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Innovating engineering education: Insights and lessons from the pandemic

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Abstract

This study presents how engineering education evolved during the COVID-19 pandemic, offering a comprehensive scientometric analysis of research lessons and insights. By examining 933 relevant documents from Scopus published between 2020 and May 2023, the study identifies key shifts in focus, particularly the rapid adoption of online learning, distance education, and virtual teaching methods. The pandemic catalyzed a rapid transition to online and hybrid models, prompting innovative approaches to maintain educational quality and accessibility. The findings highlight how the pandemic accelerated the transition to digital and hybrid models, with "online learning," "distance education," and "e-learning" emerging as dominant themes indicating a major focus on remote education technologies. Despite challenges posed by remote settings, active and project-based learning remained essential, while psychological factors such as anxiety and depression underscored the importance of supportive learning environments. Global research collaboration flourished, with significant contributions from the United States, India, and Spain. A co-occurrence network analysis using VOSviewer reveals distinct research clusters, ranging from innovative teaching strategies to student mental health. This research article offers valuable insights into how the engineering education community adapted to unprecedented challenges during the pandemic, thereby providing recommendations for continuous innovation and the future of education after a pandemic.

Keywords: COVID-19, Educational efficiency, Educational needs, Educational strategies, Online learning, Pedagogical innovation, Student assessment.

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Contents

Contribution of this paper to the literature

The primary contribution of this paper is its integration of frequency analysis and h-index-based keyword evaluation to uncover both the popularity and scholarly impact of research trends in engineering education during the COVID-19 pandemic. This approach provides a dual-perspective scientometric analysis that has not been previously applied in this context, offering a comprehensive understanding of the evolving research landscape during this period.

1. Introduction

Engineering education is one of the main pillars of the modern technological environment, which trains future engineers to meet the challenges of the future and design innovative solutions (Gürdür Broo, Kaynak, & Sait, 2022). In view of the changing global conditions, it is imperative that engineering education should also evolve parallelly to develop professionals who can work effectively in the global context. Research in engineering education has helped investigate and propose theoretically backed strategies for teaching and learning, thereby contributing to the improvement of engineering programs worldwide (Finelli & Froyd, 2019).

This interest in research in engineering education has organized groups like the World Engineering Education Forum (WEEF), Research in Engineering Education Network (REEN), International Federation of Engineering Education Societies (IFEES), and the American Society for Engineering Education (ASEE), among others. These organizations focus on tracking and outlining the pace and direction. Furthermore, there are ongoing efforts at the institutional and individual levels to enhance the quality of engineering education (Michler, Engelbrecht, Schwarzbach, & Michler, 2022). Current research in engineering education encompasses a number of topics, for instance, student-centered learning, cooperative learning, integrated curriculum, and general traits such as communication, teamwork, and ethics (Asok, Abirami, Angeline, & Lavanya, 2016; Hernández-de-Menéndez, Vallejo Guevara, Tudón Martínez, Hernández Alcántara, & Morales-Menendez, 2019).

Exceptional events, for example the COVID-19 pandemic which was first reported in December 2019 and the World Health Organization (WHO) responding by declaring a Public Health Emergency of International Concern on January 30, 2020, and confirming the pandemic on March 11, 2020, have in many ways impacted society and education. The rapid transition to online and hybrid learning models forced educators and researchers to adapt swiftly, catalyzing the emergence of innovative educational strategies and new research opportunities. Universities worldwide faced substantial challenges, including maintaining educational quality, ensuring equitable access to resources, and supporting the well-being of students and faculty within a remote learning framework (Shekh-Abed & Barakat, 2021). Adapting to student safety measures and social distancing restrictions required novel and creative approaches to teaching and learning, fostering new educational models that persisted throughout the pandemic's development period (2020–2021) and control period (2021–2022) until the global emergency declined in May 2023, when WHO declared the end of the public health emergency. Therefore, much can be learned retrospectively to continue evolving teaching and learning practices.

One approach to deriving new knowledge from previous research is scientometric analysis of scientific articles (Blümel & Schniedermann, 2020), which enables the identification of research trends, lessons, and insights specifically, insights and lessons in engineering education during the pandemic (January 2020–May 2023). Identifying insights and lessons is crucial for understanding the implications of this event, establishing a baseline of research conducted during the pandemic, and recognizing emerging topics and areas of interest. This process allows researchers to prioritize studies addressing urgent issues, enrich the knowledge base, and develop innovative pedagogical approaches while guiding future research trajectories. Moreover, monitoring the evolution of insights and lessons helps the engineering education research community identify gaps in the literature, stimulate interdisciplinary collaborations, and ultimately improve the quality of engineering education.

This article presents a comprehensive scientometric analysis of research insights and lessons in engineering education, utilizing metadata from articles published since 2020, with a specific focus on the ramifications of the COVID-19 pandemic until May 2023. Key concepts in engineering education are examined, including active learning, problem-based learning, curriculum design, assessment, faculty development, and diversity and inclusion. The goal of this analysis is to establish a baseline of research conducted during this period, which affected the global population, and to highlight potential avenues for future investigations. Specifically, this study is guided by the following research questions: (a) What are the main topics related to engineering education research reported by authors in response to the changes brought about by the COVID-19 pandemic? and (b) What insights and lessons can be identified by analyzing the academic impact of reported topics through keyword analysis?

2. Methods

To conduct a scientometric analysis of insights and lessons in engineering education during the COVID-19 pandemic, a systematic approach consisting of five steps was followed. Figure 1 provides an overview of the methodology.

As the first step, the process of extracting journal articles was carried out. The primary data source for this study was the Scopus database, recognized as one of the most comprehensive and reliable sources of bibliometric information and commonly used in research of this nature (Vaishya, Gupta, Kappi, & Vaish, 2022). Documents published after 2019 focused on research in engineering education were selected. The data extraction was conducted on May 29, 2023. The search strategy was designed to include documents explicitly addressing engineering education, using the search equation presented in Table 1.

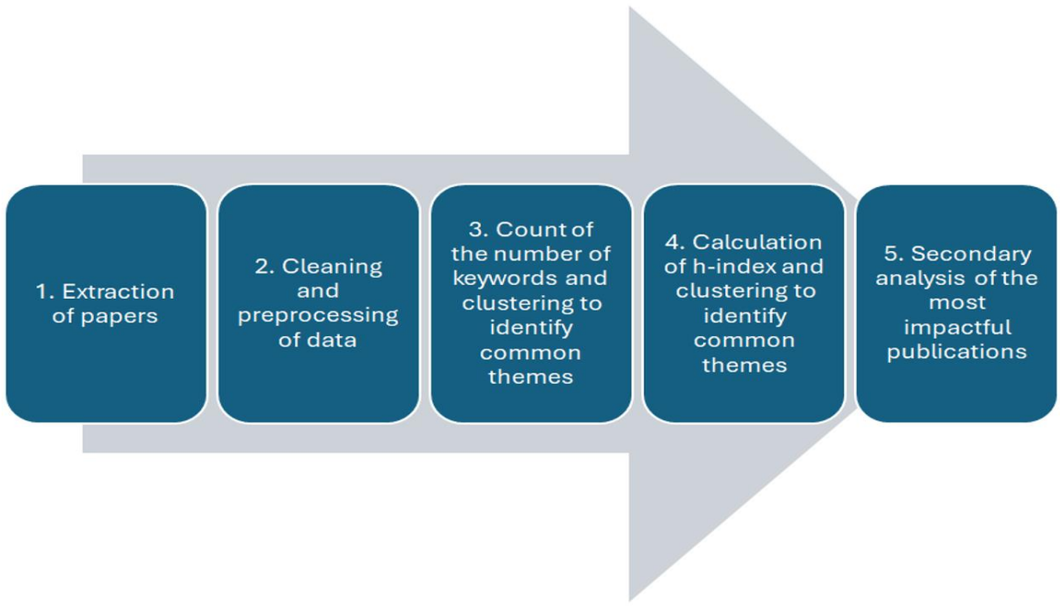

Figure 1. Overview of the methods.

Table 1. Search equation.

Id	Expression
1	engineer* AND (educati* OR curricul* OR teach* OR faculty OR student* OR undergrad* OR course* OR bachelor* OR degree*)
2	engineer* W/0 (educati* OR curricul* OR teach* OR faculty OR student* OR undergrad* OR course* OR bachelor* OR degree*)
3	engineer* W/3 (educati* OR curricul* OR teach* OR faculty OR student* OR undergrad* OR course* OR bachelor* OR degree*)
4	covid* OR *corona* OR "sars co*" OR pandem* OR lockdown* OR outbreak* OR epidemic*
(TITLE(1) OR ABS(2) OR AUTHKEY(3) OR SRCTITLE(1)) AND TITLE-ABS-KEY(3) AND PUBYEAR > 2019 AND SRCTYPE(j) AND NOT DOCTYPE(er OR tb)	
(TITLE(engineer AND (educati* OR curricul* OR teach* OR faculty OR student* OR undergrad* OR course* OR bachelor* OR degree*)) OR AUTHKEY(engineer* W/0 (educati* OR curricul* OR teach* OR faculty OR student* OR undergrad* OR course* OR bachelor* OR degree*)) OR ABS(engineer* W/3 (educati* OR curricul* OR teach* OR faculty OR student* OR undergrad* OR course* OR bachelor* OR degree*)) OR SRCTITLE(engineer* AND (educati* OR curricul* OR teach* OR faculty OR student* OR undergrad* OR course* OR bachelor* OR degree*))) AND TITLE-ABS-KEY(covid* OR *corona* OR "sars co*" OR pandem* OR lockdown* OR outbreak* OR epidemic*) AND PUBYEAR > 2019 AND SRCTYPE(j) AND NOT DOCTYPE(er OR tb)*	

Note: The asterisk (*) is a wildcard character used to retrieve different word variations with the same root.

The metadata, including publication year, author affiliations, countries, institutions, and keywords, was extracted from a corpus of 933 documents. This dataset comprised various document types, including articles (901), reviews (15), editorials (8), notes (7), and letters (2). To ensure consistency and accuracy in terminology throughout the study, a keyword homogenization process was conducted. This process involved reviewing the initial keyword list, identifying variations or synonyms, and standardizing them into a unified format. By eliminating inconsistencies and redundancies, this procedure aimed to enhance search result precision and improve the reliability of subsequent data analysis.

The documents covered a publication period of approximately four years, from 2020 to May 2023, with an annual distribution of 110 documents in 2020, 297 in 2021, 400 in 2022, and a partial count of 126 in 2023, as data collection concluded in May of that year. Geographically, the United States contributed the largest share of documents (176), followed by India (119) and Spain (70). China accounted for 51 documents, while the United Kingdom and Malaysia each contributed 34. Additionally, Indonesia and Mexico produced 32 documents each, while Peru and Brazil had 25 each. Australia closely followed with 24 contributions, and the Russian Federation and Chile each contributed 21. Canada, Germany, and Turkey each accounted for 19 documents, while South Africa recorded 17. The United Arab Emirates and Saudi Arabia contributed 16 and 15 documents, respectively, with Italy rounding out the top 20 contributors with 15 documents.

In the second step, the collected metadata underwent a cleaning and preprocessing procedure to ensure uniformity and facilitate further analysis. This included harmonizing similar author keywords and discarding those derived directly from search equation terms, such as "engineering education," "education," "engineering," "engineering teaching," "teaching," "engineering students," "students," "curriculum," "engineers," and "engineering undergraduates." The exclusion of these generic terms minimized noise in the co-occurrence network analysis.

The third step involved an exploration of insights and lessons based on the frequency of author keywords. In particular, keywords in the top 1% of occurrences were examined to determine the most significant topics and the predominant research interests in the field. Specifically, keywords in the top 1% of occurrences were examined, allowing the identification of the most frequently mentioned topics and the predominant research interests in the field.

Next, a co-occurrence visualization of these keywords was performed using VOSviewer, an open-source software widely used to develop and visualize bibliometric networks, including keyword co-occurrence networks. It was used in this study to determine the prevalent topics and their interconnections, providing a comprehensive understanding of the research landscape. This approach aligns with established bibliometric methodologies, enhancing the robustness and credibility of our findings. To ensure an accurate visualization of the keyword co-occurrence network, LinLog/modularity normalization was applied. This statistical adjustment technique effectively mitigated data

distortion, leading to a more reliable representation of keyword associations. The visualization of nodes and connections was determined by an attraction value of two and a repulsion value of minus one, which defined the degree of proximity or dispersion in the visualization. These parameters played a crucial role in the spatial distribution of nodes, highlighting the relative strengths of keyword connections. Also, the clustering resolution was set to two, and a minimum cluster size of five was established to gain better control over the number and size of the identified clusters. This helped the delineation of distinct thematic clusters, refining the granularity of our analysis and ensuring meaningful aggregation.

In the fourth step, in order to obtain a more detailed view of the academic output of the topics, the h-index for each keyword was calculated. The h-index, a well-known scientometric metric, provided a measure of the productivity and citation impact of the identified keywords. A second co-occurrence analysis was then conducted using VOSviewer, focusing specifically on documents containing the highest h-index keywords. This approach aimed to elucidate the interrelationships between the most impactful research topics in engineering education.

The fifth and final step was to analyze the findings within each cluster to identify insights and lessons in engineering education during the COVID-19 pandemic. The results of this scientometric analysis, along with a discussion of their implications for future research and practice in engineering education, are presented in the subsequent sections of this paper.

The fifth and final step was to analyze the findings within each cluster to identify insights and lessons in engineering education during the COVID-19 pandemic.

3. Results

In the analyzed corpus of 933 documents, a total of 857 documents contained author-provided keywords. These author keywords comprised 1,962 unique terms. As shown in Table 2, the maximum number of keywords observed in a single document was 12, recorded in two documents, while the minimum number of keywords was one, found in 28 documents. Among the documents, the most common keyword frequency per document was four, appearing in 244 documents, followed by three keywords in 213 documents and five keywords in 160 cases.

Table 2. Number of keywords observed by document.

Keywords	12	11	10	9	8	7	6	5	4	3	2	1
Documents	2	1	4	5	11	21	62	160	244	213	106	28

The analysis revealed significant variations in keyword occurrence. This variability provides insights into the distribution and relevance of different keywords within the dataset. The prevalence of a keyword across multiple documents suggests its importance and potential role as a major theme or focal area within the document collection. Conversely, the presence of keywords found in only one document indicates a broader range of specialized and infrequently used terms. In the analyzed documents, 1,588 keywords appeared only once.

The initial phase of identifying insights and lessons focused on analyzing the frequency of the most prominent keywords within the corpus. Specifically, keywords ranking within the top 1% in terms of occurrence were examined. The results of this analysis provide valuable insights into the dominant topics and areas of focus in the research field. These top keywords, representing the highest frequency occurrences, are presented in Table 3.

Table 3. Author keywords frequency.

Author keyword		**Frequency**	**Author keyword**		**Frequency**
1	Online learning	93	22	Information and communication technologies	13
2	Distance education	70	23	Student engagement	13
3	Online teaching	51	24	LMS	12
4	E-learning	41	25	Academic performance	12
5	Blended learning	34	26	Anxiety	12
6	Active learning	29	27	First-year students	12
7	Project-based learning	29	28	Gamification	12
8	Emergency remote education	28	29	Student perception	12
9	Online education	26	30	Sustainable development and sustainability	11
10	Virtual laboratory	25	31	Web-based education	11
11	Flipped classroom	24	32	Educational technology	10
12	Remote learning	20	33	Hybrid model	10
13	Augmented reality	19	34	Online classes	10
14	Student motivation	19	35	Perception	10
15	Virtual reality	19	36	College students	9
16	Mental health	17	37	Hands-on learning	9
17	Remote laboratory	17	38	Depression	8
18	Virtual learning	16	39	Gender issues	8
19	Chemical engineering	15	40	Online assessment	8
20	Collaborative learning	15	41	Outcome-based education	8
21	Assessment	13	42	Problem-based learning	8

As indicated in Table 3, the most frequently used keywords were "online learning" with a frequency of 93, "distance education" (70), "online teaching" (51), and "e-learning" (41). These terms, along with "online education" (26), which ranked ninth in frequency, highlight a clear trend toward internet-based and flexible, non-traditional education methods. "Blended learning," an approach combining face-to-face and online teaching methods, appeared 34 times, while "hybrid model" was mentioned 10 times. The terms "virtual laboratory" (25) and "remote learning" (20) reflect adaptations made to facilitate hands-on learning in a virtual context. Innovations such as augmented reality (AR) and virtual reality (VR), each mentioned 19 times, illustrate experimentation with immersive technologies to enhance learning experiences.

The keywords "active learning" (29) and "project-based learning" (29) indicate a shift toward more interactive and application-based education. The frequent use of technology-driven tools and platforms for remote and online learning is evident in mentions of "Information and Communication Technologies (ICT)" (13), "remote laboratory" (17), and "Learning Management System (LMS)" (12).

Growing worries regarding students' psychological health and their perceptions of university are evident, given the frequency of terms such as 'student motivation' (19), 'mental health' (17), 'anxiety' (12), and 'depression' (8). The reference to 'first-year students' (12) shows a specific concern with the experiences of those starting their engineering education during these difficult times.

Furthermore, there is also evidence of a focus on the quality and outcomes of engineering education. Terms such as "academic performance" (12), "assessment" (13), and "outcome-based education" (8) emphasize the ongoing commitment to maintaining high educational standards and effective assessment methods despite the challenging circumstances. Also, keywords such as "sustainable development" and "sustainability" (11) suggest ongoing curriculum development and adaptation, responding both to immediate crises and long-term trends in engineering education.

After the frequency analysis, VOSviewer was applied using the full counting method for the initial co-word analysis, utilizing each occurrence of a keyword, not just its first occurrence in a document. Specifically, keywords ranked in the top 1% in terms of frequency were included, ensuring a minimum of eight occurrences, consistent with the values presented in Table II. To ensure an accurate visualization of the keyword co-occurrence network, LinLog/modularity normalization was applied, an adjustment technique that effectively mitigates data distortion. The visualization of nodes and their connections was determined using an attraction value of two and a repulsion value of minus one, defining the degree of proximity or dispersion in the network. Additionally, the clustering resolution was set to two, and a minimum cluster size of five was established, enabling better control over the number and size of identified clusters, thereby refining the analysis.

The resulting visualization, derived from normalization followed by clustering, is presented in Figure 2. The analysis identified seven clusters, each representing a group of closely related keywords. These clusters exhibited frequent co-occurrence, indicating their association with shared research themes or topics. For clarity, Table 4 provides detailed information on each cluster, including a graphical representation and a description.

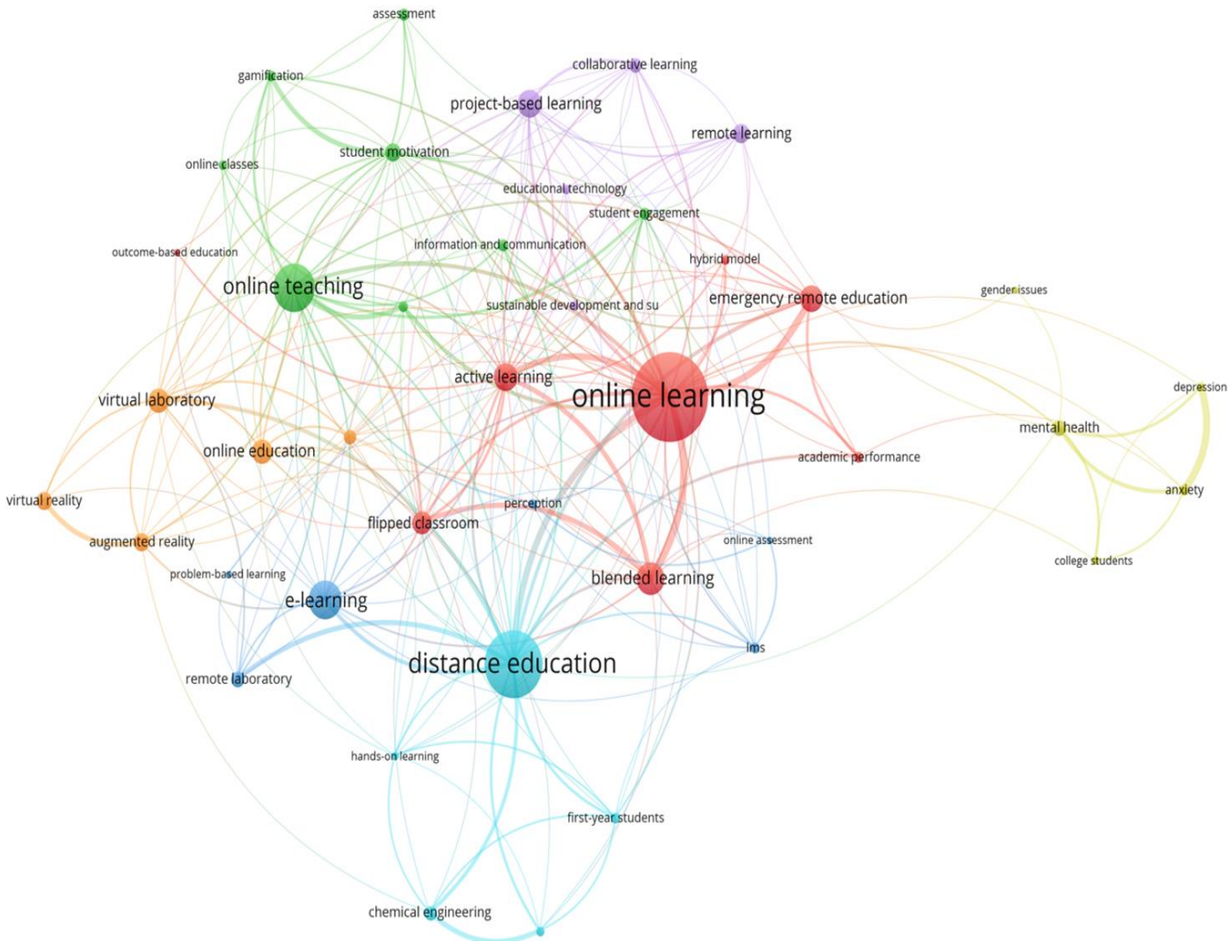

Figure 2. Clusters visualization made with VOSviewer.

In the second analysis, the h-index was calculated for each keyword to obtain a more accurate picture of its academic impact. This approach provides a comprehensive perspective on the relevance and influence of each topic. Besides the h-index, the analysis includes the total number of documents associated with each keyword, the accumulated citations, the citation rate per document, the highest number of citations received by a single document, and the number of documents in which the keyword appears but has not received citations. All these metrics together can be used to determine the overall impact of each keyword.

Table 5 presents these metrics for the keywords that were ranked in the top 1% in terms of h-index (With a minimum value of five).

Table 4. Detailed information on clusters.

Cluster	Keywords	Description
Red	"Online learning," "blended learning," "active learning," "emergency remote education," "flipped classroom", "hybrid model", "academic performance"	The focus is on the shift to online and blended learning models during the pandemic. In addition, it emphasizes teaching styles, academic performance, and results.
Green	"Online teaching", "online classes", "assessment," "information and communication technologies," "gamification", "student perception", "student engagement", and "student motivation"	The focus is on the strategies and challenges of online teaching. The terms "online teaching" and "online classes" indicate a broad shift in instructional methods towards online platforms. Also, in the motivation, commitment, and perception of students in the online environment. In addition, innovative techniques and tools such as "assessment," "information and communication technologies," and "gamification" were mentioned.
Blue	"E-learning," "remote laboratory," and "LMS" (learning management system), "perception" and "online assessment." "Problem-based learning"	The focus is on specialized aspects of online education. Specific platforms and methods used for distance learning, such as "e-learning," "remote laboratory," and "LMS" (learning management system), are highlighted.
Yellow	"Mental health," "anxiety," "depression" "college students", "gender issues"	The focus is on the psychological impact of the pandemic on students. Keywords such as "mental health," "anxiety," and "depression" indicate a specific emphasis on the psychological well-being of students during this time. The term "college students" suggests that this concern might be particularly relevant for students at the university level. The mention of "gender issues" hints at research examining differential impacts on mental health across gender lines.
Purple	"Project-based learning," "remote learning," "collaborative learning", "sustainable development and sustainability" and "Educational technology"	The focus is on project-based and collaborative learning strategies and the principles of sustainability and the role of technology. "Educational technology" is the science and practice of designing and using tools and resources to support the effective application of these approaches in teaching and learning.
Turquoise	"Distance education", "web-based education", "chemical engineering" "First-year students" and "hands-on learning"	The cluster is based on different topics of distance learning, and the possible subtopics may vary according to demographic groups and disciplines. The use of the phrase 'hands-on learning' highlights the issues and significance of practical and experiential learning in distance education.
Orange	"Online education", "virtual laboratory," "virtual reality," "augmented reality," and "virtual learning"	The focus of the cluster is on the advanced technologies used to improve the quality of online learning processes. The term 'online education' can be considered the general context for the cluster. The keywords 'virtual laboratory', 'virtual reality', 'augmented reality', and 'virtual learning' imply the application of immersive technologies to simulate real-life learning environments in the context of online education.

Table 5. Metrics for keywords that ranked within the top 1% in terms of h-index.

N	Keyword	h-index	Documents	Total citations	Citations by document	Max citations	Documents without citations
1	Online learning	12	93	879	9.45	245	29
2	Distance education	11	70	637	9.1	137	18
3	Flipped classroom	9	24	455	18.96	147	8
4	Emergency remote education	8	28	532	19	245	8
5	Blended learning	8	34	355	10.44	147	13
6	E-learning	8	41	326	7.95	86	9
7	Augmented reality	7	19	183	9.63	86	5
8	Virtual reality	7	19	182	9.58	86	6
9	Virtual laboratory	7	25	171	6.84	56	11
10	Student motivation	7	19	107	5.63	22	6
11	Online teaching	7	51	267	5.24	103	24
12	Web-based education	6	11	110	10	27	0
13	Chemical engineering	6	15	143	9.53	29	2
14	Active learning	6	29	246	8.48	147	12
15	Collaborative learning	6	15	93	6.2	24	5
16	Project-based learning	6	29	119	4.1	24	8
17	Online education	6	26	94	3.62	29	11
18	First-year students	5	12	133	11.08	43	3
19	Mental health	5	17	138	8.12	53	7
20	Gamification	5	12	59	4.92	22	5
21	Virtual learning	5	16	68	4.25	22	4
22	Remote laboratory	5	17	59	3.47	11	4

One of the primary insights and lessons relates to digital and remote education, as evidenced by keywords such as "online learning" (h-index 12), "distance education" (h-index 11), "emergency remote education" (h-index 8), "blended learning" (h-index 8), "e-learning" (h-index 8), "web-based education" (h-index 6), "online education" (h-index 6), and "virtual learning" (h-index 5). The citation range per document for these keywords, from 3.62 to 19, reinforces their significance. Collectively, these keywords form a group highlighting various educational modalities that leverage digital technologies to facilitate learning beyond the traditional classroom.

Another prominent insight and lesson focuses on the integration of advanced technologies in education, as demonstrated by "augmented reality" (h-index 7), "virtual reality" (h-index 7), "virtual laboratory" (h-index 7), and "remote laboratory" (h-index 5). These topics also exhibit a significant range of citations per document (3.47 to 9.63). They represent a cluster addressing the incorporation of cutting-edge technological tools into the educational process, enhancing student engagement and learning outcomes.

A notable insight and lesson are observed in pedagogical approaches and innovative teaching methods, as indicated by "flipped classroom" (h-index 9), "active learning" (h-index 6), "collaborative learning" (h-index 6), "project-based learning" (h-index 6), and "gamification" (h-index 5). The citation range per document (4.1 to 18.96) for these keywords further underscores their importance. This group encapsulates instructional strategies designed to promote active student participation and collaboration, enriching the overall learning experience.

Another significant insight and lesson focus on student and educator-related aspects in the educational context, as suggested by "student motivation" (h-index 7), "online teaching" (h-index 7), "first-year students" (h-index 5), and "mental health" (h-index 5). The citation range per document for these keywords varies between 5.24 and 11.08. These terms form a cluster emphasizing critical aspects related to students and educators, with a strong focus on factors contributing to successful learning outcomes.

The second analysis of keyword co-occurrence was conducted using VOSviewer, focusing specifically on the 441 documents containing the 22 keywords with the highest h-index values. A visualization was generated in VOSviewer while maintaining the same parameters. Only keywords that appeared at least four times within the corpus of 441 documents were included. This graphical representation is presented in Figure 3. This second analysis resulted in the identification of six clusters, each representing a set of closely associated keywords. Detailed descriptions of these groups are provided in Table 6.

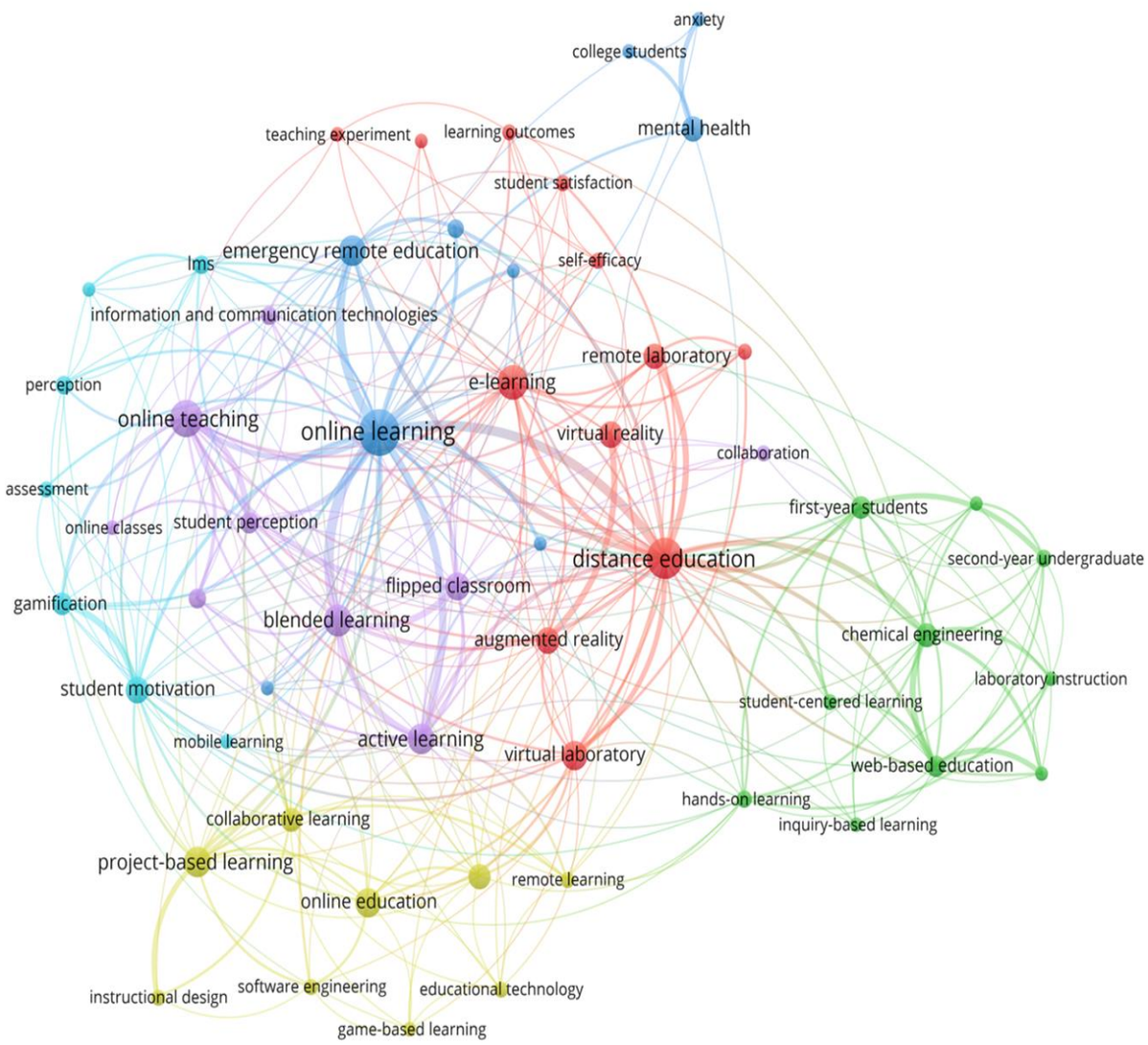

Figure 3. Clusters visualization of documents with the highest h-index.

Table 6. Detailed information on clusters created using documents with the highest h-index.

Color	Keywords	Description
Red	"Distance education", "e-learning", "virtual laboratory", "virtual reality", "augmented reality", "remote laboratory", "student satisfaction", "self-efficacy", "learning outcomes", "digital twin", "problem-based learning", "teaching experiment"	Incorporation of advanced, immersive technologies in distance education, emphasizing student-centric factors such as satisfaction and self-efficacy, as associated with emerging technologies and pedagogical strategies.
Purple	"Online teaching", "blended learning", "active learning", "flipped classroom", "student perception", "student engagement", "information and communication technologies", "collaboration", "online classes"	Confluence of contemporary pedagogical techniques and technology-enhanced learning environments, underscoring the significance of student perception and engagement in collaborative and interactive educational settings.
Blue	"Online learning", "emergency remote education", "mental health", "academic performance", "student experience", "learning analytics", "anxiety", "college students", "hybrid model"	Focus on the psychological facets of students within online and emergency remote learning contexts, with the incorporation of learning analytics indicating the utilization of data-driven techniques to amplify student experience and outcomes.
Yellow	"Project-based learning", "online education", "virtual learning", "collaborative learning", "software engineering", "instructional design", "remote learning", "educational technology", "game-based learning"	Combination of technology, collaboration, and project-based strategies within online and remote learning environments, with a specific focus on fields like software engineering, emphasizing active, collaborative, and applied learning.
Turquoise	"Student motivation", "gamification", "learning management system (LMS)", "perception", "assessment", "mobile learning", "online assessment"	Emphasis on motivational factors, technology, and evaluation within online learning, with the utilization of gamification and mobile learning indicating an inclination towards engaging, flexible learning methodologies.
Green	"Chemical engineering", "first-year students", "web-based education", "second-year undergraduate", "hands-on learning", "student-centered learning", "inquiry-based learning", "computer-based learning", "laboratory instruction", "problem solving"	Application of diverse pedagogical techniques within specific educational contexts, such as chemical engineering and early undergraduate education, with a robust focus on experiential, student-centered education.

4. Discussion and Implications

The initial phase of identifying insights and lessons often involves analyzing the occurrence of keywords within the selected corpus. This approach provided an initial thematic overview, offering insights into the dominant topics and areas of focus within the field of study. To balance coverage across a broad range of topics while emphasizing the most recurrent and potentially significant ones, this study grouped data using two criteria aligned with the initial research questions: (1) employing keyword co-occurrence and frequency as defined by the authors to identify general patterns, and (2) using the h-index to identify the most impactful topics.

The results initially reveal a growing interest in facilitating the integration of online learning, first as a response to the inability to attend in-person classes (Fernández & Vicente, 2022; Liu, 2023) and later as an opportunity to expand the reach of the education system, eliminating temporal and spatial barriers (Huang, 2012; Mushtaha, Abu Dabous, Alsyouf, Ahmed, & Raafat Abdraboh, 2022). Overall, the findings obtained through both criteria clearly demonstrate that the COVID-19 pandemic was not only a catalyst for the adoption of online learning but also a turning point in rethinking its implementation.

The results demonstrated how the COVID-19 pandemic directly impacted traditional educational models, transforming them in response to the realities of the time. This transition was not straightforward, as educational models and teaching-learning strategies had historically been designed primarily for in-person interaction. When the possibility of physical interaction was eliminated, questions arose regarding existing strategies, necessitating their reevaluation. This highlighted the need for information on engineering education during the pandemic and the subsequent changes reflected in online and hybrid learning models (Desai, Rai, & Karekar, 2023; Shi, Peng, & Sun, 2022), active learning (Motade & Deshpande, 2022; Patil, Mane, & Shinde, 2022), emergency remote education (Mazzola, Bozzi, Testa, Sancassani, & Zani, 2023), and the flipped classroom model (Tang et al., 2023; Zhu et al., 2022).

At a more detailed level, the necessity to redesign learning experiences, monitor student performance, and develop new assessment methods became evident (Álvarez-Alonso & Bonet, 2023; Liang, Jiang, Ping, & Jiang, 2024; Ulutas, 2022). Experiments conducted with engineering students showed improvements in class attendance, engagement, and overall performance. However, challenges also emerged, particularly at the beginning of the lockdown, when instructors faced an increased workload, combined with various adverse conditions, including limited digital literacy, insufficient support for educational technology, and lack of access to appropriate devices and tools for carrying out their activities. These factors affected their willingness and ability to adopt new learning platforms and online tools.

The integration of technology, collaboration, and project-based strategies within remote and online learning environments was another key insight and lesson. The use of information and communication technologies (ICTs) and technology-based teaching and learning techniques was evident during the pandemic years. Given the significant differences between in-person and remote instruction, it was necessary to understand and address these differences separately to minimize their impact on students and education.

Face-to-face teaching and learning offer advantages such as psychological and emotional connections between participants, which are difficult to replicate in remote environments. However, studies demonstrate that online learning, particularly in engineering and technology-related subjects, adapts well to this model due to its reliance on highly visual content and computational tools, such as dynamic modeling or automation system planning based on interface visualization (Grace-McCaskey, D'Anna, Hagge, Etheridge, & Smith III, 2022; Gutierrez et al., 2022). One significant insight and lesson that exemplifies this shift was the emphasis on student engagement and participation in collaborative and interactive educational environments. This was especially relevant in online learning and emergency remote education, where learning analytics techniques were used to enhance student experiences and outcomes. This insight and lesson were particularly pronounced in fields such as chemical engineering and early university education, where experiential, student-centered learning became a focal point.

Another important insight and lesson was the use of gamification (Raju, Bhat, Bhat, Souza, & Singh, 2021) and collaborative and interactive educational environments (Daineko et al., 2022; Sankaranarayanan et al., 2020), which favor the use of engaging and flexible learning methodologies (Parra-González, López Belmonte, Segura-Robles, & Fuentes Cabrera, 2020). Collaborative learning platforms, online resources, and virtual practices were used extensively during this period; therefore, research on these topics is timely. Many people also pointed out the advantages of online learning, including technology-mediated collaborative learning. The use of social networks, instant messaging applications, and videoconferencing tools like Zoom helped students to communicate and collaborate with ease, without the pressure of face-to-face interactions. In addition, these tools helped instructors support learners outside the classroom. Other benefits reported included the flexibility of learning and access to online materials, especially in fields like software engineering where active, collaborative, and applied learning are emphasized.

Nevertheless, challenges associated with remote learning were also identified. One key issue was the lack of uniformity in remote learning offerings across different subjects, requiring increased hours of independent study, which students often perceived negatively.

One major concern was the students' perception of online classes, which some of them found depressing and ineffective. Research also established that students' attention spans turned out to be much lower than during the first 25 minutes of class (Pelucio, Simões, Dourado, Quagliato, & Nardi, 2022; Pitel, Phan, Bonnaire, & Hamonniere, 2023). Moreover, the reports from the Organization of American States (OAS) indicated that the impact of COVID-19, isolation, and the move to online learning impacted students and faculty in different ways. However, the effect on vulnerable student groups was especially severe because they had no access to the necessary tools and resources.

Another area of focus was the psychological aspect of students in remote and emergency online learning contexts. Keywords like "mental health," "anxiety," and "university students" are indicative of a rising concern for student well-being during this period (Del Savio, Galantini, & Pachas, 2022; Hernández-Yépez et al., 2022).

On the other hand, the use of virtual reality (VR) and augmented reality (AR) to improve the online learning processes and to simulate real real-life learning environment was another important insight and lesson learned from the pandemic (Grosser, Xia, Alt, Rüppel, & Schmalz, 2023). The inability to conduct in-person practical exercises likely contributed to this phenomenon. Although VR and AR are not new technologies, they have become more relevant in recent years across various fields, including tourism, medicine, and education. These two technologies have gained importance in engineering education due to the need for practical and hands-on simulations.

The application of AR and VR in learning can be used to address the challenges of transitioning to an online learning model by offering engaging and innovative methods of instruction. The benefits of AR-based instruction for students include: (1) simplifying the process of delivering information, especially for large datasets; (2) helping students improve their communication skills; (3) providing a greater sense of realism; (4) enabling the use of large datasets; and (5) integrating virtual and physical objects within the same environment. These advantages align with engineering education and other similar disciplines that rely on practical and applied teaching and learning processes (Daineko et al., 2022; Grosser et al., 2023; Huang, Amini, Jiang, & Yin, 2023).

While technological advancements offer numerous benefits, it is crucial to balance them with associated costs. During the pandemic, ICTs enabled the continuation of academic activities but also contributed to increased anxiety and depression due to social isolation and the pressure to adapt to new learning methods. Educational institutions must address these mental health challenges by implementing support services and stress management strategies, ensuring a holistic approach to learning.

For disciplines like engineering, real-world practical experience is vital. Digital environments powered by technological advancements can simulate real-world conditions at a lower cost, facilitating technical training. However, this requires significant investment in IT infrastructure, continuous training, and maintenance of these systems. Institutions must also strengthen their IT departments and employ specialized personnel to support these initiatives.

As a result of this study and its implications, educational institutions should consider investing in IT infrastructure to develop online learning environments. This includes acquiring new and improved hardware and software, as well as strengthening network capabilities to enhance reliability and efficiency. Furthermore, it is crucial to implement ongoing training programs for educators on the use of advanced technologies and pedagogical strategies. These programs will assist educators in incorporating digital tools into their teaching strategies, thereby creating a collaborative and engaging online learning community. Institutions should also revise curricula to include digital tools and integrate real-life scenarios that can be recreated with the help of technology, providing practical learning experiences to students.

It is important to provide extensive mental health support services to help cope with the psychological effects of online learning. Counselling, stress management programs, and other support services should be provided by institutions for students, faculty, and administrators. In this regard, it is important to build on increased collaboration and engagement strategies using interactive tools and techniques that can help foster active participation and teamwork. At the same time, the role of administrative support for the integration of ICTs in education should be enhanced, so that there are sufficient resources, policy guidelines, and leadership to support the technology-induced changes in teaching and learning. With the help of the following recommendations, online and distance learning can be improved in terms of quality and effectiveness, which will result in a more resilient and adaptive education system.

Some limitations of the present study relate to the scientometric analysis. The results may be biased, and insights into engineering education and lessons proposed by organizations such as WEEF, REEN, IFEES, and ASEE might be missed by limiting the study to the pandemic period. Future research should explore the rise of new teaching and learning strategies to determine whether they were circumstantial or have led to lasting educational transformations.

Another limitation relates to the scientometric analysis itself. In this manner, while this approach enables a comprehensive analysis of publication patterns, it does not have the capability of a systematic review. Scientometric analysis, which deals with a large number of publications, may fail to capture certain qualitative aspects that a systematic review would have captured.

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