative to examine the bibliometric aspects, such as the number of publications, impact factor, citations, H-index, authors, and country-wise contribution to this research stream. The co-citations network was employed to access the most important papers cited in this field. As a holistic approach to identifying the key research trends, we selected the authors' keywords used in the selected studies. This study employed the multidimensional scaling factor analysis method to explore the research trends using the authors' keywords, which is considered a sophisticated technique in a given research area.^{47–49}

Assessment of Academic Influence

The current research employs an H-index to assess the academic influence of authors, journals, and research institutions. The H-index was first propagated by Hirsch⁵⁰ as:

Table 1 Details of Selected Studies

Description	Results
Main Information About Data	
Timespan	2020–2021
Sources (journals, books, etc)	589
Documents	1595
Average years from publication	0.49
Average citations per document	1.996
Average citations per year per document	1.109
References	54,909
Document Type	
Article	1529
Review	66
Document Contents	
Keywords plus (ID)	2113
Authors' keywords (DE)	3014
Authors	
Authors	5557
Author appearances	5898
Authors of single-authored documents	256
Authors of multi-authored documents	5301
Author Collaboration	
Single-authored documents	264
Documents per author	0.287
Authors per document	3.48
Co-authors per document	3.7
Collaboration index	3.98

a researcher has an index H if H of his/her publications (N_p) at least have H citations each, while the rest of each N_p - H publication has no more than H citation.

Thus, the evaluation criteria for an H -index integrate the number of citations and number of publications as a precise measure of academic contribution, where a high H -index demonstrates a high academic impact. Nevertheless, it is a helpful analytical tool to measure institutional strength in a specific discipline.⁵¹

Academic Collaboration

A significant and distinctive feature of academic research is the extensive collaboration among academics and researchers at several levels.⁵² The degree of academic collaboration is a useful indicator to gauge research collaboration.⁵³ The present study evaluates authors, institutions, and countries to measure the degree of academic collaboration by employing the following equation:⁵⁴

where denotes the country-level degree of collaboration, while represents the number of countries for the year i , and N represents the total number of publications on COVID-19 and online learning.

Social Network Analysis

Social network analysis is a tool used to analyze the patterns of relationships among social actors in groups. This study employed social network analysis to cluster common citations among the selected studies. In social network analysis, “points” illustrate social actors, and “edges” show the association among “points”.⁵⁵ Hence, it is a potent tool to quantify the relationship among the social network actors, which can be further classified into a matrix of social connections and a graph of social networks.⁵⁶ Rows and columns represent social elements and social actors, whereas matrix values show the association between various social actors. In a network graph, social actors are denoted by nodes, and the association among actors is illustrated by connecting the leads between nodes.⁵⁶ The betweenness centrality method is the most widely available way to capture how many variations exist in a node compared to other nodes in a network.⁵⁷ In this study, we have used the betweenness score to measure the network’s betweenness centrality. A higher betweenness score shows the dominance of a node/actor in the network.⁵⁸

Keywords Analysis

Keywords indicate the essence of a research document, and co-occurrence analysis reflects key research trends within a specific discipline.⁵⁹ The current research analyzes keywords to observe influential research hotspots in publications on COVID-19 and online learning. The occurrence of two or more similar keywords indicates a research direction in a given research area.⁶⁰ Likewise, the co-word analysis uses a terminology or noun phrase to identify research themes in a literature stream.⁶¹ The current research performs a multidimensional scaling factor analysis method through the authors’ keywords to ascertain research themes in the selected studies.

Results and Discussion

Bibliometric Impacts

Table 2 presents the findings of the top 20 countries in terms of research productivity in the area of the COVID-19 pandemic and online education. The top countries’ contributions are as follows: the USA, 772 research publications (48%); India, 214 (13%); and Indonesia, 197 (12%). Moreover, the USA demonstrates a superior academic impact to the rest of the world, with the highest number of citations (558). The UK is ranked seventh in research publications and second in citations (262). Lastly, developing, emerging, and technologically advanced economies such as India, Indonesia, Saudi Arabia, and China have contributed significantly to this field, with these countries contributing 214, 197, 171, and 139 research publications, respectively.

Academic research collaborations are essential for sharing and transferring knowledge among researchers and institutions. By employing social network analysis, as shown in Figure 2, countries are classified into five clusters based on their degree of research collaboration in the field. In the first cluster (blue), researchers in the USA and the UK are the dominating collaborators, with betweenness scores of 331.63 and 243.21, respectively. Likewise, the second

Table 2 Top 20 Productive Countries in Terms of Research Publications on COVID-19 and Online Learning

No.	Country	Publications	%	Citations	Average Citations Per Article
1	USA	772	48%	558	2.122
2	India	214	13%	154	2.232
3	Indonesia	197	12%	86	2.263
4	Saudi Arabia	171	11%	169	2.965
5	China	139	9%	107	2.184
6	Australia	128	8%	80	2.051
7	UK	126	8%	262	5.574
8	Malaysia	122	8%	66	1.467
9	Germany	103	6%	79	1.975
10	Spain	97	6%	100	2.5
11	Pakistan	87	5%	122	4.88
12	Italy	78	5%	26	1.083
13	Jordan	74	5%	54	2.842
14	Canada	66	4%	34	1.619
15	Brazil	61	4%	34	2.125
16	South Africa	51	3%	20	1.053
17	Poland	46	3%	32	2.000
18	Turkey	45	3%	5	0.357
19	Egypt	42	3%	6	0.400
20	Portugal	42	3%	13	1.444

cluster (green) indicates that Malaysian and Saudi Arabian researchers are the highest collaborators, with betweenness scores of 105.4 and 54.56, respectively. In contrast, the degree of research collaboration in the remaining 13 countries in this cluster is quite minimal.

The third cluster (red) shows that Australia demonstrates the highest degree of collaboration, with a betweenness score of 99.58, while China is in second place in the network with a betweenness score of 28.26. In the fourth cluster (orange), the Netherlands and Ghana have intensive research networking, as reflected by betweenness scores of 110 and 38, respectively. In contrast, Nigeria and Hungary have the least research collaboration in this cluster. Finally, the last cluster (purple) demonstrates Italy's maximum research collaboration, with a betweenness score of 111.79. At the same time, France, Switzerland, and Austria do not show considerable research networking. In a nutshell, technologically advanced economies such as the USA, the UK, Australia, China, and Italy are at the forefront of research on the COVID-19 pandemic and online learning as they have the required infrastructure to support online teaching and learning activities.

Our sample constitutes 1595 research articles from 589 academic journals. Table 3 lists the top 20 most productive journals in terms of research output. In total, 457 (29%) of the research publications appeared in these journals during 2020–21. The *Journal of Chemical Education* stands out as the most prolific research outlet, with 118 research documents (7%) and 199 total citations. *Sustainability* journal, with a more multidisciplinary orientation, is second with 51 publications (3.19%).

With 35 publications (2.19%) and 98 citations, *Education Sciences* is ranked third. *Education and Information Technology* journal is ranked fourth, with 26 publications and 61 citations from the subject category of information technology. The rest of the top journals are from the medical education, environment, and public health domains, with 15 publications each.

Information regarding the research contributions of the top 20 authors is presented in Table 4. Benjamin Luke Moorhouse, from Hong Kong Baptist University, Hong Kong, China (<https://orcid.org/0000-0002-3913-5194>), and

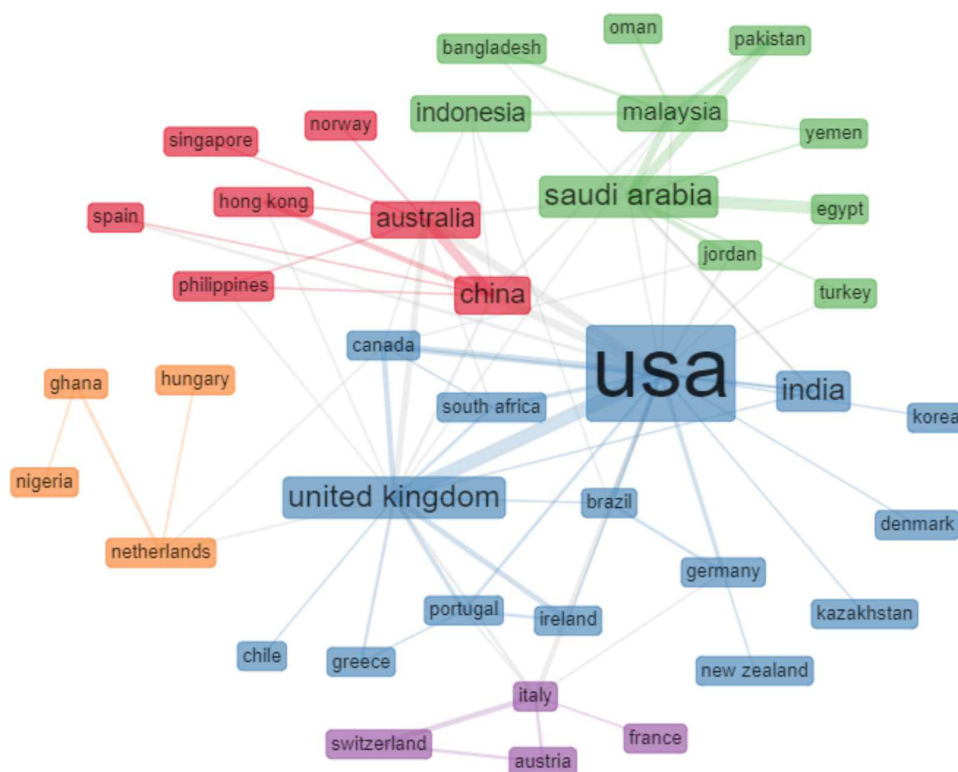


Figure 2 Country-wise research collaboration.

Notes: In the first cluster (blue), the USA and the UK are the dominating countries based on centrality; the second cluster (green) indicates that Malaysian and Saudi Arabian researchers are dominant based on centrality; the third cluster (red) shows that Australia demonstrates the highest degree of collaboration; in the fourth cluster (orange), the Netherlands and Ghana have intensive research networking; and the last cluster (purple) demonstrates Italy's maximum research collaboration. The thickness of the lines shows that a country serves as a bridge between different countries in their network.

Sangeeta Sharma, from India (<https://www.bits-pilani.ac.in/pilani/sang/profile>), each published six research articles, with total citation scores of 76 and 44, respectively. Moorehouse's research mainly concentrates on homework practices, teaching immersion, and e-learning. Sharma primarily published on distance learning, technical communication, and creative thinking. Besides, it is worth noting that most of the authors in the list of top 20 researchers are from emerging economies such as China and India. Their research is somewhat less impactful in citations than that of authors from advanced countries.

To explore the most common literature in this field, we employed the co-citation network depicted in Figure 3. We identified the four different clusters of most widely cited studies in this field.

In the first cluster (purple), the publications of Bao⁶² and Hodges and Fowler⁶³ are the most cited studies, with betweenness scores of 285.84 and 189.96, respectively. For instance, the most significant contribution in this cluster was research conducted by Bao,⁶² who presented a case study from Peking University on adjusting online teaching to maximize students' remote learning, forced by the pandemic. Online instructional design, adequate delivery of online information, proper support by the teaching staff, optimal student participation, and contingency planning to deal with the unexpected glitches in online platforms were the main facets of this research.

Likewise, in the second cluster (blue), Sahu⁶⁴ emphasized the impact of the closure of universities due to the spread of COVID-19 on the education of students and academic faculty, and this stands out as the most cited study, with a betweenness score of 134.68.

In the third cluster (red), the most frequently cited study, based on the highest betweenness score of 49.62, was conducted by Almaiah et al,³⁰ and explored the critical challenges and factors influencing the use of online learning technologies during the surge of the COVID-19 pandemic.

Table 3 Top 20 Productive Journals in Research on COVID-19 and Online Learning

Source	NP	h_index	TC	PY_st.
Journal of Chemical Education	118	5	199	2020
Sustainability (Switzerland)	51	5	127	2020
Education Sciences	35	5	98	2020
Education and Information Technologies	26	2	61	2020
GMS Journal for Medical Education	20	1	4	2020
Information and Learning Science	17	4	53	2020
Communications of the Association for Information Systems	16	1	3	2021
International Journal of Learning, Teaching and Educational Research	16	2	22	2020
BMC Medical Education	15	5	75	2020
Journal of Engineering Education Transformations	15	0	0	2020
Frontiers in Psychology	14	3	24	2020
Universal Journal of Educational Research	14	2	10	2020
Biochemistry and Molecular Biology Education	13	1	6	2020
International Journal of Environmental Research and Public Health	13	4	44	2020
Medical Science Educator	13	1	11	2020
Online Learning Journal	13	1	36	2020
Xlinguae	13	1	2	2021
Ecology and Evolution	12	2	9	2020
Journal of Education for Teaching	12	7	129	2020
Frontiers in Education	11	1	11	2020

Table 4 Top 20 Productive Authors in Research on COVID-19 and Online Learning

Author	NP	h_index	TC	PY_st	Affiliated Country
Moorhouse BL	6	2	76	2020	Hong Kong, China
Sharma S	6	1	44	2020	India
Joshi A	5	1	8	2020	Nepal
Baber H	4	2	12	2020	Korea
Elsalem L	4	3	19	2020	Jordan
Zain NHM	4	0	0	2020	Malaysia
Zhang X	4	2	31	2020	China
Zhao Y	4	1	7	2020	Spain
Ahmed S	3	0	0	2020	Bangladesh
Antonini Philippe R	3	3	14	2020	Switzerland
Bell A	3	2	4	2020	Australia
Biasutti M	3	3	14	2020	Italy
Cai H	3	1	2	2020	China
Chen Y	3	1	4	2020	China
Cheng X	3	1	2	2021	China
Chu KM	3	1	9	2020	Hong Kong, China
Degel A	3	0	0	2020	Germany
Dube B	3	2	15	2020	South Africa
Gintrowicz R	3	0	0	2020	Germany
Kim S	3	1	1	2020	USA

Studies in the last cluster (green) are mainly centered on the adaptation of online teaching by the academic staff during the COVID-19 pandemic. The highly cited work by König et al⁶⁵ studied the capability of young teachers to use educational technologies and maintain social interaction with their students. Their findings assert that the digital

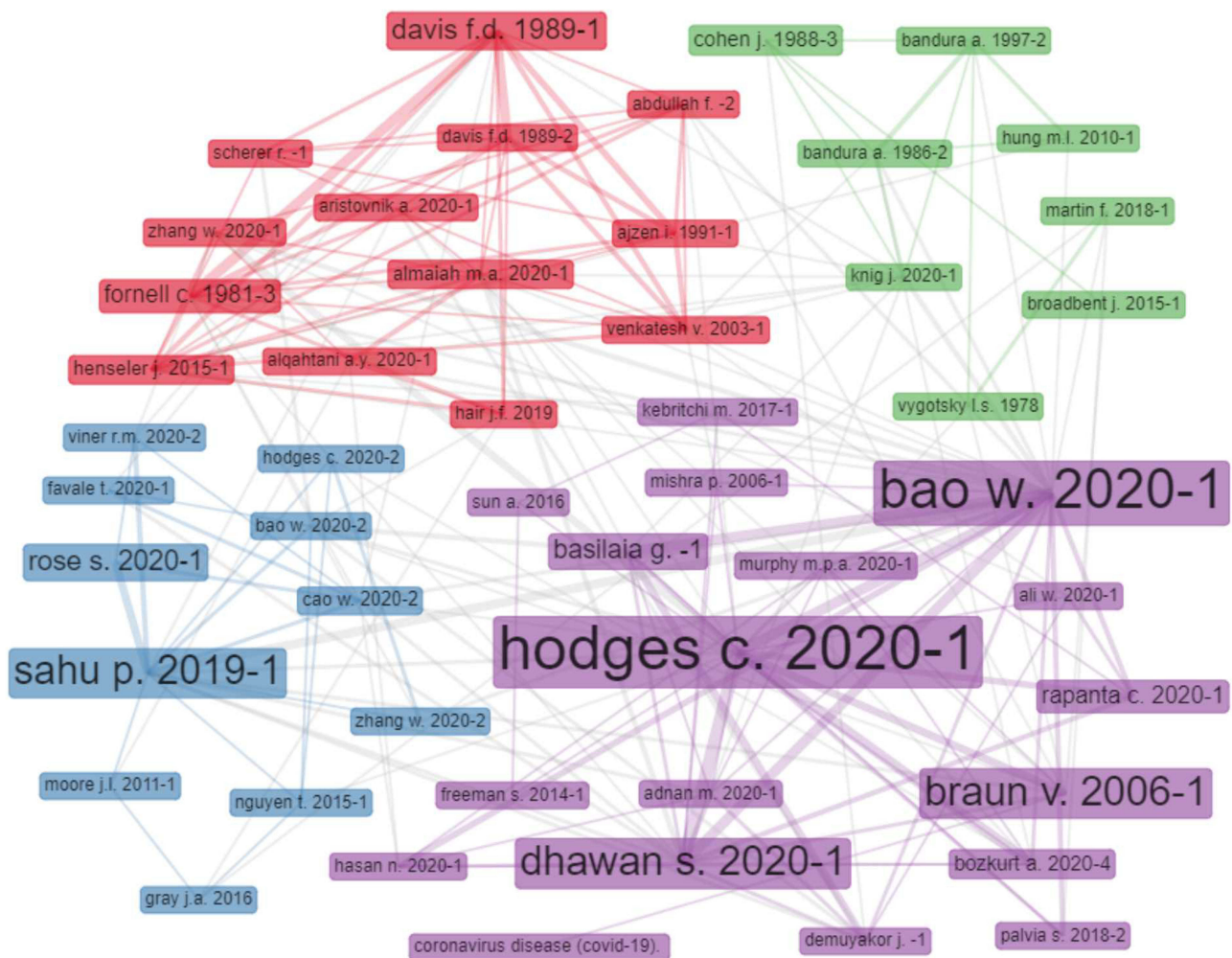


Figure 3 Most frequently cited studies.

Notes: The thickness of the boxes and lines indicates the importance of the studies that serve as a bridge in common citations in their respective network based on betweenness scores. The first cluster (purple) contains the most highly co-cited studies in the field, followed by the second cluster (blue) and then the third cluster (red); finally, the last cluster (green) contains the fewest co-cited studies.

competence of the faculty and opportunities for training in information and communication technologies (ICT) prove instrumental in enhancing teachers' digital competence.

Table 5 presents the top 20 most cited studies in this field, with total citations and citations per year.^{30,32,66–71} For example, Iyer et al⁶⁸ was the most cited work, with 88 citations, which examined the impact of COVID-19 on dental education in the USA. Their study discussed the lack of guidance from medical authorities on ensuring social distancing to protect students, patients, faculty, and staff from this deadly outbreak. The study presents some simple strategies that can be implemented to ensure the continuity of dental education. After that, Dedeilia et al³² was the second most highly cited study, with 69 citations; these authors conducted a systematic review of challenges and innovations in medical and surgical education during the COVID-19 outbreak.

Most research appeared in medical education, learning technologies, and multidisciplinary journals. Moorhouse⁷¹ was the third most influential work, with 63 citations. He illustrated how a face-to-face teacher's education course was adapted to be delivered online owing to COVID-19, and the challenges faced in adjusting the course contents and online delivery. Equally impactful research, with 62 citations, was published by Favale et al,⁶⁶ highlighting the unusual pressure exerted by the COVID-19 pandemic on the online teaching platform. Their findings show that the internet platform has been resilient in coping with this unprecedented challenge of conducting online teaching.

Table 5 Top 20 Most Cited Publications on COVID-19 and Online Learning

Paper	DOI	TC	TC Per Year
Iyer P, 2020, J Dent Educ	10.1002/jdd.12163	88	44
Dedeilia A, 2020, In Vivo	10.21873/invivo.11950	69	34.5
Moorhouse BL, 2020, J Educ Teach	10.1080/02607476.2020.1755205	63	31.5
Favale T, 2020, Comput Networks	10.1016/j.comnet.2020.107290	62	31
Kapasia N, 2020, Child Youth Serv Rev	10.1016/j.chilyouth.2020.105194	56	28
Almaiah MA, 2020, Educ Inf Technol	10.1007/s10639-020-10219-y	54	27
Longhurst GJ, 2020, Anat Sci Educ	10.1002/ase.1967	48	24
Iivari N, 2020, Int J Inf Manage	10.1016/j.ijinfomgt.2020.102183	43	21.5
Mukhtar K, 2020, Pak J Med Sci	10.12669/pjms.36.COVID19-S4.2785	43	21.5
Mailizar M, 2020, Eurasia J Math Sci Technol Educ	10.29333/EJMSTE/8240	43	21.5
Aristovnik A, 2020, Sustainability	10.3390/su12208438	42	21
Knig J, 2020, Eur J Teach Educ	10.1080/02619768.2020.1809650	42	21
Demuyakor J, 2020, Online J Commun Media Technol	10.29333/ojcm/8286	40	20
Abbasi S, 2020, Pak J Med Sci	10.12669/pjms.36.COVID19-S4.2766	38	19
Johnson N, 2020, Online Learn J	10.24059/olj.v24i2.2285	35	17.5
Woolliscroft JO, 2020, Acad Med	10.1097/ACM.0000000000003402	34	17
Krishnamurthy S, 2020, J Bus Res	10.1016/j.jbusres.2020.05.034	32	16
Rasmitadila R, 2020, J Ethnic Cult Stud	10.29333/ejecs/388	32	16
Watermeyer R, 2021, High Educ	10.1007/s10734-020-00561-y	31	31
Mohammed AO, 2020, Innov Infrastruct Solut	10.1007/s41062-020-00326-7	29	14.5

Trend Analysis

Figure 4 presents a strategic diagram of the most influential research themes in the literature on COVID-19 and online learning extracted through the multidimensional scaling factor analysis method. We identified four clusters that provide us with the main research trends in this field.

Cluster 1: Challenges in Online Learning and Blended Learning Strategies

The first cluster (red) covers the studies focused on the challenges and coping mechanisms in online learning, blended learning, and online teaching strategies. It also includes the studies regarding the adoption of educational technologies to optimize remote learning and assessment. Specifically, studies discussed the key challenges faced by the teaching faculty and students, including access to a stable online connection, lack of professional development of educators and students online, and switching from classroom learning to remote learning, a lack of social interaction, and difficulty in fostering an effective learning environment.^{29,31,72}

The studies on blended learning show that educational institutions have adapted blended learning to carry out academic activities as the pandemic is still evolving. For example, Amir et al⁷³ claimed that most students (55.8%) prefer classroom learning over distance learning (44.2%), as distance learning creates more communication problems and delivers less learning satisfaction. Likewise, Långegård et al⁷⁴ report that two-thirds of the students' responses favored proximate or in-class learning.

In contrast, one-third of the students in the research by Långegård et al⁷⁴ favored distance learning, suggesting the need for blended learning. Likewise, Müller and Mildenerger⁷⁵ observed that the effective application of blended learning could yield equivalent outcomes to proximate learning. Studies on the adoption and use of educational technologies were also part of this cluster. For example, Tejedor et al⁷⁶ claim that adaptation of digital literacy in teaching and learning strategies is essential for successful immersion in online education.

Cluster 2: Student-Centered, Collaborative Learning, and Curriculum Design

The second cluster (blue) focuses on student-centered and collaborative learning, and covers curriculum design studies. The studies on student-centered learning found that students' feedback is imperative to evaluate the success of technology-driven learning endeavors. For example, Dietrich et al³ examined the input of students and teachers regarding

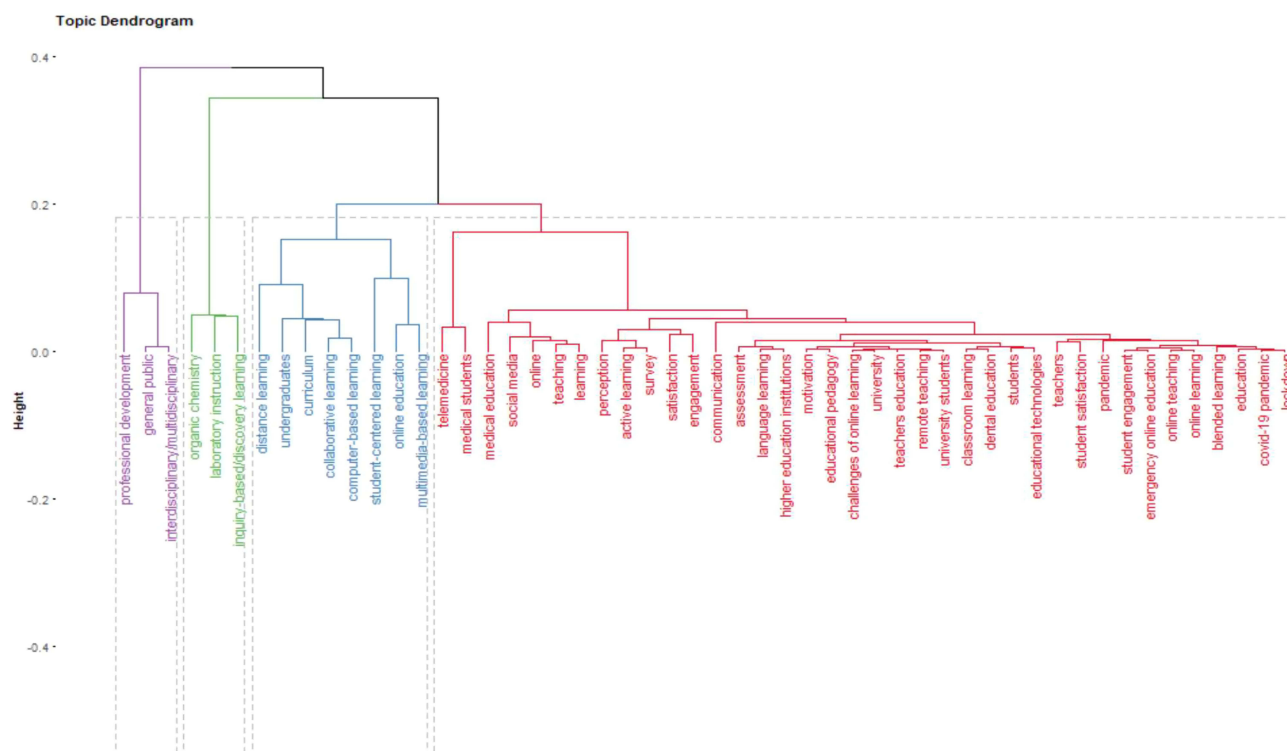


Figure 4 Strategic diagram representing research trends.

Notes: Clusters are divided based on topic modeling, as indicated in different colors. These are portrayed from right to left, with the first cluster (red) having the highest number of possible topics and sub-topics, and the last two clusters (green and purple) having the fewest topics.

their e-learning experiences at INSA Toulouse, France. Their findings suggest that online learning proved to be a mixed bag, with some remarkable success stories and some failures. Similarly, Petillion and McNeil³³ noted that major issues, such as personal scheduling, lack of motivation and engagement, communication with the teaching faculty, and increased stress and anxiety, were faced by the students owing to an abrupt shift from proximate to online education. Nevertheless, remedial teaching, mentoring, and peer support can considerably optimize the online educational outcomes of the students.³⁴

Regarding collaborative learning, one of the challenges of online learning is to ensure collaboration among the students. Nickerson and Shea³⁵ describe the use of Zoom breakout rooms and student learning assistants to simulate the classroom experience for the students. In addition, introducing slack time for questions and discussion was associated with an enhanced online learning experience for students. Against the backdrop of forced online education, Youssef et al³⁶ suggest adjusting both the scientific content and instructional design of chemistry education courses to ensure student engagement and collaboration.

Finally, regarding curriculum design, Johnson et al³⁷ emphasize the need for extensive and careful curriculum planning at the department level before switching to remote learning platforms. The application of structured active learning techniques can help increase the application of the course materials. The educational material and activities can be designed for students to apply their knowledge and skills to topic-based active learning projects administered by the instructor.³⁸

Cluster 3: Home-Based Laboratory Learning

The third cluster (green) is centered on home-based laboratory learning. For example, Jones et al³⁹ delivered two online laboratory courses during the summer of 2020 and observed students' perceptions regarding online learning. Likewise, Kelley⁴⁰ shares the process of conducting wet laboratory experiments at home for an organic chemistry course, in a safe, convenient, and inexpensive manner. Nguyen and Keuseman⁴¹ also shared the experiences of students and instructors regarding several laboratory experiments performed online during the pandemic. However, empowering students to

conduct laboratory experiments at home is an uphill task. Ibarra-Rivera et al⁴² found that only 80% of the students in an online laboratory course could successfully carry out experiments at home.

Nevertheless, academics have been swift in designing new teaching methods for laboratory-specific courses to optimize students' online learning. Warning and Kobylanski⁴³ claimed that using more interactive learning approaches in online laboratory-based experiments, such as "choose-your-own-adventure-type" activities, could enhance students' online learning during the pandemic. Similarly, Caraballo et al⁷⁷ designed a series of environment-friendly and inexpensive laboratory exercises on acid–base equilibrium that could be performed at home. Moreover, they illustrate how these online exercises can be adapted to be taught to diverse age groups and socioeconomic settings.

In laboratory-intensive courses, inquiry-based teaching has also gained traction among academics to alleviate the pitfalls of online education amid the pandemic. Mirowsky⁷⁸ shared his personal experience on how the instructor successfully transitioned the laboratory course to an inquiry-based distance learning course at home. All the experiments were inquiry-based, and students were asked to design their projects. Zewail-Foote⁷⁹ also suggests adapting teaching strategies and course designs in chemical education to cope with the abrupt shift to online education. The author demonstrates how the focus of a research project in biochemistry was shifted from laboratory skills to research skills and a community outreach interactive activity. Sikora et al⁸⁰ found that inquiry-based learning strategies helped biochemistry students to effectively link between computational and laboratory-based techniques. Furthermore, Ohn-Sabatello⁸¹ stressed incorporating technologies for interactive videos, computer simulations, student voice and choice options, and online assessments to deliver online courses such as chemistry.

Cluster 4: Teachers' Professional Competence and Interdisciplinary Learning

The fourth cluster (purple) consists of studies on the effects of the professional competence of teachers and interdisciplinary learning. Toto and Limone⁸² found that some school teachers were reluctant to use digital technologies owing to a lack of skills in using digital technologies in education. Similarly, a survey of academics from 91 countries revealed a 51% variance in the role of the instructor's demographics and professional competence in adapting to remote learning technologies.⁴⁴

This cluster also reflects some multidisciplinary studies, mainly discussing the interaction of technology with COVID-19 and online education. For instance, Stevens et al⁴⁵ presented an inexpensive learning tool that students can use with their laptops for real-time interaction with their instructors. Engelberger et al⁸³ developed a cloud-based platform for structural bioinformatics to integrate the software with interactive codes and visualization exercises to boost the online learning experience of the students. Similarly, Singhal³⁸ illustrated the use of advanced Zoom features to facilitate active learning for medicinal chemistry during a campus closure due to the COVID-19 outbreak.

Implications and Future Research Directions

This scientometric and systematic synthesis of the literature on the COVID-19 pandemic and online learning yields emergent themes which have several implications for regulators, educational administrators, and academics. First, the research trends highlighted in our analysis from the studies published in 2020 mainly focused on the rapid shift to distance learning by educational institutions around the globe in response to the pandemic.^{30,84} However, research in 2021 largely centered on adopting technology and blended learning.^{12,15,75} These studies also focused on collaborative learning strategies and online assessment methods to optimize the online teaching and learning forced by the pandemic.^{39,43} Therefore, we follow the DLPCA model of Lapitan et al,¹² who presented an online strategy that facilitated the transition from traditional face-to-face learning to complete online instruction. Furthermore, another pedagogical strategy, the DEAPP model,¹³ facilitates online teaching and allows students to perform self-assessment through quizzes or online multiple-choice questions.

Second, we have observed that the COVID-19 pandemic has created several challenges, such as a lack of preparedness and teacher training to deliver laboratory-intensive and mathematical courses online, an abrupt change in curriculum design, and student assessment, for teachers and students changing from face-to-face learning to online learning.^{11,15,29–32} Therefore, our study suggests that the regulators and leaders of educational institutions should make necessary and proactive educational pedagogies for the post-pandemic era and future disruptions. Specifically, we recommend that more

academic collaborations and exchange programs should exist among educational institutions, such as sharing laboratories and online educational resources, faculty development programs, and capacity-building programs for student-centered learning.^{85–87} The universities and the upcoming research can take important insights from the recent studies for establishing the best possible collaborations in the time of crisis.^{58,88,89}

Regarding future research directions, there is a dearth of studies on post-pandemic strategies to address the underlying shortcomings of the existing educational framework exposed by COVID-19 and to design proactive mechanisms to deal effectively with such disruptions in the future. Hence, researchers need to explain how educational institutions should reform their instructional design, pedagogical strategies, and assessment methods to sustain teaching and learning in a dynamic environment pivoted by digital education.⁹⁰ Ease and accessibility, connectivity, course materials, the effectiveness of online instructional design, and the quality of interaction between students and academics are the key parameters that can determine the success or failure of a remote learning environment.⁹¹ Therefore, future studies may contribute to this contemporary literature by focusing on the success and failure stories of online learning during this pandemic, from diverse regional and cultural settings, to gain more insights into the opportunities and challenges offered by remote learning.

The natural sciences and laboratory-intensive disciplines, especially in developing countries, are severely affected by this transition to remote learning as students lack the hands-on training, virtual support, and materials to perform laboratory experiments at home, which badly hampers their learning outcomes.² Therefore, concerned educational administrators should seek support from world-class universities to provide online instructional materials and simulation exercises to bridge this learning gap. Furthermore, our collaboration analysis reveals that authors from developed countries such as the USA, the UK, Australia, Italy, China, and Middle Eastern countries exhibit the highest degree of collaboration in this field. In contrast, researchers from underdeveloped countries and regions have negligible collaboration, underpinning the impact of the digital divide on e-learning endeavors around the globe.⁹² Therefore, future research should include more cross-country collaborative studies to contrast and compare the empirical outcomes across countries and cultures.

Moreover, the educational system of developing countries has been hit hard by the pandemic, as reflected in the negligible contribution to online learning research, and due to the technological, personal, institutional, and social barriers confronted by poverty-stricken nations trying to switch to digital learning.⁹ Hence, there is an urgent need for the United Nations and other international education bodies to come forward to support these countries in the adoption of online learning technologies and infrastructure. We suggest that researchers could contribute to this literature by exploring cost-effective education-centric platforms and more effective collaborative ways for developing countries to deliver sustainable education. Besides, high-ranking universities could provide vital support to developing countries via capacity-building programs, such as offering free access to online materials, teacher training, and student exchange programs.

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