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EMERGING RESEARCH ON VIRTUAL REALITY APPLICATIONS IN VOCATIONAL EDUCATION: A BIBLIOMETRIC ANALYSIS

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ABSTRACT

Aim/Purpose	This study explores the subject structure, social networks, research trends, and issues in the domain that have the potential to derive an overview of the development of virtual reality-based learning media in vocational education.
Background	Notwithstanding the increasingly growing interest in the application of virtual reality in vocational learning, the existing research literature may still leave out some issues necessary for a comprehensive understanding. This study will point out such areas that need more exploration and a more comprehensive synthesis of the literature by conducting a bibliometric analysis. It will be interesting to keep track of the changing concepts and methodologies applied in the development of VR-based learning media in vocational education research.
Methodology	This review was carried out using bibliometric methodology, which can highlight patterns of publication and research activity in this hitherto little-studied

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area. The results of the study have the potential to lead to evidence-based priority in VR development, which will tailor work for vocational contexts and set the compass against the growing worldwide interest in this area. The study provides a descriptive analysis of publications, citations, and keyword data for 100 documents published between the years 2013 and 2022 from the Scopus database, which is conducted to illustrate the trends in the field.

Contribution

This study also counts as a contribution to understanding the research hotspots of VR-based learning media in vocational education. Through bibliometric analysis, this study thoroughly summarized the relevant research and literature laying a knowledge foundation for researchers and policy makers. Additionally, this analysis identified knowledge gaps, recent trends, and directions for future research.

Findings

The bibliometric analysis revealed the following key findings:

1. A growing publication trajectory, with output increasing from 7 articles in 2013 to 25 articles in 2022.
2. The United States led the contributions, followed by China, and Germany.
3. The most prominent authors are affiliated with American medical institutions.
4. Lecture proceedings include familiar sources that reflect this nascent domain.
5. Citation analysis identified highly influential work and researchers.
6. Keyword analysis exposed technology-oriented topics rather than learning-oriented terms.

These findings present an emerging landscape with opportunities to address geographic and pedagogical research gaps.

Recommendations for Practitioners

This study will be beneficial for designers and developers of VR-based learning programs because it aligns with the most discussed and influential VR technologies within the literature. Such an alignment of an approach with relevant research trends and focus can indeed be very useful for the effective application and use of VR-based learning media for quality improvements in vocational students' learning.

Recommendations for Researchers

In fact, in this bibliometric review of VR integration within vocational classrooms, a future call for focused research is presented, especially on teaching methods, course design, and learning impact. This is a framework that seeks to establish its full potential with effective and integrated use of VR in the various vocational curricula and settings of learners.

Impact on Society

From the findings of the bibliometric analysis, it is evident that virtual reality technologies (VR) have significantly led to transformation within educational media. There is no denying that the growing interest and investment in the integration of virtual reality into vocational education has been well manifested in the substantive increase in publications in the last decade. This shows what the innovation driving factor is in the United States. At the same time the rapid contributions from China signal worldwide recognition of the potential of VR to improve technical skills training. This study points the way for more research to bridge critical gaps, specifically how VR tools can be used in vocational high school classrooms.

Furthermore, research should be aligned to meet specific needs of vocational learners and even promote international cross-border partnerships, pointing out the potential of virtual reality to be a universally beneficial tool in vocational education. The examination of highly cited articles provides evidence of the potential of VR to be an impactful pedagogical tool in vocational education. The findings suggest that researchers need to move forward looking at the trajectory of VR in vocational education and how promising it is in defining the future for innovative and effective learning methodologies.

Future Research

This study is an exceptionally valuable contribution, a true landmark in the field of dynamic development, and one that denotes very meaningful implications for the future course of research in the dynamically developing field of bibliometric analysis of VR-based learning media for vocational education. The increase in the number of publications emanates from growing interests in the application of virtual reality (VR) technologies in vocational education. The high concentration of authorship from the USA, along with the ever-increasing contributions from China, spotlights the increasing worldwide recognition of the impact of immersive technologies in the enhancement of training in technical skills. These are emerging trends that call for research to exemplify the diverse views and global teamwork opportunities presented by VR technologies.

The study also highlights critical areas that need focused attention in future research endeavors. The fact that the embedding of VR tools into classrooms in vocational high schools has been poorly researched points to the major gap in pedagogical research within authentic educational settings. Therefore, further investigations should evaluate teaching methods in VR, lesson designs, and the impacts of VR in specific vocational trades. This supports the need for learner-centered frameworks that are tailor-made to the needs of vocational learners.

This calls for more direct and focused investigations into identified research gaps noting a growing dominance in the field of health-related research with the most cited articles in this field, to integrate virtual reality into additional vocational education contexts. In this way, the gaps present an opportunity for researchers to make significant contributions to the development of interventions responsive to the unique needs of vocational learners; this will contribute to strengthening the evidence base for the worldwide implementation of VR within vocational education systems. This was recommended as the intention of such a bibliometric analysis: supporting the potential of VR as a pedagogical tool in vocational contexts and providing grounding for a strong and focused future research agenda within this burgeoning area of educational technology.

Keywords

virtual reality, bibliometric, vocational education

INTRODUCTION

Virtual reality (VR) has been identified as one of the disruptive technologies in vocational education with the potential for a revolution through immersive and interactive learning experiences (Neupane et al., 2023; Prasetya, Fajri, et al., 2023; Prasetya, Syahri, et al., 2023). The use of VR headsets, controllers, and specialized software make it possible for learners to be taken to more realistic virtual worlds that simulate reality (Junfithrana et al., 2020; Shermon & Stout, 2018; Wonsick & Padir, 2020). The usability and importance of VR are seen in many sectors, such as manufacturing, healthcare, entertainment, and education (Alamäki et al., 2021; Kemp et al., 2022; See et al., 2023).

In vocational education, VR is particularly promising if it is used to design appealing and authentic learning environments so that the theoretical environment gets very close to real practice (Di Natale et al., 2020; Liaw et al., 2023; Samala, Dewi, & Mursyida, 2023). As such, VR, being highly immersive, allows learners to apply skills and knowledge in an environment that is not only secure, but one in which accidents and mistakes that might happen in real-world environment-based training are less likely to occur (Kozinets, 2023). Furthermore, the VR method improves the engagement of learners, the development of critical thinking, and the ability to visualize content and mastery of the content, which finally results in improved learning (Zhang et al., 2020).

Experiential learning provided by VR is particularly well suited to vocational education where hands-on training and practical experience are essential to developing job-ready skills (Fromm et al., 2021; Le et al., 2022; Wulansari & Nabawi, 2021). VR exposes learners to lifelike vocational contexts and experiences in which they practice and polish their competences as if in real-life conditions. Consequently, VR can lead to building confidence, competence, and, consequently, employability for the student within the vocational training program. Given the need for more skilled labor in many industries and the necessity of keeping abreast of emerging technologies, innovative approaches to vocational education are needed.

The challenges facing VR integration include offering an opportunity to provide flexible, cost-effective, and scalable solutions to deliver high-quality vocational training. This study provides valuable conclusions and recommendations for practitioners and researchers regarding the current state of research on VR applications in vocational education. These findings have important implications for vocational education in the 21st century.

In many countries, vocational education is fundamental to the provision of technical skills and practical training relevant to many trades, occupations, and industries (Gonon & Deissinger, 2021; Odo, 2023; Watrianthos, Ambiyar, et al., 2022). Vocational education prepares students for direct entry into the workforce when they leave school emphasizing hands-on learning in the classroom (Muskhir et al., 2023; Sansi et al., 2023). Critical trends in vocational education involve collaborative paradigms between schools and employers, the application of new technologies in virtual and augmented reality (Fortuna et al., 2023), and stackable certification (Chan et al., 2022; Ramadhan et al., 2021; Trust et al., 2021).

However, there are several challenges facing vocational education including public prejudice, complicated funding structure, and ensuring curricula to reflect industry trends (Thurzo et al., 2023). Experiential learning remains very important in vocational settings. In this line of thought, the use of simulations of on-the-job experiences has been developed for the purpose of allowing students to apply skills in real world type settings. Quality vocational education fosters a pipeline of qualified labor considering the shortage of skilled trades (Haviland & Robbins, 2021).

Above all, aligning vocational training with every-evolving industry needs while creating foundational skills for the future remains a recurring challenge. This complex vocational landscape provides a critical context within which to consider the potential of emerging technologies such as virtual reality. The possibility of developing occupational simulators could prove to be transformational in delivering cutting-edge vocational education at scale (Jiawei & Mokmin, 2023). This will require considerable personalized research, development, and investment. Therefore, it is necessary to lay the basis for the research of VR applications in this domain by elaborating on the importance attached to vocational education and the opportunities and challenges that come with it.

In the past few years, there has been exponential growth in the latest information and communication technologies that have fueled growing research interests in virtual reality (VR) across numerous domains. This study examines titles and abstracts together with keywords in publication trends based on VR research data from the Scopus database for the period 2018-2022. From the graph presented below, it is apparent that the focus on VR as a research source has increased, most notably from 2018 to 2022. The five-year period showed a total of 56,402 articles, representing an increase of 3963

articles from 2018 to 2022. This exemplifies huge growth in VR research production, which tends to suggest growing attention from academicians, as VR has been one of the most researched topics among modern-day researchers.

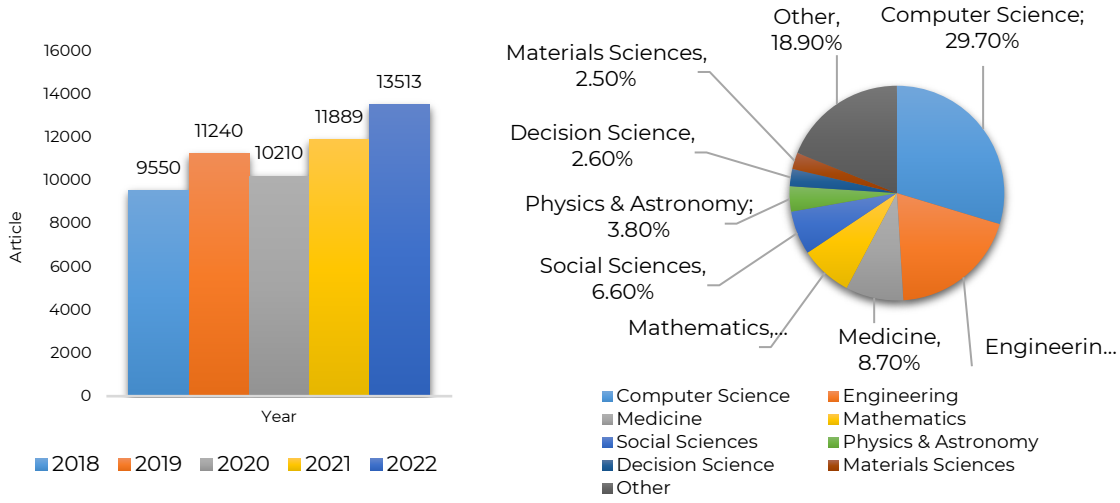

Figure 1. The graph illustrates the upward trend in the number of publications related to virtual reality within the Scopus database from 2018 to 2022

Research productivity on virtual reality (VR) from 2018 to 2022 has increased substantially. In summary, these factors - technical maturation, pandemic-prompted demand, cheaper costs, and expanded funding - have contributed to the marked growth in VR research since 2018 (Samala, Usmeldi, Taali, Daineko, et al., 2023; Won et al., 2023). This trend is expected to continue as VR technology consolidates its status in the market and reaches indispensability in a number of sectors, such as education and healthcare (Won et al., 2023; Xi et al., 2023). Figure 1 shows the distribution of the scope of research fields that investigate VR applications. Most, 29.7%, fall into the field of computer science, followed by engineering at 19.4%, and medicine. It is a growing trend that the potential of virtual reality is being capitalized as a pedagogical approach and medium for practical learning contexts (Hadgraft & Kolmos, 2020; Hamilton et al., 2021).

Virtual reality (VR) confers distinct advantages and opportunities when implemented within vocational education contexts compared to traditional general education settings (Steffen et al., 2019; Zhang et al., 2020). The main objectives of vocational education are the provision of practical, hands-on competencies and applied skills targeted at specific trades and occupations (Jalinus et al., 2023). In turn, the highly emerging and particularly highly experienced characteristic of virtual reality befits the development of engaging simulations in real and vivid vocational environments and activities. This speaks to the reality and significance of the occupational learning experiences that students could be offered by VR in ways that are impossible, dangerous, or logistically infeasible within a classroom setting (Yuan et al., 2023). Such a line of research in the use of VR integration in vocational education is very compelling.

The objective of this study is to continue the bibliometric review in a comprehensive way of the application of VR technology in vocational education contexts to identify the main trends and themes of the emerging literature in this context. Therefore, the following are the research questions for this bibliometric review:

1. What are the research trends on virtual reality applied in vocational education in the last 10 years?
2. Who are the top 10 authors, journals, and publishers of the top 100 cited articles on virtual reality in vocational education?

3. What are the implications and recommendations for the use of virtual reality in vocational education from 2013 to 2022?

The main objective of the study involves the identification and visualization of published research in the context of the application of VR in vocational education. This will be done using the bibliometric analysis method intended to explore publishing trends and theme visualizations within the virtual reality application in the vocational education domain. Bibliometric analysis is part of a statistical methodology that searches for patterns in the published literature (Gatto et al., 2022; Lyu et al., 2023). Bibliometrics is of the utmost critical sense in laying the quantitative foundation for the most impactful publications and contributions in each field (Donthu et al., 2021; Tarragona et al., 2020). Within the publication data set, bibliometric analysis employs a framework of holistic knowledge through synthesis techniques from the natural sciences, mathematics, and statistics. Bibliometric research enables qualitative and quantitative in-depth investigation of publication and citation trends within a scope bound to a chosen theme (Cardoso et al., 2020).

Bibliometric studies indicate the use of qualitative and quantitative indexes in the analysis of phenomena related to volumes of publications, author affiliations, journal titles, languages in which papers are published, networks on collaboration, types of documents, issuing countries, and subject categorization (Watrianthos, Ambiyar et al., 2022; Watrianthos, Sagala, et al., 2022). In the last decade, bibliometrics has been used to map research trends and influential contributions within different scientific domains (Ahmad et al., 2023; Watrianthos, Ambiyar, et al., 2022).

For example, the research that Abdullah (2021) did in higher vocational education, reviewed scholarly research conducted over time. In this paper, the most pertinent topic or keyword is given with respect to higher vocational education. In this bibliometric review, the review presents a summary of research in higher education that could be useful to practitioners and researchers in higher education who may wish to draw on or breathe new life into the knowledge source. This is an example of the accepted value that bibliometric techniques carry, making it possible, for instance, to base the production of maps on research data with a view to subdomain issues like educational technology or vocational education. Developing a tailor-made bibliometric methodology applied to drill into the specialized niche area of VR applications in vocational education could make it possible for the first time to obtain a rigorous, quantitative elucidation of patterns within this vitally important but underexplored emerging literature.

This bibliometric analysis aims to characterize the leading trends, contributors, affiliations, outlets, research lines, terminology, and seminal sources of the available literature (Samala, Bojic, et al., 2023; Watrianthos et al., 2023). To be specific, this study will attempt to identify the most prolific authors and reveal the institutional and geographic locations of pioneering researchers. Additionally, it will identify key publication venues to be used for the dissemination of the main findings, chart the temporal evolution of the publications, point out prevalent concepts and keywords, and find citations to critically evaluate the research lacunae ripe for future investigation. In line with this, the objective of the paper is to offer a holistic overview of the prevailing research activities with respect to VR in vocational education by synthesizing this dimension. This systematic review aims to outline the direction to take in establishing promising scholarship in this emerging research area.

METHODOLOGY

Bibliometrics has already provided a statistical approach to analysis of data that shows how knowledge has been changing, measures the impact of research, illustrates subtle trends in academic fields, and finds research themes. It provides a systematic overview of the information described in publications in a statistical way that supports the analysis of tendencies and themes of a given area of research (Watrianthos et al., 2023) (Samala, Usmeldi, Taali, Ambiyar et al., 2023). Such techniques provide systematic insights by describing statistical information in publications, allowing the examination of trends and themes in each area of research (Adeabah et al., 2023). There are four stages of

research in bibliometric analysis (Samala, Usmeldi, Taali, Daineko, et al., 2023), which are illustrated in Figure 2.

Figure 2 describes the four stages involved in the bibliometric analysis method. The first step is to identify the topic that will be analyzed within the Scopus database. The reason for using Scopus in this analysis is that it has many advantages, such as its scope of features and extensive coverage. This was, to a much greater extent, influenced by the completeness and richness of the available information, its overall most widely recognized reputation, a strong citation network, and, most importantly, its ability to provide detailed and rolling analysis (Gusenbauer, 2022; Pölönen et al., 2020). The high quality and credibility of Scopus places it as a reliable reference source on 29 June 2023, through applying focused search parameters. The search was filtered for title of article, abstract, and keywords, restricted to the date of publication from 2013 to 2022, and limited to the English language in a journal or conference proceeding.

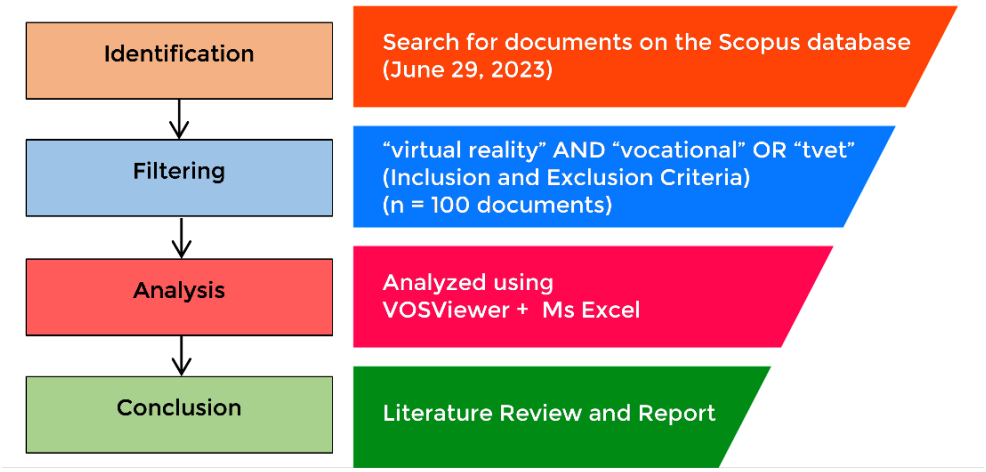

Figure 2. Stages of the bibliometric analysis method

This systematic screening process through all filters resulted in an initial corpus of 100 relevant documents across the Scopus database, centered on virtual reality in vocational education, spanning the years 2013–2022. Following inclusion and exclusion criteria, considerations for the final sample included 100 articles, forming the bibliometric data set analyzed in this study. All papers were in English, published in a reviewed academic journal or proceedings, and embraced the words "virtual reality" in their titles with "vocational" or "tvet" in the title, abstract, or keyword. This corpus is the final sample enabling quantitative mapping of the emerging research domain, which includes the ones likely to apply some form of the term "virtual reality" in conjunction with "vocational education."

To answer the third research question related to the implications and recommendations concerning the use of virtual reality in vocational education during 2013-2022, our bibliometric approach is very close to the stated objectives of this inquiry. First, the analysis is conducted through keyword co-occurrence to reveal main topics and themes reflected in the literature related to the use of virtual reality in vocational education. The salient features of the study were established, and recurrent ideas would not be repeated but discovered again in the text by frequency and co-occurrence of keywords like "virtual reality," "vocational education," "training."

Second, to find such a document, this research applied the analysis of the citation network of articles to identify the most influential and highly cited articles. By visualizing the citing relationships among the papers, the present pioneering work that has given shape to the research landscape, together with the key authors and institutions who are driving development in this field, can be clearly identified. The geographic distribution mapped research activity and patterns of collaboration throughout the world.

We do this using the institutional affiliations of the authors, institutional affiliations, and geographic distributions of the publications to outline leading countries, leading institutions, and where there might be gaps or opportunities for international collaboration. Merging these symbiotic bibliometric approaches made it possible to get a fuller and more sophisticated picture of the research landscape than would have been possible simply by following leads emanating from any one of these approaches.

The third and final stage of this bibliometric software is the phase in which visuals and mapping of the publication data set are carried out (Ahmad et al., 2023). VOSviewer is software that helps in generating visualized maps developed through network analysis, in which relationship overlays among the entities that co-occurred (authors, publications, keywords, or subject categories) are applied in visual form (van Eck & Waltman, 2017). The visualization of these relations through distance-based graphs identifies patterns and tendencies within academic literature that might not otherwise emerge through mere quantitative measurement. Specifically, the visualization of links using VOSviewer is much clearer. It shows the existing relationships among the leading authors, publications, countries, and keywords in the literature based on virtual reality in vocational education. In addition, it generates a heat map showing the geographical distribution of the publications in terms of country.

RESULTS

The aim of this bibliometric analysis was to reveal the emerging domain within the research scope of virtual reality applications in vocational education, showcasing insightful patterns of citing and publishing. Of particular interest is the clear and steep rise in volumes of publication over the past decade, with the most prolific authorship largely attributed to authors affiliated with institutions in the United States.

The most influential publications, in terms of citation counts, would be those coming from high-impact journals, that is, the British Journal of Educational Technology. Lecture proceedings are the usual channel utilized to disseminate findings made in this particular specialized niche. The United States leads in productivity, followed by China and Germany. Keyword analysis showed that the dominance was in the conceptual orientations of technology and virtual reality, with gaps around the terminologies of learning. These key milestone publications, citations, and keyword trends are identified and mapped in the relevant sections of this manuscript.

RESEARCH TRENDS

The line graph in Figure 3, on the trend of publication year-over-year of publications on VR applications in vocational education from 2013 through 2022, shows that in the years after, there is an indication of the steadiness of the publication number and after 2019, it has been quite significant. This tendency, one may say, reflects the rise of interest and research activity in this field, especially during the last years, when VR technologies have advanced with easier access.

Publication output increased steadily from 2013 to 2022, with the highest number, 25, reported in 2022. This, in turn, indicates an increasing scholarly interest in the exploration of virtual reality applications within vocational educational environments. Some implications can be deduced from this upward output trend. One is the increasing level of interest in the promising potentials of virtual reality for the transformation of vocational training during the transition of the 21st-century technical workforce development. First, we have sustained productivity growth. More importantly, imperatively, further research must be carried out at a faster rate to cope with the technological and pedagogical innovations and developments needed for the successful implementation of virtual reality in experiential vocational learning on a large scale.

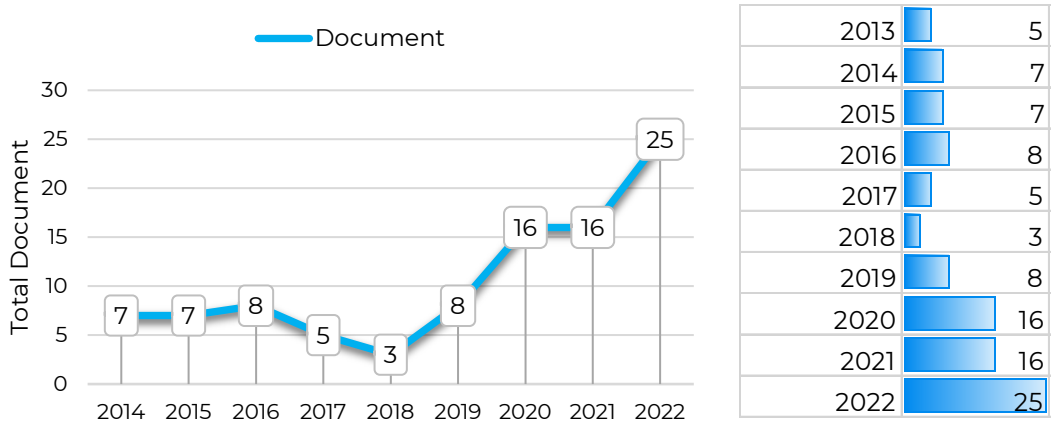

Figure 3. The trend of publication of virtual reality in vocational education over the past ten years

Top Authors, Journals, and Articles

The authorship analysis, which considered the number of publications and citations per author, revealed that, when applying a threshold of a minimum of five citations per document, 11 authors emerged as the most prolific. Most of these authors have published more than four articles each on virtual reality applications in vocational education. The three authors with the greatest number of publications and citations in virtual reality are Smith, M.J., Bell, M. D., and Fleming, M. F. Table 1 presents the names, institutional affiliation, country, documents, and citations of the most prolific authors by volume of articles and citations.

Notably, the institutional affiliations of the top contributors include research universities and medical institutions in the United States. Such an affiliation pattern may suggest that American academia has served as an early leader in the investigation of virtual reality for vocational contexts.

Table 1. Top authors based on the number of documents

Rank	Authors	Institutional	Country	Documents	Citations
1	Smith, M. J.	Northwestern University Feinberg School of Medicine	USA	14	495
2	Bell, M. D	Yale University School of Medicine	United States	11	476
3	Fleming, M. F	Medicine, New York, USA	USA	9	495
4	Wright, M. A	Northwestern University Feinberg	USA	8	447
5	Olsen D	School of Medicine, University of Michigan, Chicago, IL Simmersion LLC, US	USA	8	264

However, there is a gap in which direct authorship from vocational education institutions is lacking. In the latest development, an improved vocational school and program research leader could catalyze improved pedagogical innovation and adoption. This sets the stage for expanded collaboration be-

tween leading authors and computer science, engineering, and technical training programs at the intersection of vocational education. The diversification of authorship and affiliations promises to enrich research insights in the implementation of virtual reality for experiential vocational learning.

Table 2. Top source based on the number of documents

Rank	Sources	Documents	Citations
1	Lecture notes of the Institute for Computer Sciences, Social-Informatics and Telecommunication	7	5
2	Journal of Physics: Conference Series	5	40
3	Applied mechanics and materials	3	3
4	British journal of educational technology	3	9
5	Lecture notes in computer science	3	9

With this number of citations and publication frequency, the minimum threshold must be set at 3 citations per document. Five sources emerge as particularly prolific, each garnering more than two publications. The three periodicals with the highest publication and citation counts related to the application of virtual reality are from the Institute for Computer Sciences; Social Informatics and Telecommunications Lecture Notes; Journal of Physics: Conference Series; and Applied Mechanics and Materials. The sources have been captured according to rank, the name of the source and the documents in Table 2, five of which are shown following the number of documents published and the citations received. It brings to light the lecture proceedings, where computer science and engineering conferences are the most dominant sources of dissemination of studies on virtual reality in vocational education. The conference papers include the latest findings that feature these emerging domain characteristics.

However, the relative paucity of representation from sources focused on vocational, technical training, and education-focused journal sources seems to illustrate a possible gap in related disciplines that would have the most bearing on the integration of virtual reality for experiential learning. The change in the field will further enable an increase in the production of academic work in vocational education outlets, leading to greater pedagogical strength and providing a means of translating technological innovation into research-based instructional practices. It is understood from the sources that the outward diffusion of this information to cross-disciplinary audiences could act as a pushing factor to speed up the process of its broader use. The power through the development of more vocation-specific journals would further make the educational communities in these field areas more cohesive.

Table 3 presents the top 10 articles with the highest citations, reflecting rank, authorship, title, publication year, and total citations accrued from the journal of publication. This strongly suggests that customizable VR experiences have great potential to develop scaffolded learning opportunities for diverse vocational students. Table 3 highlights baseline studies that have quantified, to date, the notable research impact of applications of virtual reality in vocational education through citation metrics. The most quoted article, by Smith, Ginger, Wright, Wright, Taylor, et al. (2014) underlines the efficacy of using virtual reality to impart to youth on the autism spectrum the skills of interviewing. This raises the potential for scaffolded learning environments that respond to the needs of diverse vocational students with customized virtual reality experiences.

Table 3. Top 10 cited articles

Rank	Authors	DOI	Journal & Publisher	Citations
1	(Smith, Ginger, Wright, Wright, Taylor et al., 2014)	10.1007/s10803-014-2113-y	Journal of Autism and Developmental Disorders (Springer Link)	222
2	(Smith, Fleming, Wright, Losh, et al., 2015)	10.1007/s10803-015-2470-1	Journal of Autism and Developmental Disorders (Springer Link)	88
3	(Tsang & Man, 2013)	10.1016/j.schres.2012.12.024	Schizophrenia Research (ScienceDirect)	67
4	(Smith, Fleming, Wright, Roberts, et al., 2015)	10.1016/j.schres.2015.05.022	Schizophrenia Research (ScienceDirect)	61
5	(Levac & Miller, 2013)	10.3109/09593985.2012.762078	Physiotherapy Theory and Practice (Taylor & Francis Online)	50
6	(Bracq et al., 2019)	10.1016/j.nedt.2019.05.026	Nurse Education Today (ScienceDirect)	48
7	(Alashram et al., 2019)	10.1016/j.jocn.2019.04.026	Journal of Clinical Neuroscience (ScienceDirect)	45
8	(Man et al., 2013)	10.3109/02699052.2013.794969	Brain Injury (Taylor & Francis Online)	44
9	(Smith, Ginger, Wright, Wright, Boteler Humm, et al., 2014)	10.1097/NMD.0000000000000187	The Journal of Nervous and Mental Disease	39
10	(Pedram et al., 2020)	10.1016/j.compedu.2020.103891	Computers & Education (ScienceDirect)	37

The salient fact, that authors such as Smith, Bell, and Fleming are all extremely prominent in these heavily cited studies, certainly speaks to the powerful contributions that these authors have made to pioneering scholarship in this nascent domain. The most impactful articles come primarily from prestigious educational, vocational, and technical training-focused journals, highlighting the widespread highlights of rigor and interest in multidisciplinary research. Furthermore, the fact that most articles have been published in the last five years shows a rapid emergence of high-impact research on the use of virtual reality embedded in vocational contexts.

LEADING COUNTRIES

This paper aims to make an analysis of country-specific metadata in volume of publication and citation count, respectively, and finds that applying a threshold of at least five citations per document, it finds that seven countries come into the highly productive category, with the production standing at more than four documents each. The three leading countries in the publication and citation of the application of virtual reality in vocational education are as follows: United States with 23 documents and 655 citations; China with 20 documents and 72 citations; and Germany with 8 documents and 105 citations.

Figure 4 clearly shows how the United States has claimed a large share of the research output in the adoption of virtual reality in vocational education. This only further highlights that American academia and industry have been at the forefront and have led in almost all technological innovations and implementations that their students and workforces can imagine, including those related to virtual reality for experiential technical training. A close second, therefore equally prominent, goes to China among the most published countries, reflecting its rapidly growing expertise in virtual reality technologies.

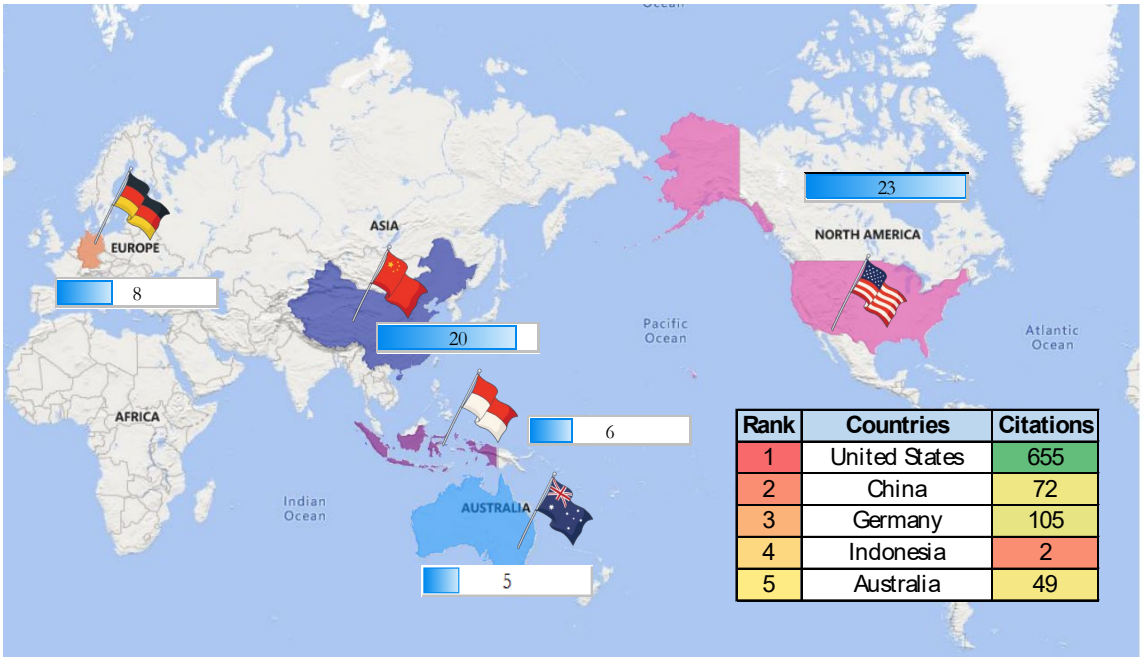

Figure 4. Top countries based on the number of documents

Perhaps one most striking omission on this list is the lack of any European nations that, for so long, have had very strong systems in vocational education. Collaborations further stimulate American technical scholars with European vocational educators in virtual reality research, which will lead to faster growth in turning innovations into impactful practice. It has also pointed out the outstanding underrepresentation of the developing world, indicating even chances of expanding in this region relating to access to state-of-the-art virtual reality vocational training through appropriate strategic research partnerships. Correspondingly, the growing interest in virtual reality from all over the world can only further increase the cross-cultural perspective made possible by the many nationalities involved in its development.

Keyword Analysis

Keyword analysis, in short, is one of the approaches used in the bibliometric process, which helps clarify the core terminology of the academic literature, where frequency appears within keywords or terms in some publications and is instrumental in finding research tendencies or subjects (Kim et al., 2021; Wang & Chai, 2018). Therefore, the comparison is made especially between the occurrences of the keywords to know the terms that emerge more prominently. Keyword analysis provides very critical information on focal topics and knowledge that are not covered in a given domain of research. The authors used VOSviewer software to graphically depict the interconnection of the keywords appearing together within a publication (van Eck & Waltman, 2010). The co-occurrence, therefore, does show the occurrence of the placed keywords together within the document.

It is on this view that the threshold in the complete count analysis has been operationalized at a minimum of five documents per keyword. Of the total of 2,552 keywords extracted from the 100 articles,

38 of them exceeded the minimum frequency threshold of 10 documents. The irrelevant keywords were re-evaluated and refined to 20 relevant interrelated ones that meet the research objectives. Figure 5 provides the visualization network map of co-occurrence keywords within the analyzed publications. The map pointed out two principal areas of focus: one area was around the evaluation of VR for specific vocational skills training (e.g., "autism spectrum disorder," "intervention," "training"), and the other was around its application to a broader thematic of VR in vocational education (e.g., "education," "learning," "teaching"). This visual summary details the main areas of research and how they are interrelated, highlighting key areas of focus and potential literature gaps.

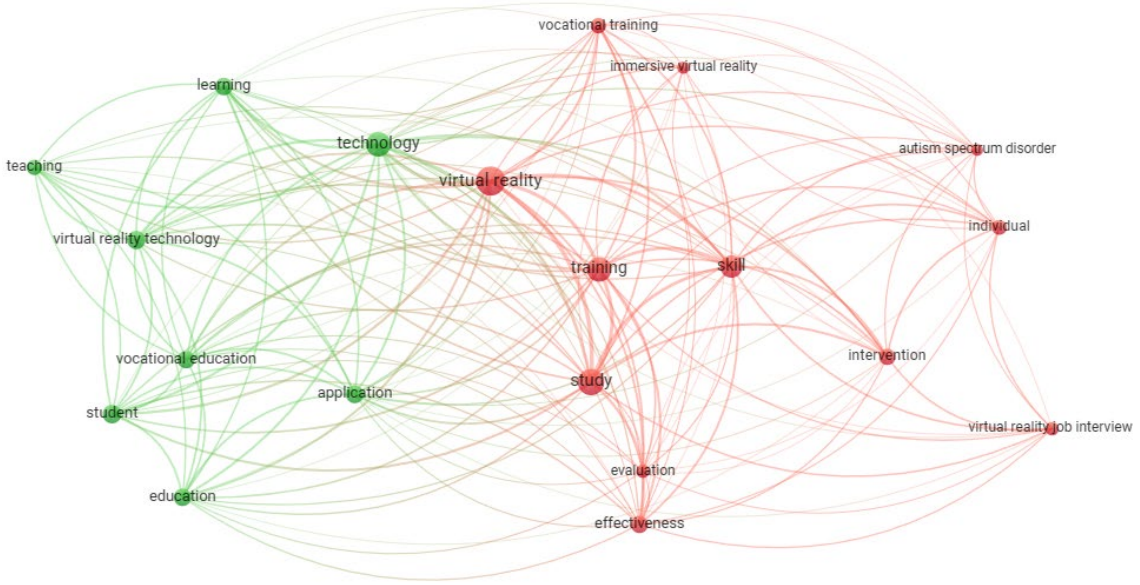

Figure 5. Network visualization of co-occurrence of author keywords

In Figure 5, the much smaller red cluster contains the search terms oriented around virtual reality integration for general teaching and learning in comparison to all others. These include "education," "learning," "teacher," and "vocational education." What these represent is greater emphasis and focus on how to better adapt virtual reality toward bettering the pedagogical methods and outcomes of the learner in this area of the vocational classroom. The presence of these dual thematic clusters might open up further interdisciplinary research that synthesizes the strengths of both foci. This would integrate the gap between skill training evaluations situated in virtual reality and generalizable pedagogical frame-works, thus affording greater purchase on the subject, taking into account angles in a holistically evolving model of optimal integration of virtual reality within vocational education.

A check of the overlay visualization in Figure 6 indicates that the most recent keywords from 2018-2020 are overlaid in yellow with the base underpinning keyword, of 'virtual reality'. Similarly, checking is done, on the basis of clustering, for key 'vocational education,' 'teaching,' and 'learning' to qualify that, indeed, the topics fall under the emerging themes, directions, and gaps of the literature scope. Although the most recent literature has focused on technology in "virtual reality" and skills assessment and training, newer research has included topics such as the use of "virtual reality" and the potential effects on vocational pedagogy and curriculum. That is to say, it already forms a very promising trend when many educators are engaged in this particular area of study. However, the rare publications at the intersection of virtual reality teaching and learning methods point to an area for further research.

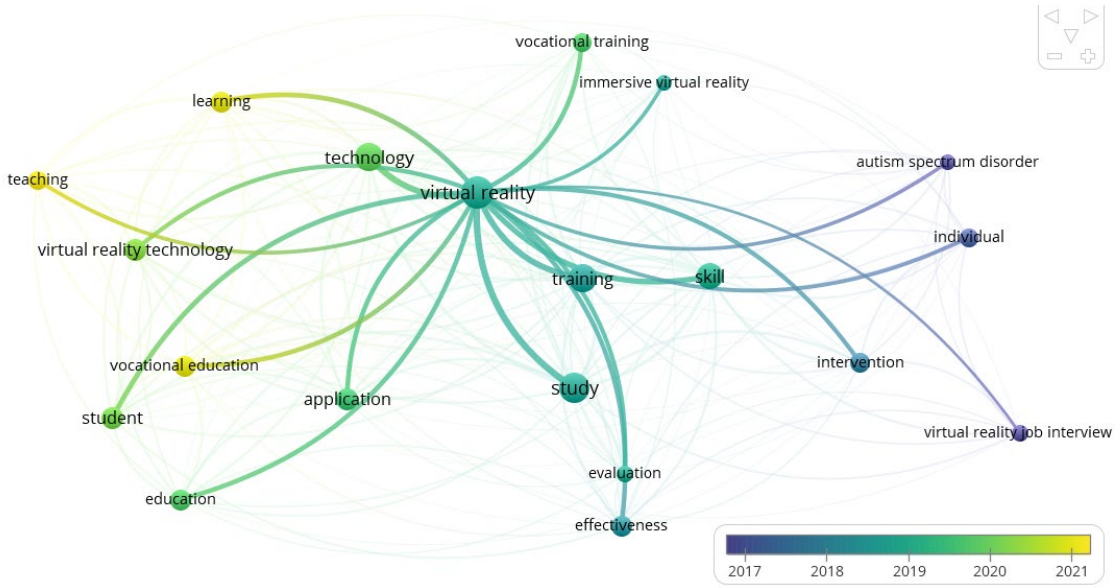

Figure 6. Visualization of overlays against co-occurrence of author keywords

The domination of "virtual reality" in these words means and, hence, reflects a targeting of this technology. Virtual reality tools are certainly important, but their linking to the needed vocational learning contexts must be ensured. "Study" appears as the keyword for high concentration, possibly suggesting concentration in studies and experiments aiming to assess the effectiveness of virtual reality. The relative paucity of learning-oriented keywords, such as "teaching," "learning," "pedagogy," or even "curriculum," goes some way to perhaps indicating just how much scope there is for future research from the perspective of the vocational educator. Therefore, it is critical that this gap is filled for technology, pedagogy, and practice. This visualizes work that would extend this investigation of the method of virtual reality teaching and associated learning outcomes, particularly work tailored to the needs of vocational students. It will be based on building a strong knowledge base around the integration of pedagogical and curricular activities for extended adoption.

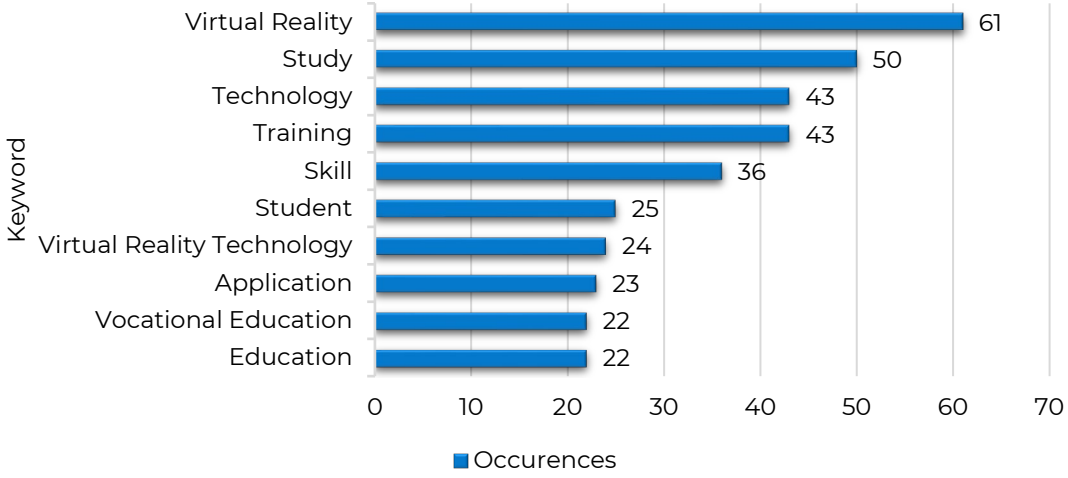

Figure 7. Most keywords published in the article

Figure 7 illustrates the most frequently occurring keywords in the analyzed articles, further highlighting the emphasis on virtual reality, skills, and training, while also indicating the need for more research on education and vocational education specifically.

In addition, virtual reality research has not been able to directly involve any of the learning variables that are specifically located in the context of vocational high schools. Therefore, this would stimulate scholars, practitioners, and researchers in this area to further investigate the adoption of virtual reality in vocational learning environments and the associated pedagogies. More studies that integrate virtual reality technologies with the unique needs and priority characteristics of vocational secondary school curricula would go a long way in inform innovative translation into impactful practice tailored for vocational learners.

DISCUSSION

This study uses a bibliometric analysis of the recent emerging corpus of research studies related to the applications of virtual reality technologies in vocational education settings. Scopus has been used for the last decade to scrutinize trends in publication and citation that will bring to light the patterns of development in this new area of inquiry. This context was guided by the aim of obtaining critical insights that will outline gaps and inform future research based on research growth, influential contributions, regional perspectives, and conceptual focus. Bibliometric findings reveal the following key trends: a steep publication increase, a concentration of authorship largely from US-based institutions, the importance of lecture proceedings as the most favored venues for their publications, and the frequency with which they mention virtual reality tools and vocational pedagogy in their keywords. Synthesizing these quantitative metrics with visualization provides an evidence-based view of how to adapt VR approaches in vocational education settings.

The analysis revealed 100 articles published on the confluence of virtual reality and vocational education in the last decade in Scopus-indexed journals and conference proceedings. The year 2022, with 25 publications, witnessed the highest number of articles for the 10 years under consideration. A marked growth was observed only for eight publications between 2019 and 2020, a coincidence in the wake of rapid technological development that expanded the capabilities of virtual reality and related applications. In its place, research has been substantial in the development of new virtual reality technologies. One of the motivating factors for independent research is the growing pace of technological innovation. These include the integration of virtual reality, which greatly heightens the quality of education and offers further pedagogical benefits such as an increase in students' engagement and enhancement in academic results. A further concentration analysis of authorship shows that 3.4% of the contributors had published more than four articles, which attests to the ability of emerging scholars to expand further into this area within their own research.

The firm's bibliographic findings on productivity and impact give a clear direction to geographic trends, which could serve to further the global adoption of virtual reality in vocational education (Chawla & Goyal, 2022; Maphosa & Maphosa, 2023). The United States has a leading record in publication volume and citation tally, furthering the country's status with respect to leadership in technology innovation that could catalyze the integration of virtual reality in vocational institutions within America. However, a growing contribution from China testifies to the fact that virtual reality applications in vocational education are beginning to be accepted worldwide, as even international researchers point to the potential of immersive technology in improving technical skills training (Xie et al., 2021). The number of publications on this topic is much fewer, yet the great influence of Germany coincides with a historically strong tradition of generally reliable vocational education.

Such a country-based research pattern highlights existing strengths of the present but also represents a great opportunity to diversify views and enhance deep global collaboration. With growing global interest in adopting virtual reality technologies for learning, forging partnership links between researchers and vocational institutions across borders supports the advancement of context-specific virtual reality-enhanced vocational pedagogies. This would mean that international advances and progress in terms of the implementation of virtual reality for vocational training will be driven by fo-

cused cross-country research collaborations. A bibliometric analysis thus made it clear that virtual reality technologies have a direct and clear interlinkage to vocational educational technologies, which clearly points to research opportunities for more detail studies analyzing the integration of virtual reality in vocational learning environment contexts. Therefore, several important research gaps remain to be identified, providing the basis for the focus of research following this study.

First and foremost, the under examination of the fact that the use of virtual reality tools remains relatively poorly considered within real classroom settings at vocational high schools in general has been underexamined in the literature overall and specifically with regard to pedagogical research taking place within actual educational environments. Prospective research should be able to look in-depth at virtual reality teaching methods, lesson designs, and associated learning impacts across specific vocational trades in schools. Therefore, the findings of current research can guide the effective translation into instructional practice. Second, most current literature generally defines the capabilities of virtual reality rather than prioritizing or aligning with those needed by the vocational learner. Research progress must be made in learner-focused frameworks tuned to ensure that effective adoption follows the specified requirements.

Finally, the geographic concentration of existing research signals the need to expand collaborations around the world. Therefore, researchers must strongly advocate for the promotion of active partnerships with international vocational institutions in the quest to catalyze localized innovation. Filling these identified research gaps through context-specific and pedagogically driven VR vocational training investigations is likely to build evidence guiding the implementation of VR within vocational education systems around the world.

The most obvious question that springs from the examination of the top 10 most cited articles emanating from this bibliometric analysis is how a limited sample such as this speaks to the topical breadth indicated as existing within the field. Within these, only two areas of virtual reality have been directly investigated in the context of vocational education, with the majority focusing predominantly on the health sector. Highly influential research explains with clarity the use of virtual reality technology in helping adults train on how to interview people suffering from autism spectrum disorders (Smith, Fleming, Wright, Roberts et al., 2015). The research by Smith et al. concluded that participants demonstrated improved performance in job interviews after VR training to a greater extent than when they were exposed to traditional preparation approaches.

Although existing studies in vocational education are very limited, a work in progress focuses on the validation of a developed course module of practicum in the field of welding based on virtual reality (Prasetya, Fajri, et al., 2023; Refdinal et al., 2023). The results confirmed the effectiveness of this immersive resource for the welding technology curriculum. The study further considered the use of virtual reality in laboratory settings, whereby the cognitive knowledge of the students' participating in a web-based virtual laboratory environment showed 57.2% improvement (Wahyuman et al., 2021). These applications of virtual reality in an experiential learning environment have great promise for increasing student motivation and hence academic performance. In summary, although still emerging, initial studies related to the use of virtual reality in vocational education justify the argument that it can be a powerful pedagogical vehicle in vocational settings.

IMPLICATIONS AND RECOMMENDATIONS

The co-occurrence results point to several themes that occur dominantly in the research, such as "virtual reality," "vocational education," "training," and "skill development." From these themes, it can be discerned that the main areas of focus or research priorities in the area point to an overwhelming interest in the application of virtual reality technology to improve vocational training and the acquisition of skills. The themes of importance will be those that point to the potential of virtual reality to revolutionize vocational education by enabling a medium for immersive and interactive learning experiences that can bridge the notoriously problematic gap between theory and practice.

Such flagship research themes have a profound impact on VR applications in the field of vocational education. First, the emphasis on VR technology itself underscores the need for more research and development to afford, gain access to, and use VR systems and devices within vocational training. These might include advances in hardware and software and user interface designs that would make virtual reality technologies more adaptable for specific applications within vocational education. Second, the pronounced aspect of vocational education and training raises the need for close-to-the-curriculum and learning-objective VR application development. There is a need for close collaboration between VR developers, subject matter experts from education, and industry practitioners so that VR simulations and modules are authentic, context-relevant, and pedagogically sound. The curriculum of vocational education should be infused with VR technology in view of best practices, where emphasis should be placed on complementing and not replacing or repeating the conventional practice of teaching and practical training.

The focus on skill development would thus indicate that VR technology can help in the development of practical skills and competences applied while learning vocations. Virtual reality is very instrumental in enhancing capacity and bridging the skills gap between the education sector and the sector of employment, giving students further opportunities to apply and perfect those skills in realistic virtual-created environments. Its effectiveness for the prescribed learning outcome has not yet been determined. Skills transferred to real-world settings and retention of the skill have not yet been validated. The development of VR-based training still needs further research to reach its full potential.

It should be noted that the mapping research activity in this area of VR applications within vocational education brings clear patterns in the case of international collaboration and the sharing of knowledge within this area. Analysis has shown that the United States, China, and Germany are in the top three positions as the leading countries in research output and collaboration. Most importantly, this finding singles out these countries as the main actors in achieving innovation and advancement. However, the analysis also revealed potential gaps and disparities in research activity in different regions. For example, the clearly noticeable underrepresentation of developing countries and regions of the world would therefore be indicative of the fact that such countries and regions have limited access to virtual reality technologies and research opportunity windows. This difference further emphasizes the greater need for improved international, more inclusive, and equal collaboration and knowledge exchange to ensure that the benefits of vocational education are not limited to or lost to some institutions.

This challenge can only be addressed by fostering transnational research networks and partnerships that should aim to attract researchers, practitioners, and policy makers from a wide diversity of geographic and cultural backgrounds. Such a network would enhance the sharing of ideas, collaboration in technical expertise, and possibly sharing resources while further building the capacity toward VR research and development for such underrepresented regions. Collaborative research projects of developed countries with partners from developing countries and communities, supported by international funding agencies and organizations, will also receive priority support.

The results of the citation network analysis carried out have brought to light the most influential and widely cited studies within the field of VR applications in vocational education. Furthermore, it provided evidence to identify key research questions, methodologies, and findings that have driven the development of this field. The first of the implications of this analysis is the need for future researchers to develop and expand the findings of these influential studies. This, of course, will require copying and validation of such a study's results in other settings and populations, updating this present, in comparison, rather meager piece of study in terms of the limitations and gaps identified within the research and the generation of new research questions and methodologies flowing from the results.

Moreover, analyzing the citation network can have many implications for the emergence of trend tracking and even research frontiers within a particular discipline. Examination of the more recent,

highly cited studies, as well as a detailed discussion of them, do help to glean the more current developments and innovations that are taking place in the literature and in the realm of VR applications for vocational education. These will tell us what areas of priority are for future research efforts and how to invest resources in these most promising and impactful areas of research. Further work may help identify potential biases in the current research landscape and highlight the limitations of the work carried out here. For example, if the most-cited works are occupied by a few countries or institutions, it will sound an alarm for the representation of diversified research perspectives. It may also be the case that influential studies used the same research methodologies and theoretical frameworks in mass or even exclusively. This condition probably indicates the case for more pluralistic and even interdisciplinary approaches in the study of VR in VE.

Limitations of the Study

The current research methodologically still represents several limitations and challenges; first among these is the scope that the database used allows. Although Scopus represents a huge and well-known database, this study is certainly limited as regards the scope presented by the database. The relevant literature cannot always be found by Scopus, and this may be the case in other sources, such as the Web of Science or Google Scholar. Therefore, less extensive results could be presented. Future research could search and engage a larger number of databases to track more relevant literature, including sources from 'gray' literature. This will further inform an overview of the research field, and, in particular, will clearly be able to identify more trends, patterns, and gaps within the subject area of "Virtual Reality Applications in Vocational Education."

The other limitation of the study is the time it covers, which spans 2013–2022. The fact that the analysis is based on the last 10 years implies that the work that is considered seminal or historical trends in the application of virtual reality in vocational education might not have been captured. Therefore, the window of time is too narrow for us to track the development of the research landscape over a longer period and to find possible changes in research priorities or methodological approaches. Future studies might be expanded in order to give a more complete picture of the historical development and long-term trends in this research domain. This would allow a more detailed analysis of the way development within the field has taken place over the years, and hence pinpoint possible gaps or areas from which further digging is to be carried out in order to better consolidate the basic foundation laid down by the work.

Another limitation of this study is the relatively small sample size of 100 articles. Although this sample allowed for focus and delimitation of recent trends and research patterns, we understand that a larger sample would allow for not only stronger but also richer findings. A larger dataset might be able to pick up more nuanced patterns, subdomains, and emerging themes in the application of virtual reality in vocational education. This will allow for a more fine-grain analysis of the collaborations between research and its associated research networks, including geographic distributions.

Therefore, in the future, the sample size and scope of this search should be expanded to more databases and publication types using keywords such as "conference proceedings" and "book chapters," among others, in the search string. From this, the landscape offered would expand to additional research projects and would help identify complementary trends, gaps, and even future areas. However, this study contributes valuable insights within the state of current research, which can serve as a basis for further, more in-depth analysis in the field of bibliometrics.

Methodological Challenges

In addition to the limitations mentioned above, various methodological challenges were evident in this study. One of the most salient areas was data cleaning and pre-processing. Deduplication was performed and the harmonization was done to correct for variations in author names, affiliations, and keywords to make the data uniform. Raw data from the Scopus database had some inconsistencies, for example, in the case of different spellings or abbreviations of the same author or institution,

which required manual verification and correction. The same goes for terms, spelling, and the attention to detail given in the way an author writes a certain keyword.

Finding and grouping concepts together turns out to be a very difficult task. Correction of inconsistencies in data entry was the key to proper analysis and visualization of the data, but also introduced ways in which potential sources of error or bias might be admitted. Thus, future research would greatly benefit from further development of advanced data cleaning and preprocessing techniques in relation to the use of machine learning algorithms for entity recognition and disambiguation, which would facilitate automation and semi automation in those processes. This would require standardized data entry and validation protocols within bibliometric databases to minimize differences, and hence improve the quality of analysis.

Another methodological limitation encountered in this study is the interpretation of bibliometric indicators. In other words, bibliometric analysis uses several measures through co-citation networks, keyword co-occurrence maps, and collaboration networks, which point out patterns and tendencies of the investigated reality. However, such signs are manifestations of some complex variables, and their interpretation of a given sign will have to be in-depth in their understanding of the conceptual and consequential web in the given domain of research. For example, by means of co-citation networks, one could bring to light the association of very often quoted papers with a number of other papers, although judgment about the relevance and quality of the relationship must lie with domain knowledge and a critical appraisal of the contents of those cited works themselves.

In the same way, keyword co-occurrence mapping outlines, in a very general manner, the main themes and topics under discussion in the literature. Understanding the clusters and their interrelationships may require intimate knowledge of the field and its specific terminologies. Misinterpretation of the results or building superficial conclusions only on the quantified measures may often be the case when domain knowledge is lacking. To meet this challenge, future bibliometric studies should be conducted in collaboration between bibliometric experts and domain specialists so that clear and meaningful interpretations can be derived from the results. The literature review will therefore be an interdisciplinary exercise that links the technical skills of bibliometric analysis with subject knowledge so that the data are in a position to place them in their context and derive meaning from them.

Finally, it is important to acknowledge the inherent limitations of the bibliometric approach itself. Bibliometric analysis is mainly focused on quantitative metrics, such as citation counts, publication volumes, and keyword frequencies, which essentially sideline the quality dimensions of research, including factors such as depth and originality of ideas presented or possible impacts of the findings on practice. Another limitation is that bibliometric indicators are affected by the citation practices of the research community and, in doing so, may introduce biases. For example, the most cited articles do not always reflect the most innovative or impactful; rather, they show the popularity or visibility of some authors or institutions.

Similarly, the scope and coverage of the bibliographic database used may influence the result in such a way that some relevant publications are excluded or underrepresented. Explanation thus must be taken judiciously within the purview of these limitations, and an analysis of a different type, systematic literature reviews, or even better, meta-analyses, needs to be done to get a whole understanding of the research landscape. Future bibliometric analyzes might also consider using multiple databases and data sources to reduce possible biases. However, bibliometric analysis has invaluable use in revealing trends and research patterns despite such limitations. Furthermore, this study is important to provide important information on current and future research on virtual reality applications in vocational education.

CONCLUSIONS

This article analyzes the literature on current studies on the application of virtual reality in vocational educational settings to reveal trends, citations, and keyword use in the past decade. The remarkable insights in question originate from a quantitative synthesis of 100 documents drawn from the Scopus database. The current volume of publications points to an upward trajectory with increasing scholarly attention as virtual reality technologies mature. Keyword analysis found a technology-centered focus that contrasted with minimally learning-oriented themes. Therefore, it is still very important to integrate virtual reality effectively into classrooms. The general findings depicted a landscape more of an emerging nature, with key lacunae surrounding international and pedagogical research. These results have strong implications for the further development of the use of virtual reality in vocational education.

This underscores that appropriate training frameworks and curricula designed for classroom vocational learners must be developed through more classroom-based studies. Virtual reality developers from these places may also be encouraged to establish international links between vocational educators with a view to localized innovations. Adherence to the learning-oriented research perspective will be an illuminating experience with respect to optimal integration approaches. It develops an empirical foundation that will illuminate clear avenues for advancing the applications of virtual reality in vocational education around the world.

The result showed that virtual reality in vocational education was a niche with emerging characteristics, meaning an increase in interest over the last few years. Growth has been largely attributable to active contributions from China, the United States, and other Asian countries. Asian researchers have contributed to this field mainly through the formal literature. The productivity of the United States was first, China was second, and the evidence generated was third in the ranking of Germany. Metadata descriptions revealed two keyword-dominant clusters focusing on the terms "virtual reality," "study," and "technology."

Bibliometric findings may reveal the clear interconnection between virtual reality and vocational education. The number of publications per author was used to illustrate that the figure of authors having four or more publications only signifies that the follow-up research in this area continues to remain low based on these previous publications. This highlights a gap, which may motivate authors, readers, and researchers in this domain to do much more work in this regard. Going beyond the simple pointing out of salient patterns in the emerging literature, the contribution of the present study's findings is that they identify which areas bear promise for impactful discoveries, thus orienting future research.

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