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Virtual Simulation in Biomedical Education: A 20-year Bibliometric Study Using Biblioshiny

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Abstract: Virtual simulation is a method that employs a digital environment with partial immersion to create real-life experiences for specific purpose. It has become a key tool in multiple fields, including military, manufacturing, healthcare, business, games, sports, education, tourism, and more. Nowadays, bibliometrics has played an important role in assessing scholarly publications. To better understand virtual simulation and its applications in biomedical education, the study employed the software Biblioshiny to analyze articles from recent decades in the Web of Science core database. The comprehensive analysis included the selection criteria for analyzed documents, completeness assessment, yearly scholarly output, mean annual citations, key relevant and local-cited sources, the most cited articles and word cloud analysis. Our research findings will offer valuable perspective on the impact of virtual simulation in biomedical education.

Keywords: Virtual simulation; Biomedical education; Biblioshiny; Biology; Teaching; Training

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1. Introduction

1.1. Virtual simulation and its applications

Virtual simulation can be defined by Dr. Foronda of the University of Miami as follows: "the use of partial immersion through a digital learning environment (e.g., computer, tablet, phone, screen, etc.) to foster a perceived lived experience for an intended outcome (e.g., learning, entertainment, etc.)" [1]. It is recognized as an important technique across multiple domains, including military [2], manufacturing [3], healthcare [4], business [5], games [6], sports [7], education [8], tourism [9], and others. In the field of education, virtual simulation has been widely used in chemistry, physics [10], pharmacy [11], nursing [12], psychology [13], intelligent manufacturing [14], art [15], medicine and biology [16].

1.2. Biological and medical education

Within higher education, Biology is an important discipline, providing a broad spectrum of applications, including medicine, crop production, environmental conservation, and biotechnology. It is a branch of science

that studies living organisms and their vital processes. Interestingly, the classification of biology is complex. It can be categorized in several ways. Based on research objectives, the field includes Botany, Zoology, Microbiology, and Virology. Different research levels consist of Molecular Biology (studying at the molecular level) and Cell Biology (studying at the cellular level). When considering its relationship with other disciplines, Biology comprises Biochemistry (biology + chemistry), Biophysics (biology + physics), Bioinformatics (biology + computer science), and Biogeography (biology + geography). From research aspects, this discipline contains Physiology, Anatomy, and Genetics. Additionally, medicine is an important application of biology, using biological principles to improve human health. Medical education enables professional evolution, shaping students into physicians through methodical learning processes and experiences [17].

1.3. Bibliometrics and its analysis tool: Bilioshiny

Bibliometrics, a newly developed field, is a crucial tool for accessing scholarly publications. According to the Oxford English Dictionary, it is defined as "The branch of library science concerned with the application of mathematical and statistical analysis to bibliography; the statistical analysis of books, articles, or other publications" [18]. There are three laws on bibliometrics, such as Lotka's law, Bradford's law, and Zip's law, which refer to the distribution patterns of citations, journal impact, and word frequency, respectively [19]. Currently, there are many tools for bibliometric analysis, including Java-based platforms (VOSviewer, CRExplorer, and CiteSpace), Python frameworks (ScientoPy and pybliometrics), and R packages (Bibliometrix and Biblioshiny). Among these tools, Bibliometrix and Biblioshiny, are among the most widely used. As of December 23, 2024, the paper "Bibliometrix: An R-tool for Comprehensive Science Mapping Analysis" [20] about this software has been cited 5,492 times on WoS and 11,246 times on Google Scholar. These high citation counts demonstrate the significant contribution of the software Biblioshiny to the field of bibliometrics.

1.4. Research objectives and questions

To better understand virtual simulation and its applications in biomedical education, the study employed the software Biblioshiny to address this issue. The objectives are as follows: (1) to analyze the current status of virtual simulation in biomedical education in the past two decades; (2) to identify the primary references contributing to this field; and (3) to investigate the main themes in the evolution of virtual simulation of biological education. Along with these objectives, the study aimed to answer the following four research questions: (1) What are the publication patterns and citation impact of research on virtual simulation in biological education? (2) What are the major research themes and their evolution in this field? This study will provide useful insights into the role of virtual simulation in biology education.

2. Materials and methods

2.1. The selection of analyzed databases

The bibliometric analysis requires high-quality literature databases. Currently, several databases are widely used, including Scopus, Web of Science, PubMed, Google Scholar, CNKI, Dimensions, and Semantic Scholar. In **Figure 1**, this study compared four major bibliometric databases. Furthermore, CNKI focuses on Chinese academic content, Dimensions integrates a large volume of linked information from diverse fields, forming a unified platform, and Semantic Scholar is an AI-powered search platform. Considering that WOS is a high-quality database and Anhui Normal University has access to it, this database was selected for the analysis. Within

the WoS platform, there are nine databases, including the Web of Science Core Collection, Derwent Innovations Index, and others. Due to its comprehensive data coverage, this study specifically selected the Web of Science Core Collection for this analysis.

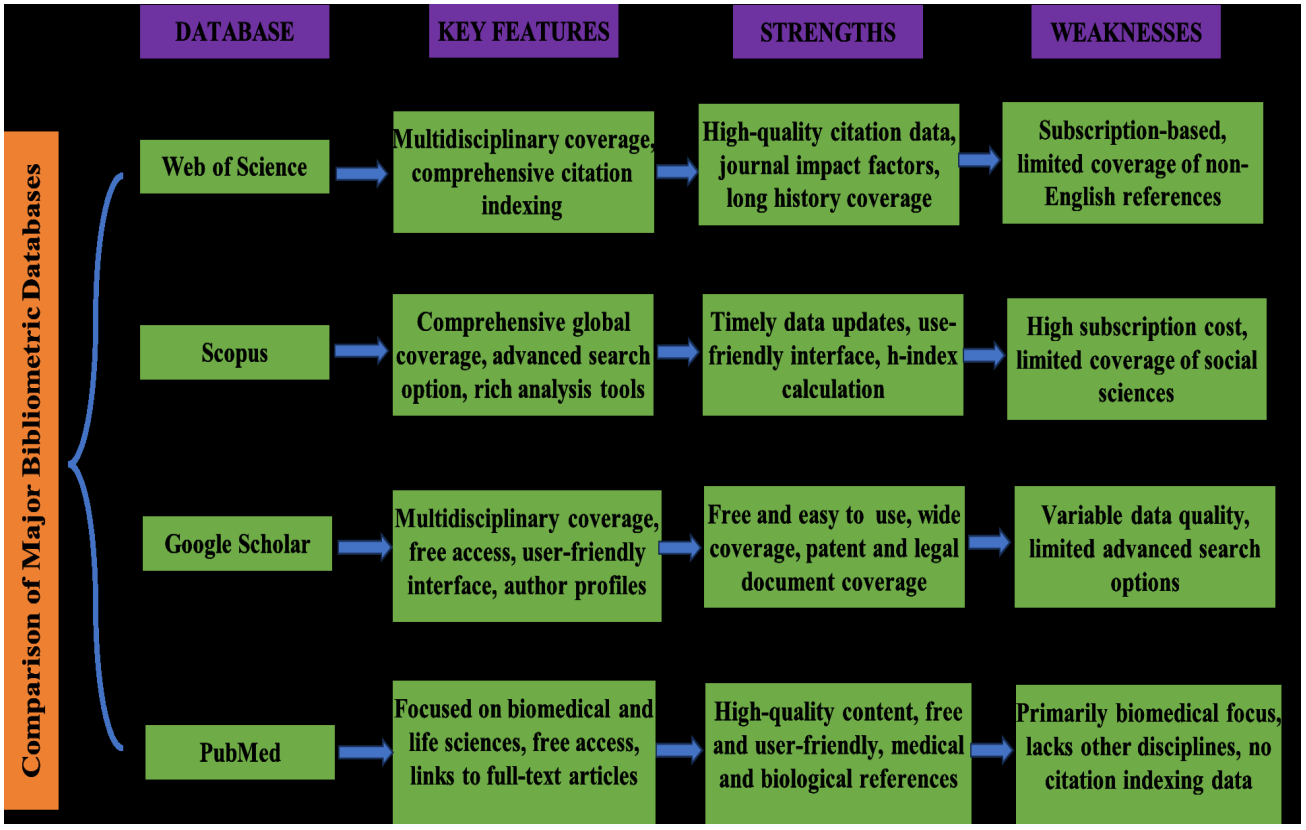

Figure 1. Comparison of major bibliometric databases.

2.2. The selection criteria of articles and bibliometric analysis

The search strategy consisted of five steps. First, the following search terms were used: "virtual reality" (Topic) OR "virtual simulation" OR "computer simulation" (Topic) AND "teaching" (Topic) AND ("biology" (Topic) OR "medicine" (Topic)). Second, documents published in the past decades were selected (2004–2023). Third, the language to English and the document types to Article or Review Article were restricted. Fourth, documents that were not highly related to the research theme were excluded. Finally, documents that lacked Keywords (DE) and Keywords Plus (ID) were removed. Through these steps, the selected documents were believed to be high-quality and can be used for further analysis. In the current study, Biblioshiny software was chosen for bibliometric analysis and used ggpolt2 for visualization. The detailed steps were listed in the previous paper [21].

3. Results and discussion

3.1. Completeness assessment of analyzed documents

To guarantee the high quality of the data analysis, this study performed a completeness assessment of 434 documents from WoS using the Biblioshiny software. This analysis calculated the missing counts and missing percentages. Based on these, the data quality was classified into three categories: excellent, good and acceptable. According to **Figure 2**, ten metadata fields (66.7%) were assessed as excellent, including key information such

as abstract, author, journal, keywords, total citations, etc. Additionally, five fields were classified as good, and only one (keywords plus) was acceptable. Consequently, this study can be concluded that the overall quality of the analyzed data is high and suitable for further analysis.

Metadata	Description	Missing Counts	Missing %	Status
AB	Abstract	0	0.00	Excellent
AU	Author	0	0.00	Excellent
DT	Document Type	0	0.00	Excellent
SO	Journal	0	0.00	Excellent
DE	Keywords	0	0.00	Excellent
LA	Language	0	0.00	Excellent
PY	Publication Year	0	0.00	Excellent
WC	Science Categories	0	0.00	Excellent
TI	Title	0	0.00	Excellent
TC	Total Citation	0	0.00	Excellent
C1	Affiliation	1	0.23	Good
CR	Cited References	1	0.23	Good
RP	Corresponding Author	1	0.23	Good
DI	DOI	12	2.76	Good
ID	Keywords Plus	65	14.98	Acceptable

Figure 2. Completeness assessment of 434 documents from WoS using Biblioshiny.

3.2. Annual scientific production between 2004–2023

This study investigated the annual number of documents on virtual simulation teaching in Biomedicine from 2004–2023. The result data was retrieved from Biblioshiny and visualized using ggplots (**Figure 3**). In most years, the number of documents is lower than 20, with the lowest (7) observed in 2016. However, the numbers increased in recent years. Specifically, all of these numbers in most recent years exceeded 45, reflecting a growing emphasis on virtual simulation as an educational tool in the field of Biomedicine.

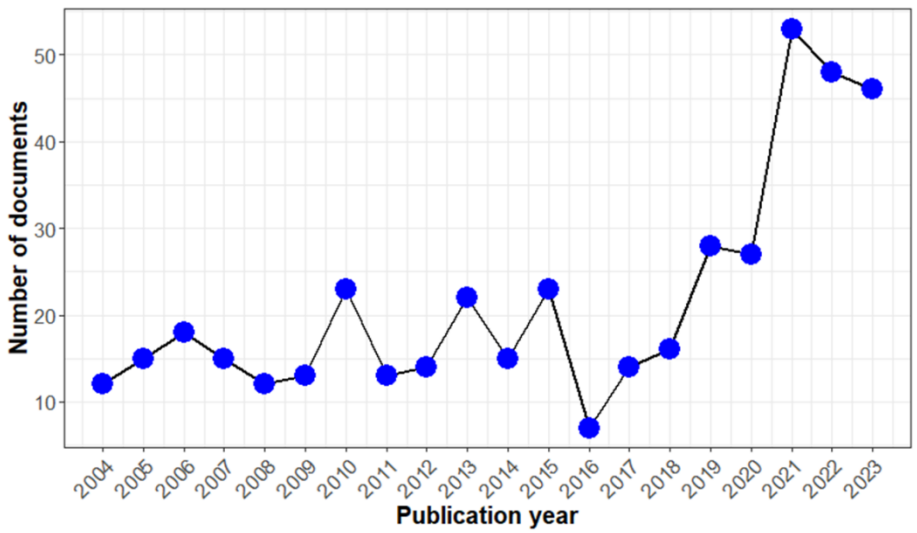

Figure 3. Annual scientific production visualized using ggplot2.

3.3. Average citations per year between 2004–2023

To investigate the trend in average citations per year (MeanTCperYear), the study calculated the citation rates for publications over the period 2004–2023 using Biblioshiny. For example, 12 papers were published in 2004, which acquired a total of 18.75 citations over the subsequent 21 years, resulting in an average of 0.89 citations per year. The calculated results are shown in **Figure 4**. The study observed that in three years (2004, 2005, and 2011), the MeanTCperYear values were very low. This indicates that the papers published in these years had a relatively small impact. In contrast, in 2008 and 2018, these values were very high, 5.5 and 8.53 respectively. Overall, the MeanTCperYear shows an upward trend, indicating that more recent articles are receiving higher citation counts. This could be due to multiple factors, such as increased research collaboration and advancements in technology.

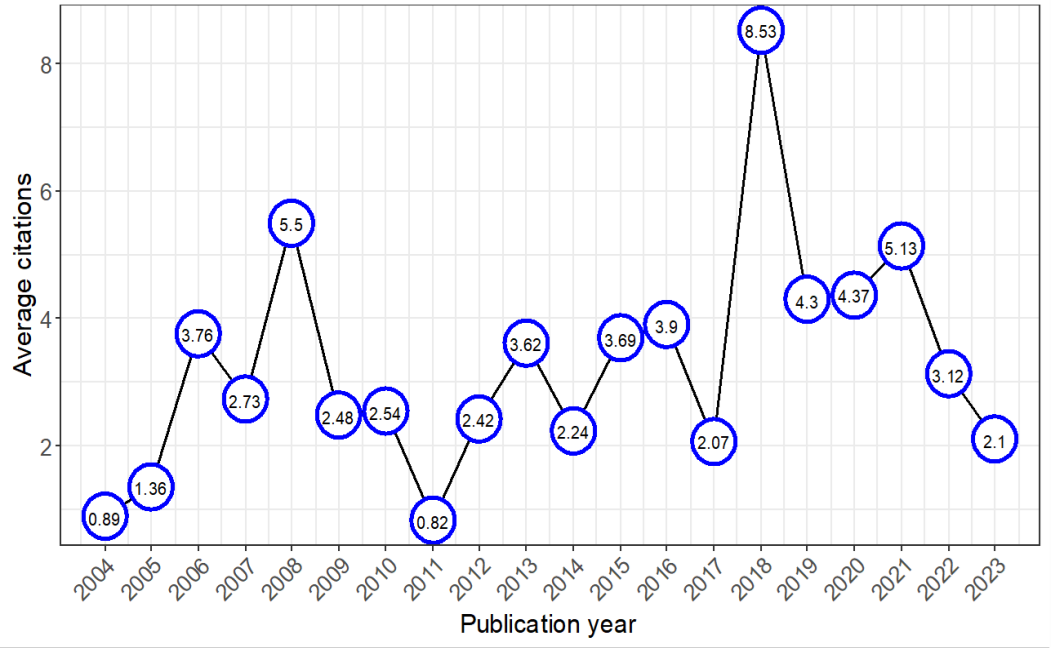

Figure 4. Average citations per year visualized using ggplot2.

3.4. Most relevant and local-cited sources

This study performed a comparative analysis of the most relevant sources and the most local-cited sources on Virtual Simulation Teaching in Biomedicine using Biblioshiny. The results were visualized using ggplot2 (**Figure 5** and **Figure 6**). The analysis of the most relevant sources (**Figure 5**), measured by publication output, revealed a primary focus on biomedical engineering, medical informatics, and surgical education. Key journals in these fields consist of *Biochem Mol Bio Educ* and *Neurosurgery* (11 articles each), followed by *Comput Methods Programs Biomed* and *Int J Comput Assist Radiol Surg* (10 articles each). Additionally, other important journals include *Int J Med Inform* (8 articles), *Interact Learn Environ*, *J Laryngol Otol*, *J Med Syst* and *Virtual Reality* (7 articles each). These journals cover a broad scope, from molecular biology to virtual reality applications in healthcare.

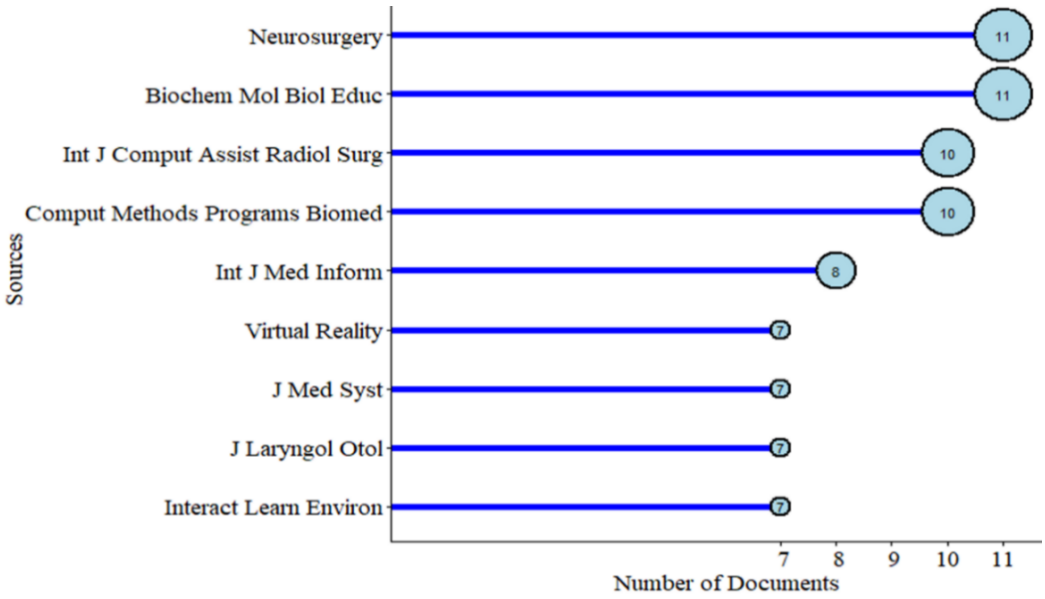

Figure 5. Top 10 relevant sources visualized using ggplot2.

In contrast, the most local-cited sources imply the influence and impact of specific journals in the field based on the frequency of their citation counts (**Figure 6**). The top five sources were *Anatomical Sciences Education* (Anat Sci Educ, 242 citations), *Computers & Education* (201 citations), *Neurosurgery* (171 citations), *Medical Education* (160 citations), and *Surgical Endoscopy* (146 citations). The comparative analysis found that some journals only presented either the most relevant or the most local-cited sources. For example, *Biochem Mol Biol Educ* and *Interact Learn Environ* appeared only in the list of the most relevant sources, while *Plos One* was present only in the list of the most local-cited sources list. It is worth noting that *Neurosurgery* appeared in both lists, implying that it has a significant impact within the field of Virtual Simulation Teaching in Biology and medicine.

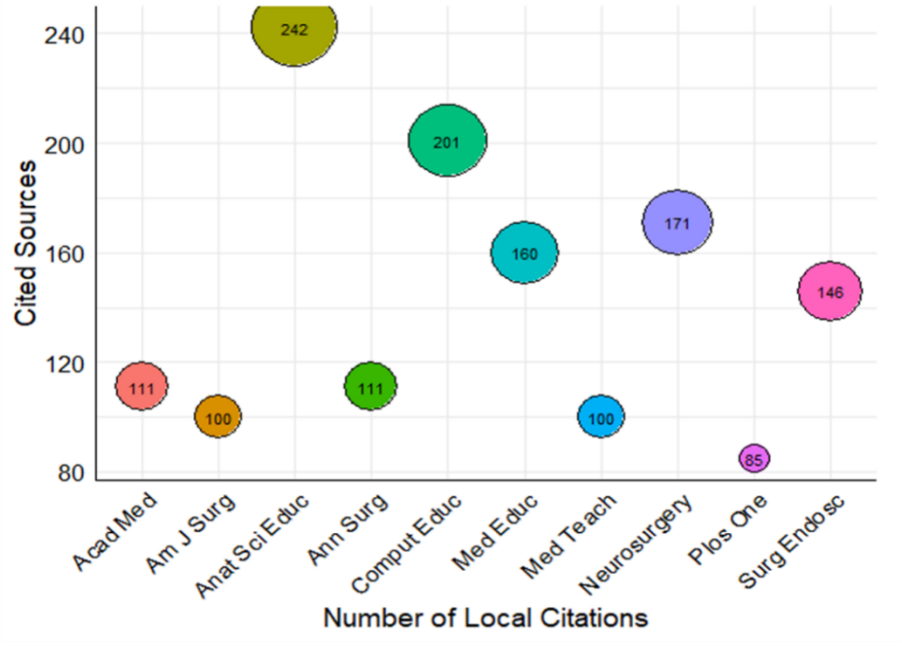

Figure 6. Top 10 local-cited sources visualized using ggplot2.

3.5. The most cited articles on Virtual Simulation Teaching in Biomedicine

To identify influential articles on Virtual Simulation Teaching in Biology and Medicine, this study analyzed the most cited documents. **Figure 7** lists the top 10 cited articles in this field, indicating the important impact of simulation-based education across diverse fields, particularly in healthcare and medical training.

The most cited article, written by Wayne *et al.* (2008) [22] and titled "Simulation-based Education Improves Quality of Care During Cardiac Arrest Team Responses," has received 459 citations. In this article, a retrospective case-control study on cardiac arrest was reported. The findings revealed that training residents using simulations can notably enhance the quality of care provided during real-life advanced cardiac life support (ACLS) events.

In a highly cited paper authored by Parong *et al.* (2018) [23], which focused on teaching cell biology and acquired 446 citations, the study showed that biology students in an immersive VR environment reported increased interest and motivation levels and achieved better results on a post-lesson test.

Furthermore, some studies investigated simulation technology in medical education, such as Hamilton *et al.* (2021) (320 citations) on pedagogical outcomes of immersive VR [24], while Scalese *et al.* (2008) (270 citations) on skills training [25]. Other key articles address robotic surgery and cranial micro neurosurgery training, suggesting diverse applications of virtual simulation in medical education.

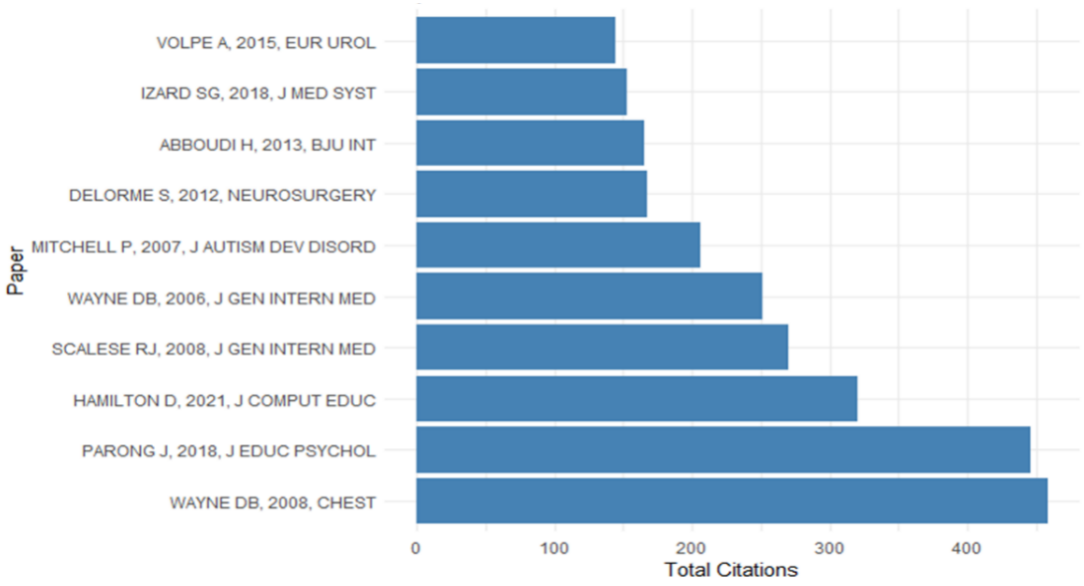

Figure 7. The most cited documents are visualized using ggplot2.

3.6. Word cloud analysis of authors' keywords

To identify key themes and research areas within the field of simulation-based teaching in medical and biological education, the study conducted a word cloud analysis. The terms and their frequencies were obtained using Biblioshiny and further visualized using the package "wordcloud 2.6" (https://cran.r-project.org/web/packages/wordcloud/). This analysis removed the terms "virtual reality" and "virtual reality" to ensure a clearer focus on other key themes. Furthermore, the study only retained terms with a frequency of more than 5 occurrences, which can filter out less frequent and potentially less important terms for subsequent analysis. The analyzed results are shown in **Figure 8**. Firstly, the study observed that three terms dominated, such as "simulation" (62 occurrences), "education" (45 occurrences) and "augmented reality." These terms suggest that simulation-based

learning and immersive technologies are central to modern biological and medical education. Secondly, high-frequency terms also included “medical education” (37 occurrences), “training” (29 occurrences), and “teaching” (20 occurrences), which focus on professional development, pedagogy and instructional design within the field. Finally, other terms such as anatomy (12 occurrences), neurosurgery (9 occurrences), surgical training (10 occurrences), “e-learning” (7 occurrences), “endoscopy” (7 occurrences), “learning” (7 occurrences), “patient simulation” (7 occurrences), robotics (7 occurrences), and virtual patient (5 occurrences) suggest a broader interest in online learning and simulation-based training. Overall, the word cloud analysis provided valuable insights into the primary areas of interest within simulation-based teaching in medical and biological education.

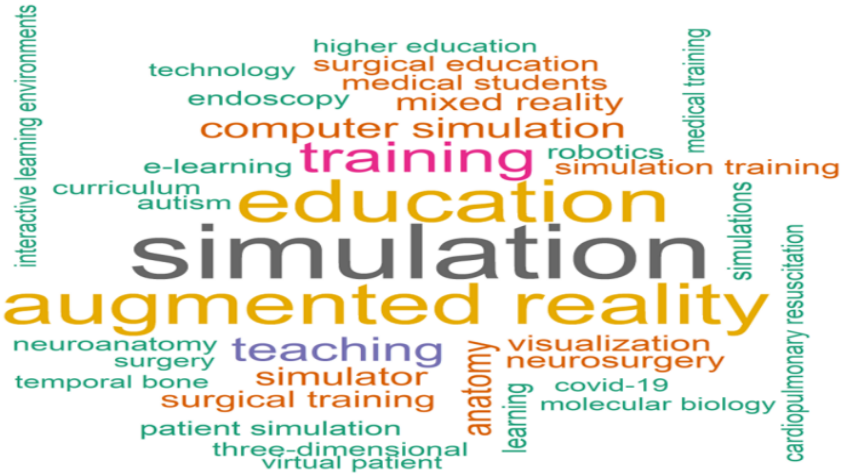

Figure 8. Word cloud analysis of authors’ keywords using Biblioshiny and the wordcloud package.

4. Conclusion

Virtual simulation is a method that employs a digital environment with partial immersion to create a real-life experience for a particular purpose. To better understand virtual simulation and its applications in biomedical education, this study employed the software Biblioshiny to analyze articles from recent decades in the Web of Science core database. The R package ggplot2 was used for visualization. The completeness assessment of the analyzed documents indicates that the overall data quality is high and suitable for further analysis. The analysis of annual scientific production shows that all numbers in most recent years exceeded 45, reflecting a growing emphasis on virtual simulation as an educational tool in the field of Biomedicine. The average citations per year, as indicated by MeanTCperYear, shows an upward trend, suggesting that more recent articles are receiving higher citation counts. This could be due to multiple factors, such as increased research collaboration and advancements in technology. Furthermore, the analysis of the most relevant and locally-cited sources revealed that key journals like *Biochem Mol Bio Educ* and *Neurosurgery* are highly relevant based on publication output, while *Anat Sci Educ* and *Computers & Education* exhibit strong local citation impact, highlighting the diverse influence of journals within the field of virtual simulation teaching in biomedicine. The most cited article, written by Wayne *et al.* (2008) and titled “Simulation-based Education Improves Quality of Care During Cardiac Arrest Team Responses,” has received 459 citations. The word cloud analysis observed that three terms dominated, such as “simulation,” “education” and “augmented reality.” These terms suggest that simulation-based learning and immersive technologies are central to modern biological and medical education. This study’s findings will provide useful insights into the role of virtual simulation in biomedical education.

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Disclosure statement

The authors declare no conflict of interest.

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