Application of Virtual Simulation in Education: Current Status, Hot Spots and Trends

Xu Dai [1, a], Xinjian Fu [2, b], Jiayu Zuo [3, c], and Lianshuan Shi [*, d]

College of Information Technology Engineering, Tianjin University of Technology and Education, Tianjin, China;

[a] 13643356765@163.com, [b] jiliangfxj@163.com,

[c] 18085292779@163.com, [d] 2735703048@qq.com

Abstract. The use of virtual simulation in teaching and learning has become increasingly widespread. However, there is still a lack of systematic reviews in the field of virtual simulation education. Using CiteSpace visual analysis software and bibliometric methods, we analyzed 223 articles from the Web of Science core dataset to examine the current status, key areas, and trends in virtual simulation education research. Additionally, we identified existing gaps and proposed future research directions. Our findings indicate that virtual simulation technology is most commonly integrated with medical education. China leads in the number of annual publications, with a significantly higher research output than other countries. However, research collaboration between countries remains limited. Regarding research themes, the integration of artificial intelligence with virtual reality in intelligent virtual simulation is expected to expand further. Researchers should enhance international collaboration, introduce emerging technologies such as generative artificial intelligence into education, explore innovative teaching methods, and reshape the virtual simulation learning environment.

Keywords: virtual simulation; educational applications; research status; research hotspots; research trends.

1. Introduction

Traditional educational methods have several disadvantages [1], including a lack of interactivity and an overemphasis on theoretical knowledge at the expense of practical teaching. With the rapid advancement of information technology, education is increasingly being integrated with these new technologies. In this context, the use of virtual simulation technology in teaching can effectively stimulate students' initiative and enhance their practical skills [2]. Virtual simulation technology refers to the use of computer systems to create realistic simulation environments, reproducing real-world scenes, processes, and phenomena [3].

In the field of education and training, virtual simulation technology has a wide range of applications and significant advantages [4]. It is not limited by time or location and provides a flexible learning environment, especially in situations where real teaching resources are scarce or practical opportunities for students are limited. Virtual simulation can recreate real learning scenarios, such as laboratory experiments, surgical procedures, engineering projects, etc., helping students better grasp abstract concepts and improve their practical skills. For example, virtual simulation technology can create a virtual laboratory where students can perform experimental tasks in a simulated environment using virtual reality devices to simulate complex experimental processes [5]. It can also simulate intricate surgical scenes, allowing medical students to learn and practice surgical procedures [6]. Similarly, virtual simulation enables students to simulate the design and construction of buildings or the operation and maintenance of mechanical equipment [7]. In aviation, flying cadet can simulate actual missions within a virtual environment, including realistic flight conditions [8]. In conclusion, virtual simulation environments allow learners to acquire the necessary knowledge and skills through immersive simulations.

Despite the abundance of research on virtual simulation in recent years, most studies tend to focus on specific application scenarios or short-term effects. In a previous systematic review, de

Paula Ferreira et al. [9] examined the use of simulation in industry, identifying 10 simulation-based approaches and 17 Industry 4.0 design principles. Foronda et al. [10] reviewed 80 studies on virtual simulation in nursing education and found that it had a positive impact on students' knowledge acquisition. Similarly, Coyne et al. [11] conducted a meta-analysis with healthcare professionals and concluded that virtual simulation is an effective strategy for assessing students' clinical competence and supporting learning in medicine and nursing. These reviews show that the majority of studies on virtual simulation technology have concentrated on medical fields, particularly nursing. However, there is still a lack of systematic assessment and summarization of the development of research themes on virtual simulation technology in education.Besides, there is a lack of discussion of cooperation between countries. Therefore, to provide an overview of virtual simulation research in education, this study analyzes the number of studies, research topics, etc., aiming to offer researchers a broader perspective.

2. Materials and Methods

Bibliometric analysis is the quantitative evaluation of knowledge across various disciplines using mathematical and statistical methods. It emphasizes quantification, with the primary metrics being the number of articles(such as publications, especially journal articles and citations) and the number of authors (both individuals and groups) [12]. In this study, we used CiteSpace, a visualization and analysis tool developed by Chaomei Chen's team at Drexel University [13].

The articles for this study were sourced from the Web of Science (WOS) Core Collection database, using a subject-based search with specific limitations on year and language. Search with keywords such as “virtual simulation” and “education”, restricted to English language publications from 2012 to 2024, resulting in a total of 2,281 search results. After excluding categories such as Review Articles, Early Access, Retracted Publications, Editorial Material, Book Chapters, and other types of documents, and retaining only Articles and Proceeding Papers, we obtained 1,921 results. Subsequently, by reviewing titles and abstracts and eliminating those that are not relevant to the topic, a final set of 223 results was selected. The criteria for exclusion were: (1) research topics not related to the field of virtual simulation in education, and (2) papers lacking clear research questions, methods, or conclusions. The screening process is illustrated in Figure 1. The search results were downloaded as Full Record and Cited References in plain text file and saved in a local data folder. The data were then imported into CiteSpace for further analysis. The current state of the research was explored through visual analysis of journals, countries, and keywords. Research hotspots were identified using keyword and cluster analyses, and research trends were examined through emergent word..

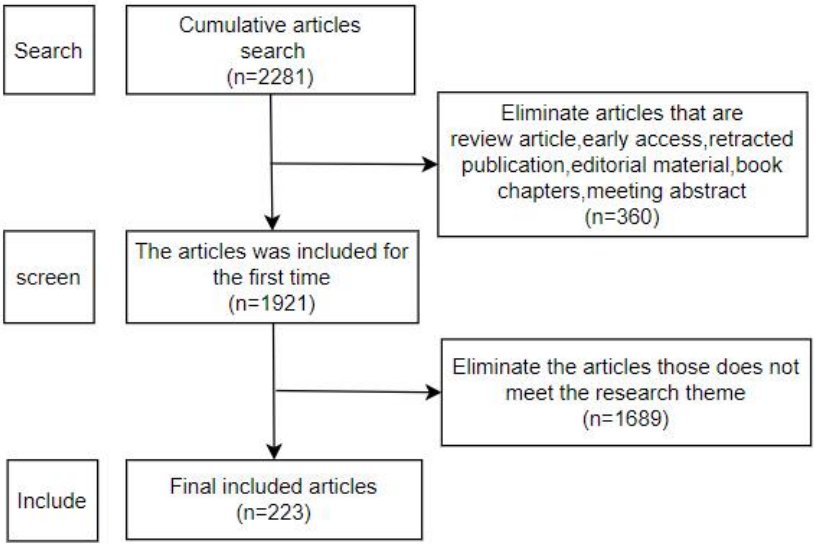

Fig. 1 Literature screening process.

3. Results

3.1 Number, Timing and Publications

3.1.1 Characteristics of the number of communications over time

The number of publications between 2012 and 2024 showed an overall upward trend. The highest number of publications, 39, was recorded in 2022 (as shown in Fig. 2). The significant increase between 2020 and 2022 may be attributed to the impact of the COVID-19 pandemic, which led to a global shift toward online education, driving widespread adoption of virtual simulation technology. However, the number of articles published in 2022-2024 has decreased, and this decline may be due to several factors. First, the return to traditional educational models following the pandemic. As schools resumed in-person teaching with the easing of restrictions, the urgency for virtual simulation education diminished, possibly reducing interest in related research. Second, the research field of virtual simulation education applications may be reaching maturity. As research deepens, innovation may slow, leading to a temporary decline in the number of publications. Third, the shift in research priorities. The rise of emerging technologies such as generative artificial intelligence and large language models has likely drawn researchers' attention to these areas. Additionally, the apparent decrease in publications for 2023-2024 may partly due to the fact that 2024 data were only collected through August, meaning that the year's research output is not yet fully published or accounted for. More complete annual data will be needed in the future to accurately assess scholarly activity during this period.

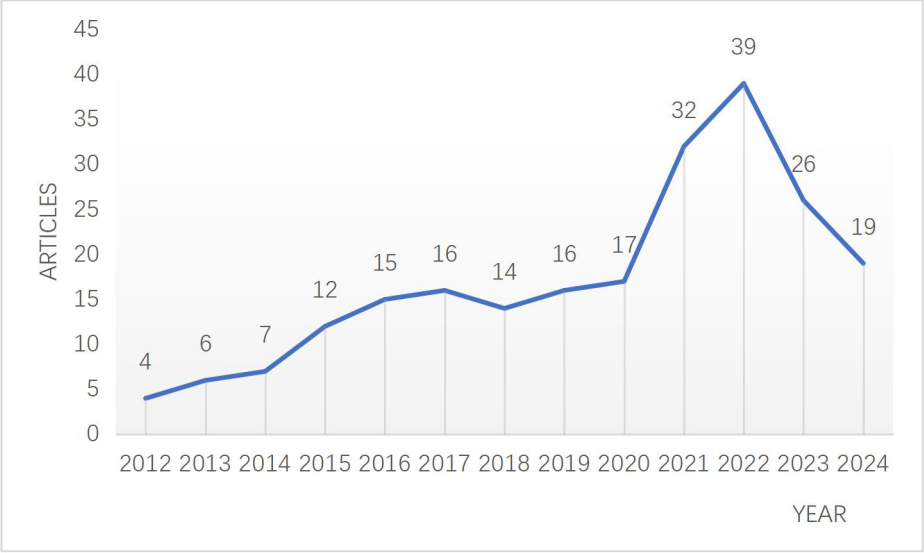

Fig. 2 Annual number of publications in the literature on the application of virtual simulation in education

3.1.2 Number of articles issued by different journals

By analyzing the main source journals in the field of virtual simulation for educational applications, the top 10 journals with the highest number of publications were identified (as shown in Table 1). Most of these journals are high-impact academic publications. Among them, COMPUTER APPLICATIONS IN ENGINEERING EDUCATION has the largest number of articles, with 14 publications.

The top 10 journals span a wide range of disciplines, including educational technology, computer science, engineering, and medicine, reflecting the interdisciplinarity of virtual simulation education. Those journals also show a high volume of citations, indicating their significant academic influence in the field. In particular, CLINICAL SIMULATION IN NURSING, COMPUTER APPLICATIONS IN ENGINEERING EDUCATION, and CIN-COMPUTERS INFORMATICS NURSING have garnered the most citations, with over 100 each, demonstrating

that articles in these journals are widely acknowledged by the academic community and have had a strong impact on subsequent research.

Table 1. The journals with many published articles on the application of virtual simulation in education (Top 10)

Ranking	Journals	Frequency	Citations	Impact factor
1	COMPUTER APPLICATIONS IN ENGINEERING EDUCATION	14	118	2.2
2	NURSE EDUCATION TODAY	6	65	4
3	BMC MEDICAL EDUCATION	6	47	3.4
4	CIN-COMPUTERS INFORMATICS NURSING	5	103	1.8
5	SCIENTIFIC REPORTS	3	12	4.3
6	COMPUTERS & EDUCATION	3	93	11.6
7	CLINICAL SIMULATION IN NURSING	3	148	3.1
8	CUREUS JOURNAL OF MEDICAL SCIENCE	3	5	1.1
9	INTERNATIONAL JOURNAL OF CONTINUING ENGINEERING EDUCATION AND LIFE-LONG LEARNING	3	14	0.4
10	SIMULATION & GAMING	3	51	2.4

3.2 Country Analysis

Table 2 shows the top 10 countries with the highest number of publications on virtual simulation educational applications, with China leading the list. This dominance can be attributed to both national strategies and policy support, as well as China's strong technological and research foundation. Additionally, the high demand for applications in fields such as medical and engineering education has significantly driven the development of this area. Table 2 also reveals that the USA and England have higher betweenness centrality, indicating a more active academic cooperation network. However, the overall betweenness centrality across countries is low, with some countries even showing a value of 0, suggesting that most countries remain relatively isolated within the academic cooperation network, occupying marginal positions with limited influence.

Table 2. Countries with the highest number of publications on the application of virtual simulation in education (Top 10)

Ranking	Country	Frequency	Centrality
1	China	110	0.06
2	USA	27	0.11
3	Spain	13	0.00
4	Canada	13	0.02
5	England	9	0.11
6	India	7	0.09
7	Turkey	4	0.00
8	Austria	4	0.00
9	Australia	4	0.09
10	Brazil	4	0.00

3.3 Keywords and Research Hotspots

Using CiteSpace software, the analysis period was set from January 2012 to August 2024, with a time slice of 1. "Keyword" was selected as the node type, and the g-index was chosen as the filtering criterion with a threshold of k=20. The frequency and betweenness centrality of keywords were calculated for 223 articles, resulting in "N=292, E=558." After identifying the top ten

high-frequency keywords (as shown in Table 3), it was found that from 2012 to 2024, research on the application of virtual simulation in education has primarily focused on integrating virtual simulation with technologies such as virtual reality and augmented reality to create interactive learning environments and teaching models. The research also highlights the widespread application of virtual simulation in disciplines such as nursing, natural sciences, and experimental education, as well as the design of various learning and teaching modes [14].

Table 3. High-frequency keywords in the application of virtual simulation in education (Top 10)

Ranking	Keywords	Frequency
1	virtual simulation	47
2	virtual reality	39
3	education	32
4	science	9
5	design	8
6	virtual laboratory	8
7	augmented reality	7
8	nursing education	6
9	model	6
10	experimental teaching	5

The article used keyword K-value clustering to analyze the identified keywords, resulting in 10 clusters (as shown in Fig. 3). The clustering modularity value was Q=0.7402 (greater than 0.3), and the average silhouette value was S=0.921 (greater than 0.7), indicating that the clustering structure is both significant and reliable. Based on the high-frequency keywords, the research hotspots in the field of virtual simulation education applications can be summarized into the following categories.

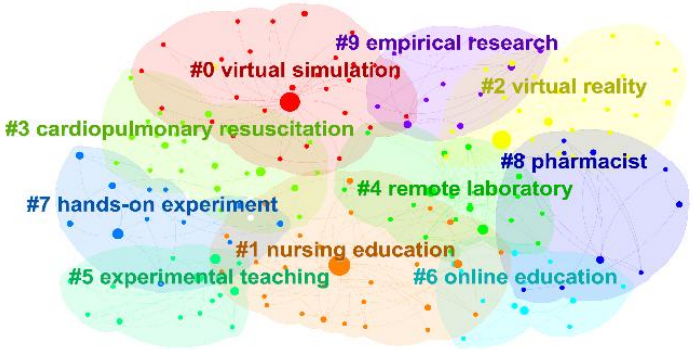

Fig. 3 The cluster map of the application of virtual simulation in education domain

3.3.1 Integration and Innovation of Virtual Simulation Technology

Virtual simulation technology is increasingly integrated with virtual reality, augmented reality, and other advanced technologies to offer learners an immersive and interactive learning environment. As technology continues to advance, virtual simulation is also exploring integration with emerging technologies such as artificial intelligence and big data to enhance the intelligence and personalization of education, thereby fostering student development. M. Sharma, S. Sharma, et al. proposed that incorporating ChatGPT and the Metaverse into nursing education could enrich the learning experience for nurses and provide remote skills necessary for patient monitoring, ultimately improving patient outcomes and care quality [15].

3.3.2 Virtual Simulation for Online Laboratory Teaching

The use of virtual simulation in laboratory teaching has become a significant focus of research in this field. With the rise of distance and online education, virtual simulation technology offers a novel solution for online laboratory teaching [16,17]. It solves the limitation of time and space in traditional experimental teaching.

3.3.3 Application of Virtual Simulation in Medicine and Other Professional Disciplines

Virtual simulation educational applications span a wide range of interdisciplinary fields, including physics, chemistry, biology, medicine, and engineering [18], where practical skills are essential. In particular, Subjects such as medicine and nursing often require human participation in teaching. There are many challenges in this way of teaching, such as high risk, high cost, and limited resources. Virtual simulation can provide an effective way to solve these problems, by building highly realistic virtual medical scenes, students can repeatedly practice complex clinical operations in a risk-free environment.

3.3.4 Effectiveness Assessment and Empirical Research on Virtual Simulation in Education

As virtual simulation technology becomes increasingly widespread in education, empirical research focused on assessing its educational effectiveness has become a key concern for researchers. Current studies evaluate virtual simulation education across multiple dimensions, including student engagement, learning satisfaction, and educational outcomes [19]. Chang, J. et al. assess the effectiveness of virtual simulation laboratory teaching using various evaluation methods, such as formative and summative assessments [20].

3.4 Analysis of Emergent Words and Research Trends

Figure 4 shows the keyword emergence intensity. Generally, the greater the intensity of keyword emergence, the higher the degree of attention to the keyword. Figure 4 shows the intensity of keyword emergence. Generally, the greater the intensity of keyword emergence, the higher the attention given to the keyword. As seen in the figure, the keyword with the highest emergence intensity is "virtual simulation technology", followed by "nursing education," "virtual simulation," and "model." Keywords like "virtual laboratory," "artificial intelligence," and "attitudes" reflect the latest developments in the field of virtual simulation education applications, especially from 2022 to 2024. These terms highlight recent hot topics in the research of virtual simulation education applications.

The timeline graph (as shown in Fig. 5) arranges keywords according to their appearance over different years. The larger the node, the more frequently the keyword appeared. Based on the timeline graph, along with the yearly changes in emergent words, the development of virtual simulation education from 2012 to 2024 can be divided into three distinct stages.

The first stage (2012-2015) marks the exploratory phase of applying virtual simulation technology in education. During this period, the theoretical framework for virtual simulation in education was still immature, and researchers focused on the feasibility of the technology and its preliminary application scenarios. For instance, C. Foronda and E.B. Bauman proposed a strategy for incorporating virtual simulation into nursing education [21]. The concept of virtual laboratories also began to emerge during this phase, offering students initial simulations of laboratory environments, though with relatively limited interactivity and immersion [22].

In the second phase (2016-2019), research hotspots shifted toward optimizing the application of virtual simulation across various disciplines, including medicine, nursing, engineering, and the natural sciences. A key focus was on creating interactive learning environments through virtual simulation to enhance students' practical skills and cognitive understanding.

The third stage (2020-2024) witnessed the broader adoption of virtual simulation, propelled by advancements in artificial intelligence (AI), big data, and 5G communication technologies. Particularly during the COVID-19 pandemic, the demand for distance learning and online education surged, and virtual simulation played a crucial role in overcoming challenges in remote laboratory teaching and hands-on training. Additionally, virtual simulation became more integrated with AI, augmented reality (AR), mixed reality (MR), and big data analysis to provide students with personalized, interactive learning experiences. At this stage, the evaluation of educational outcomes and empirical research also became more systematic and scientific.

Top 18 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2012 - 2024
faculty	2012	1.17	**2012**	2014	
interactive learning environments	2015	0.96	**2015**	2018	
improving classroom teaching	2015	0.96	**2015**	2018	
inquiry	2015	0.96	**2015**	2018	
curriculum	2015	0.72	**2015**	2020	
environment	2015	0.72	**2015**	2020	
cardiopulmonary resuscitation	2016	0.9	**2016**	2018	
virtual simulation	2015	2.12	**2017**	2019	
augmented reality	2017	2.03	**2017**	2018	
educational software	2017	1.07	**2017**	2019	
nursing education	2014	2.47	**2018**	2020	
educational technology	2018	1.05	**2018**	2020	
computer simulation	2018	0.88	**2018**	2020	
virtual simulation technology	2020	2.94	**2020**	2022	
model	2012	2.11	**2020**	2021	
virtual laboratory	2013	1.67	**2022**	2024	
artificial intelligence	2020	0.71	**2022**	2024	
attitudes	2022	0.61	**2022**	2024	

Fig. 4 The keyword emergence map of the application of virtual simulation in education

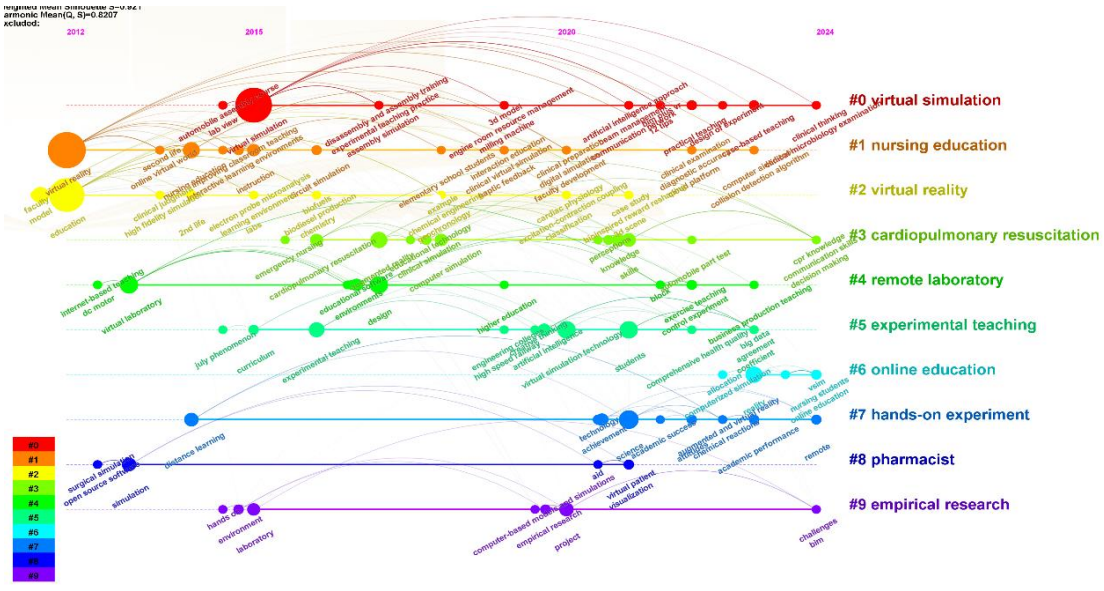

Fig. 5 Keyword timeline map of the application of virtual simulation in education

4. Discussion

Virtual simulation technology, as a significant innovation in education, has gained widespread attention in recent years and has been applied across various disciplines, particularly in practical fields such as medicine, nursing, and engineering. Additionally, the integration of virtual simulation with other technologies like virtual reality (VR) and augmented reality (AR) has enhanced the focus on students' learning experiences, learning outcomes, and the validation of independent learning

and problem-solving abilities. While substantial research has been conducted in several countries with notable results, there are still some limitations.

Although emerging technologies like generative artificial intelligence have recently garnered attention from researchers, much of the research remains in the early stages. The integration of intelligent personalization with virtual simulation is still an under-explored area. In the future, combining virtual simulation with technologies such as generative AI could enable personalized learning paths and real-time feedback based on each student's learning progress, behavioral data, and interests. This integration would also assist teachers in optimizing their teaching strategies, introducing more dynamic and adaptive learning models into their course designs.

Currently, the development of virtual simulation education applications focuses heavily on practicality, but students' interest in learning also needs to be prioritized, as it directly impacts their concentration and, consequently, their learning outcomes. In the future, virtual simulation technology can be further integrated with VR, AR, MR, large language models, haptic feedback, voice recognition, motion capture, and other technologies to achieve multimodal interaction, offering students a richer and more immersive learning experience. In recent years, there has been a growing body of research on gamified education, with some scholars demonstrating that gamification can significantly enhance students' learning experiences [23]. Therefore, integrating gamification elements, multimedia components, and reward mechanisms into virtual simulation education applications could increase engagement, improve learning motivation, and enhance learning outcomes.

Although some studies have evaluated the short-term effects of virtual simulation teaching, there is still a lack of empirical studies on long-term effects. Comprehensive evaluation of virtual simulation's teaching effectiveness through extended follow-up studies will be a critical direction for future. Such long-term empirical studies can offer educators deeper insights into how virtual simulation technology influences students' skill development, knowledge retention, and learning transfer. These insights will provide a scientific basis for optimizing virtual simulation education and refining teaching models to maximize its effectiveness.

5. Conclusion

This article uses CiteSpace software to visualize and analyze literature in the field of virtual simulation education applications, summarizing the current research status, key areas of interest, and emerging trends based on representative literature. In addition, it identifies existing gaps and proposes potential future research directions, aiming to provide valuable references for further exploration in this field. Despite notable advancements, the field still faces challenges, such as the rapid pace of technological updates and the difficulty of adapting virtual simulation to diverse disciplines and educational stages. Future research will need to address these challenges by finding effective solutions. Moreover, greater attention should be paid to emerging technologies and products, ensuring their thoughtful integration into education. Continuous exploration of optimal collaborative development models will be essential to enhancing teaching methods and advancing intelligent education.

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