Received: 12 September 2024 | Revised: 28 March 2025 | Accepted: 22 April 2025 | Published online: 14 May 2025

Artificial Intelligence and Applications
2025, Vol. 3(4) 341–358
DOI: 10.47852/bonviewAIA52024327

BON VIEW PUBLISHING

REVIEW

Advancements in Virtual Reality Technology: A Systematic Review of User Experience and Application Trends

Wenli Shang[1,*] and **Kazlova Alena**[1]

[1]*Faculty of Radio-Physics and Computer Technologies, Belarusian State University, Belarus*

Abstract: This study provides a comprehensive analysis of virtual reality (VR) technology from a developer's perspective, focusing on trends over the past two decades, device usage, content scenario requirements, the effectiveness of the user experience, and the impact on learning outcomes. The primary source of information was English articles downloaded from databases such as Web of Science for the period 2003–2023. Thirty-seven articles were selected for in-depth analysis after initial screening and detailed evaluation. The findings show that VR technology is gradually shifting toward personalized learning, with headset devices becoming standard and content scenes evolving from simple illustrations to highly detailed 3D models. In addition, user experience evaluations revealed that the majority of participants were positive about VR technology, although some noted usability challenges or shortcomings. This study offers valuable theoretical foundations and practical guidance for developers, helping them to improve the design, effectiveness, and user experience of VR systems, thus contributing to the further development of the technology.

Keywords: virtual reality (VR), user experience, technological design, personalized learning, technological standard

1. Introduction

The concept of "virtual reality" can be traced back to Stanley G. Weinbaum's 1935 science fiction story *Pygmalion's Spectacles*. In the late 1980s, Jaron Lanier, one of the pioneers in the field, further developed the concept. Subsequently, the broader term "artificial reality" gained popularity and evolved into various forms, including VR, MR, AR, and extended reality (XR). This study specifically focuses on VR. The great potential of VR technology in training medical personnel was first mentioned by Mantovani and colleagues in 2003. Lee et al. [1] noted that VR technology blurs the boundaries between the physical and virtual worlds, enabling users to be fully immersed in simulated environments. Research by Bemadi et al. [2] demonstrated that virtual simulation education outperforms traditional methods in student satisfaction and achievement. Oyelere et al. [3] concluded that virtual educational games are primarily applied in extracurricular learning, with medical education being one of the main areas. Ihamäki and Heljakka [4] presented 3D Glue, an immersive virtual platform for collaborative work that can be used to develop corporate presentation materials and collaborative educational applications. VR technology is currently being actively explored across diverse domains, including the gaming industry, education and simulation, healthcare, emergency care, and military training. In addition, VR is already in practical use in medical education, emergency room simulation training, anatomy courses, etc. Various VR devices are used for these applications. A study by Jin et al. [5] confirms that VR technology can develop laparoscopic skills in novice surgeons. Jan Egger and colleagues [6] implemented a virtual environment for the HTC Vive headset by integrating the OpenVR library into the MeVisLab platform. Additionally, de Buck et al. [7] provided an alternative implementation for linking OpenVR with MeVisLab, allowing for more flexible development of VR prototypes. Mukasheva et al. [8] presented the results of their research on the use of VR and AR in education, utilizing several types of VR headsets. Zikas et al. [9] created the COVID-19 VR Strikes Back project with Steam VR, which can be used on all desktop computers that support SteamVR. Over the past two decades, the intensity of research in the field of VR has increased considerably, and researchers from different disciplines have recognized the broad potential of this technology in modern life. However, there are relatively few studies analyzing the evolution of VR technology from the perspective of developers, including development trends, VR devices, content within virtual scenarios, and effects on users. Therefore, this study systematically reviews scientific achievements in the field of VR over the last 20 years to answer the questions listed in the table.

Addressing these questions will help clarify the needs for the development of VR technology. The structure of this article is shown in Table 1.

1) Introduction: Statement of the research problem.
2) Overview of the development of virtual reality technology: A brief overview of the current state of VR technology development, description of relevant works, and justification of how this research addresses the existing research gap.
3) Review methods and procedures: Presentation of the review methods and procedures, as well as a list of selected references.

*Corresponding author: Wenli Shang, Faculty of Radio-Physics and Computer Technologies, Belarusian State University, Belarus. Email: rct.shanV2@bsu.by

Table 1
Research questions of this study

№	Research question
RQ1	What are the trends in the development of VR technology applications?
RQ2	What is the development and current state of the use of VR devices?
RQ3	What are the needs and the current state of development of virtual scenario content?
RQ4	What are the effects of user experience when using VR technology?

4) Analysis of results: Discussion of the findings from the literature analysis across five aspects: development trends, hardware usage, virtual scenario content needs, user experience, and educational support.
5) Discussion: Discussion of the results, emphasizing the theoretical significance and limitations of the study.
6) Conclusion: Formulation of conclusions.

2. Literature Review

2.1. Overview of the history and development of VR technology

2.1.1. Origin of VR technology

The concept of VR was applied well before the 1950s. According to the Great Soviet Encyclopedia, VR is defined as the use of computer-based modeling and simulation to allow humans to interact with an artificially created three-dimensional visual or sensory environment. Research in this field began to grow significantly in the following decades. The development of VR technology can be categorized into four main stages.

The first stage, which lasted until 1962, focused on the simulation of sound, shapes, and movement, laying the groundwork for the future evolution of the VR concept. The second stage was marked by the rise of science fiction literature and advancements in computer graphics, which sparked further interest in VR. The third stage started around the 1990s, with the development of the first VR content system known as SIMNET. Since then, VR technology has rapidly evolved into the fourth stage, where it has become widely applied across various sectors.

Currently, VR technology is widely used in various industries, including the gaming industry, healthcare, emergency response, military, education, and simulation. For example, in medicine, VR is used for three-dimensional visualization of anatomical structures, surgical simulations, and training medical skills. The gaming industry continues to actively develop VR content, while in the emergency and military sectors, VR serves as a platform for simulation training.

2.1.2. The state of VR content development

In the gaming industry [10], VR content development continues with the release of numerous immersive and entertaining experiences, including VR exhibitions, concerts, and sporting events. In healthcare, VR technology offers realistic virtual anatomical models [11], medical skills training [12], and surgical operation simulations. In the military and emergency response fields [13], VR provides a platform for simulation training, which is used to train soldiers, police, and rescuers. VR technology can also be used in corporate training [14] and aviation and automotive simulators, providing a safe and cost-effective way for students to learn.

Based on the above analysis, several key application scenes for VR technologies can be highlighted.

1) Gaming Industry: VR content in the gaming industry creates immersive gaming worlds and events such as exhibitions, concerts, and sports, offering new entertainment possibilities and increasing user engagement.
2) Healthcare: In the medical field, VR technology offers realistic virtual anatomical models, enhancing medical skills training and surgical simulations. This significantly enhances their training by allowing future doctors to practice in a safe virtual environment.
3) Emergency Response and Military: VR is being used to create simulation training platforms for soldiers, police, and rescue workers, enabling realistic training in a virtual environment, enhancing preparedness for real-world situations, and boosting response efficiency.
4) Education and Simulations: In education and simulation, VR technology is being utilized for corporate training and the creation of aviation and automotive simulators, providing a safe and cost-effective way for students to gain hands-on experience in a controlled virtual environment.

In short, VR technology demonstrates great potential across various application scenarios, ranging from entertainment to professional training and preparedness. In the gaming field, VR offers new possibilities for immersion and interactivity; in healthcare, it improves the quality of medical training; in emergency response and military sectors, VR enhances preparedness and professionalism; and in training and simulation, it enables safe and effective learning. The prospects for VR in these areas appear very promising and offer potential for further innovations and improvements in the near future.

2.2. Overview of VR technology application research

The review of research on the use of VR technology in different areas of education and industry makes an important contribution to understanding the effectiveness and potential of this technology. In the field of medical education, the published works of Zhao et al. [15] and Choi et al. [16] confirm that VR improves student performance and cognitive activity [17]. However, it is important to focus on the integration of VR into the curriculum and further evaluation of its effects on students' learning levels [18].

In anatomy education, Lahti et al.'s analysis [19] highlights VR's potential to engage students and enhance their interest in the subject. In engineering education, work by Soliman et al. [20] confirms the benefits of VR as a learning tool, and they call for a more thorough integration of this technology into the curriculum.

In the area of VR training and evaluation, the review by Xie et al. [21] provides a valuable scientific framework and methodology for developing and evaluating the effectiveness of VR in education. In the field of industrial maintenance, Guo et al.'s study [22] highlights VR's potential to optimize the development process and enhance safety, though further research is needed to adapt the technology to the specific requirements of this industry.

This review demonstrates that VR technology has a wide range of applications across various fields and confirms its potential to enhance both education and production. However, to fully realize this potential, the technology must be applied more comprehensively, considering the specific needs of each field, and further scientific research is essential to optimize processes and achieve improved outcomes.

2.3. Research questions and gaps in studies

2.3.1. Trends

Although we have reviewed the development of VR technology, there is still limited discussion of current trends in its use. The aim of this study is to analyze classic articles on the application of VR technology in order to identify these current trends. Through an analytical approach, we will highlight key developments in VR technology and identify potential areas for growth and innovation. By analyzing the identified trends, we can draw conclusions about the future development and application of VR in various fields.

2.3.2. VR device usage

Various VR devices are available, but information about these devices and their usage remains limited. The aim of this study is to systematically compile information about existing VR devices and their usage to better understand their functionality and updates. By analyzing the use of VR devices, we can identify user preferences and potential improvements to the technology and its applications. This analysis allows us to draw conclusions about the current state of the VR market and user preferences.

2.3.3. Application areas and content scenarios

Currently, VR application areas can be classified into several categories; however, the analysis of VR usage scenarios and their content is still insufficient. This paper focuses on analyzing VR usage scenarios in different fields and assessing their quality and potential. The analytical approach will identify the strengths and weaknesses of various VR usage scenarios, aiding in the optimization of their further development and application. The study of VR application scenarios will provide recommendations for enhancing content and developing new applications for the technology.

2.3.4. Technical feasibility assessment

The objective of this study is to assess the technical feasibility of VR systems, focusing on stability, adaptability, and interactive capabilities. Methods for assessing the technical characteristics and capabilities of VR technology, based on existing research and articles, will be reviewed. By analyzing technical feasibility, the study will highlight the current challenges and limitations of VR technology and propose solutions to address them. Through the analysis of technical features, conclusions can be drawn about the prospects for the development and evolution of VR technology.

2.3.5. User experience and educational effectiveness of VR

The aim of this paper is to summarize user experiences with VR systems and evaluate their effectiveness in education and training. User experience parameters and methods for assessing the effectiveness of VR learning will be considered. The analysis will identify key factors influencing user experience and learning effectiveness in VR, contributing to optimizing learning processes and improving outcomes. By examining these factors, the study will draw conclusions on the advantages and limitations of using VR in education.

3. Research Design

3.1. Information sources

Only English-language research articles were considered in our study, and literature reviews were excluded [23]. We preferred the widely recognized Web of Science database as the most reliable source of information for systematic reviews in the field of VR technology. Initially, we conducted a comprehensive search of the Web of Science and also examined other databases such as IEEE Xplore Digital Library, Google Scholar, ScienceDirect, JSTOR, EBSCO, and Taylor & Francis. The search period was limited to 2003–2023 to include the most recent and relevant research on the use of VR technology.

3.2. Selection criteria

The following criteria were defined for the inclusion of articles in the review:

1) Relates to the application of VR technology;
2) Provides an assessment and analysis of existing VR applications;
3) Evaluates learning outcomes based on VR technology;
4) Articles that did not meet these criteria were excluded from the review, including studies that were limited to virtual modeling only, without full immersive effects, and those not directly related to VR.

3.3. Search string

The search string included key terms such as “virtual reality,” “VR,” and “virtual reality technology,” combined with “system development” or “application.” The overall research process is illustrated (Figure 1). We used Boolean search logic to maximize the coverage of related research.

3.4. Selection and evaluation procedures

We retrieved 2,690 results from various search engines and then screened the articles based on their relevance to the research questions. Each article was carefully evaluated to determine whether it met our criteria. Ultimately, 37 articles were selected for further analysis, as summarized in the search results (Figure 2). The authors assessed each article based on the following criteria:

1) Is the study relevant to our research question?
2) Does the study meet our criteria?
3) The final result was the selection of 37 articles for further analysis.

3.5. Search process

The article process involved multiple steps to ensure a thorough and unbiased selection of articles. Initially, a broad search was carried out using the predefined search terms across the selected databases. The retrieved articles were then screened for a preliminary screening to exclude duplicates and irrelevant studies. This was followed by a more detailed review of the abstracts and, when necessary, the full texts to confirm that the articles met the inclusion criteria. After this, the chosen articles were thoroughly analyzed and evaluated based on their relevance to the research questions and their contributions to the understanding of VR technology applications, learning outcomes, and user experiences. This process was designed to maintain a systematic and rigorous approach, ensuring the reliability and validity of the selected literature for the review.

Figure 1
Research process

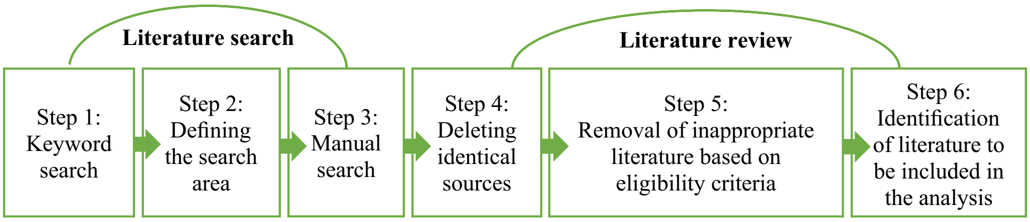


Figure 2
Search results

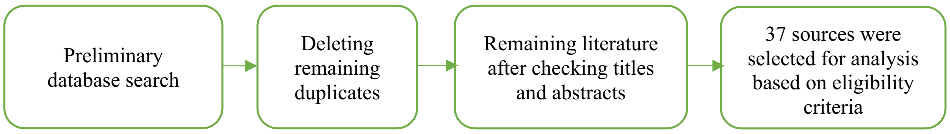


Table 2
Selected literature

No.	Year	Title	VR equipment (including software and hardware)	Research methods
1	2003	A Dental Training System using Virtual Reality	3D magnetic sensor (FASTRAK, POLHEMUS), haptic device (PHANToM DESKTOP, SensAble Technologies)	Test modeling
2	2007	Endotracheal Intubation: Application of Virtual Reality to Emergency Medical Services Education	Not explicitly mentioned	Not explicitly mentioned
3	2008	Transforming Clinical Imaging Data for Virtual Reality Learning Objects	VRLO technology, VR Worx (3D animation software)	Not explicitly mentioned
4	2012	Design and implementation of a virtual world training simulation of ICU first hour handover processes	Not explicitly mentioned	Not explicitly mentioned
5	2013	Virtual reality aided visualization of fluid flow simulations with application in medical education and diagnostics	5DT DataGlove, Vizard VR Toolkit development platform	Test modeling
6	2013	Evaluation of a Virtual Reality Simulation System for Porcelain Fused to Metal Crown Preparation at Tokyo Medical and Dental University	DentSim (Image Navigation, New York, NY)	Group experiment, survey
7	2014	Virtual Reality Medical Training System for Anatomy Education	Not explicitly mentioned	Survey
8	2015	A virtual reality based simulator for learning nasogastric tube placement	Phantom Desktop tactile device (Sensable Technologies Inc.)	Test modeling
9	2016	Design and Implementation of Traditional Chinese Medicine Education Visualization Platform Based on Virtual Reality Technology	Unity3D	Test modeling
10	2016	Virtual reality application applied to biomedical models reconstructed from CT scanning	Unity 3D, Oculus Rift glasses, 3D Studio Max	Not explicitly mentioned
11	2016	Application of a 3D Haptic Virtual Reality Simulation System for Dental Crown Preparation Training	Simodent VR simulator	Test modeling, survey

(*Continued*)

Table 2
(*Continued*)

No.	Year	Title	VR equipment (including software and hardware)	Research methods
12	2017	Through the Eye of the Master: The Use of Virtual Reality in the Teaching of Surgical Hand Preparation	GearVR headset, Bose Quiet Comfort 25 noise-canceling headphones	Group experiment, test results
13	2017	Immersive virtual reality as a teaching tool for neuroanatomy	Oculus Rift VR system	Group experiment, test results
14	2017	Anatomy Builder VR: Applying a Constructive Learning Method in the Virtual Reality Canine Skeletal System	Unity3D, Vive controller	Survey
15	2018	Cost-Utility Analysis of Virtual and Mannequin-Based Simulation	Not explicitly mentioned	Survey
16	2018	Applying Multi-User Virtual Reality to Collaborative Medical Training	Head-mounted displays, VIVE controllers	Not explicitly mentioned
17	2018	Gamification and virtual reality for teaching mobile x-ray imaging	Unity3D, HTC Vive	Test modeling, survey
18	2018	Using virtual reality in medical education to teach empathy	Oculus Rift headset, sensors	Not explicitly mentioned
19	2018	Hospital emergency room training using virtual reality and Leap motion sensor	Leap Motion controllers, Unity3D, Samsung Gear VR, other head-mounted displays	Not explicitly mentioned
20	2019	The Development and Application of Virtual Reality Animation Simulation Technology: Take Gastroscopy Simulation System as an Example	Unity3D	Not explicitly mentioned
21	2019	Collaborative Virtual Reality for Laparoscopic Liver Surgery Training	Unity3D, HTC Vive controller, VRTK, Nvidia FleX Particle System, Insight Segmentation and Registration Toolkit (ITK), Cubiquity library	Test modeling, survey
22	2019	Prosthetic Rehabilitation Training in Virtual Reality	HTC Vive, Thalmic Labs Myo gesture control arm, Unity 3D	Survey
23	2020	Simulation training for ceramic crown preparation in the dental setting using a virtual educational system	Virtual educational system for dentistry (VLNP, Dental Hospital of Nanjing Medical University, Nanjing, China) and real-time dental training and evaluation system (RDTES, Suzhou Digital Healthcare, Suzhou, China), developed and implemented by Nanjing Medical University	Test modeling, survey
24	2020	First experiences with patient-centered training in virtual reality	Simodont dental machine	Test modeling, survey
25	2020	Immersive Virtual Reality Medical Simulation: Autonomous Trauma Training Simulator	Microsoft Mixed Reality, Oculus Rift, HTC Vive, Magic Leap, mobile-based systems, and more	Not explicitly mentioned
26	2021	3D virtual reality simulation in radiography education: The students' experience	HTC Vive Pro™ headset and hand controller	Survey
27	2021	Use of 360° virtual reality video in medical obstetrical education: a quasi-experimental design	VR video headset (Oculus)	Group experiment, survey
28	2021	Efficacy of a virtual reality–based basic and clinical fused curriculum for clinical education on the lumbar intervertebral disc	VR visualization with special glasses	Group experiment, survey
29	2021	Design and key technology research of virtual training system for new coronavirus detection	Zbrush, Maya software	Not explicitly mentioned

(*Continued*)

Table 2
(*Continued*)

No.	Year	Title	VR equipment (including software and hardware)	Research methods
30	2022	The impact of teacher's presence on learning basic surgical tasks with virtual reality headset among medical students	Using the VR4HEALTHCARE application in VR with Oculus Rift S glasses	Group experiment, survey
31	2022	Using virtual reality in lumbar puncture training improves students learning experience	Cypriot video player Gizmolite® Gizmo VR, VR machine – Oculus Go (Oculus, Microsoft, USA)	Survey
32	2022	Animation of virtual medical system under the background of virtual reality technology	Unity 3D, HTC Vive	Test modeling
33	2022	Immersive Anatomy Atlas: Learning Factual Medical Knowledge in a Virtual Reality Environment	Head-mounted display (HMD), Unreal Engine version 4.23 game engine, HTC VIVE™ head-mounted display (New Taipei City Hi-Tech Computer Corporation, Taiwan, China)	Test modeling, survey
34	2022	Effects of spherical video-based virtual reality on nursing students' learning performance in childbirth education training	Second generation VR Box (virtual reality glasses)	Group experiment, survey
35	2023	Design and Development of a Virtual Reality Anatomy Medical Classroom by Utilizing Cognitive Load Theory and The Virtual Medical Technology Acceptance Model (VMedTAAM)	Not explicitly mentioned	Survey
36	2023	Immersive VR (Virtual Reality) Simulator for Vein Blood Sampling	HMD controller (Oculus Quest 2, Meta Platforms, Inc., Menlo Park, CA, USA), 3D CAD software (3ds Max 2022.3 and Cinema4D R23.110), haptic device (Touch, 3D Systems, Rock Hill, SC, USA), Unity3D	Survey
37	2023	Virtual reality as a learning tool for improving infection control procedures	Not explicitly mentioned	Group experiment, survey

A brief description of 37 key publications that detail various aspects of VR applications is presented in Table 2. The VR equipment used and research methods are specified for each article [23, 59].

4. Results

4.1. RQ1: what are the trends in the development of VR technology applications?

4.1.1. Analysis of VR technology research from 2003 to 2023 in the Web of Science database

Data analysis:

The number of publications on VR technology remained stable but low from 2003 to 2013, with some fluctuations (Figure 3). From 2014 onward, there was a gradual increase in the number of publications, reaching a peak in 2019. After this, there was a decline from 2020 to 2022, although the number of publications remained relatively high. Data for 2023 are still incomplete.

Regarding citations, from 2003 to 2013, it remained stable, but from 2013 to 2022, there was a sharp increase, peaking in 2022. This suggests that interest in VR technology continues to grow and remains an active research area.

Detailed analysis:

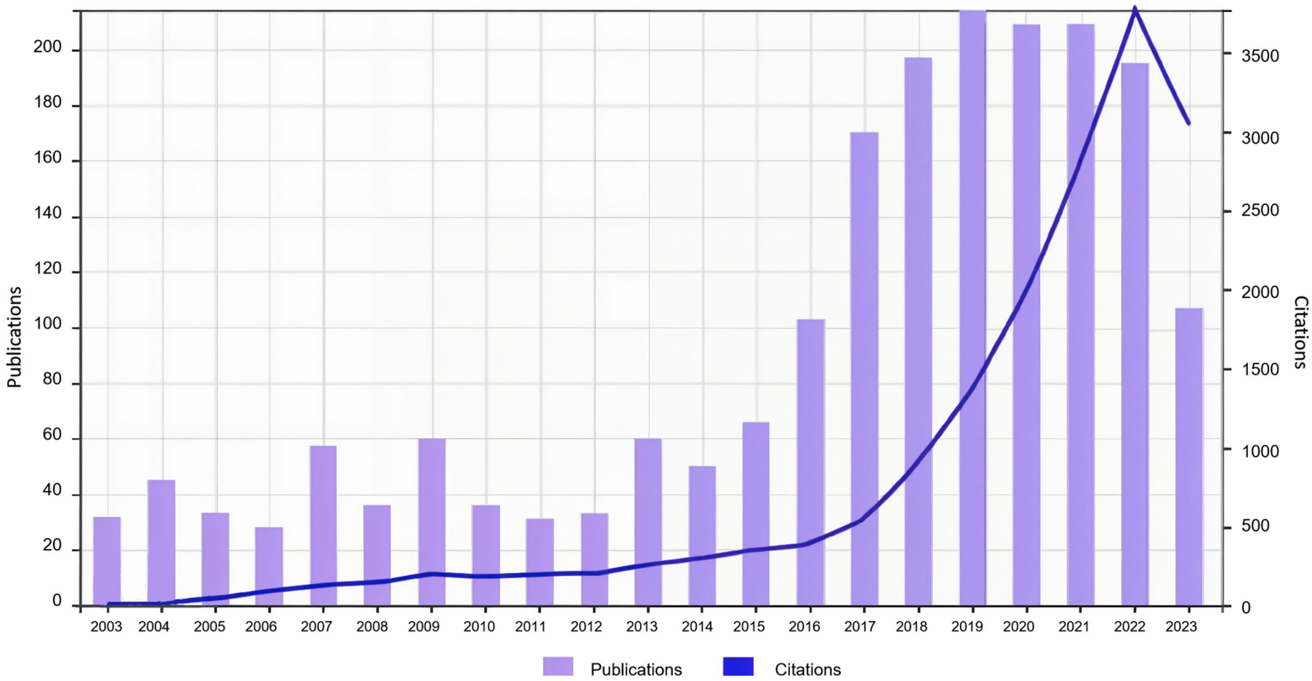
Technological progress: The increase in the number of publications since 2014 can be attributed to significant advances in VR technology. During this period, cheaper and higher quality VR devices such as the Oculus Rift and HTC Vive entered the market. These devices have provided researchers and developers with new opportunities for experimenting with VR, directly enhancing user experience by improving immersion and interaction.

Investment and commercialization: Significant investments in VR technology by tech giants and increased commercial interest in VR products also contributed to the growth of research. The prospects for using VR in areas like education, medicine, entertainment, and industry attracted investors' and researchers' attention, stimulating technology development and adoption.

Impact of the COVID-19 pandemic: The temporary decline in the number of publications from 2020 to 2022 can be attributed to the COVID-19 pandemic, but despite this, the level of publications remained high, indicating sustained interest in VR technology and its potential.

Citation of publications: The increase in citations from 2013 to 2022 signifies growing recognition and suggests a deeper exploration of VR technology's impact on various fields. This highlights an evolving focus on practical implications, rather than

Figure 3
Publications and citations on VR technology applications on the Web of Science, 2013–2023



just theoretical discussions, reflecting a shift toward real-world usability and developer needs.

Conclusion and recommendations:

Ongoing investment: In order to sustain and accelerate the growth of VR research, it is important to continue to invest in technological development and support scientific projects. Particular attention should be given to funding interdisciplinary research that can lead to new discoveries and applications of VR.

Focus on quality: Improving the quality of research and publications in the field of VR will help attract more attention and recognition in the scientific community. This includes the use of advanced data analysis methods and technologies and the conduct of more detailed and substantiated studies.

Overcoming challenges: It is necessary to address and overcome challenges associated with using VR, such as technical limitations and potential negative effects on users (e.g., dizziness). Research in these areas will help to improve the user experience and expand the application of VR.

Long-term prospects: It is important to consider the long-term prospects and directions for VR technology development, such as integration with artificial intelligence (AI) and other advanced technologies. This will help to create more powerful and adaptive VR systems that meet the growing needs of various fields. Therefore, VR technology continues to evolve and remains a significant and promising research area, offering numerous opportunities for future scientific and practical applications.

4.1.2. Statistics of publications in Chinese from 2003 to 2023 in the CNKI database

The CNKI (China National Knowledge Infrastructure) database is the largest in China and one of the largest globally, covering a wide range of scientific publications, including journals, conferences, dissertations, patents, and other types of documents. It is an important tool for finding and accessing Chinese scientific research and is a primary information source for scientists and students in China. Statistics of publications in Chinese from 2003 to 2023 in the CNKI database will allow for evaluating the dynamics and volume of scientific activity in China over the specified period.

Data analysis:

The graph shows (Figure 4) that from 2003 to 2023, 1,182 articles were published, with data for 2023 yet to be completed. From 2003 to 2016, the number of articles on VR technology in Chinese fluctuated but remained stable overall. From 2016 to 2018, there was a sharp increase in the number of publications, reflecting growing interest and investment in this field. In 2019, there was a slight decline, possibly due to market saturation or reevaluation of current research. From 2019 to 2021, the number of articles gradually increased again, peaking in 2021, reflecting renewed interest and expansion in VR technology applications. From 2022 onward, there has been some slowdown, but interest in the topic remains high.

CiteSpace analysis: CiteSpace is a software for analyzing scientific literature, designed for visualizing and analyzing citation networks. Using CiteSpace in this work, an analysis of articles on VR technologies from 2003 to 2023 was conducted, identifying key research areas, trends, and important publications in the field.

The presented graph (Figure 5) was generated using CiteSpace software after analyzing keywords obtained from the CNKI database. Keywords for the search included "Virtual Reality Technology," "virtual reality," and "VR," involving a total of 1,182 related articles.

The graph lacks the highest color level, red, with the next level, orange, being the most prominent. The largest font in the orange part is "three-dimensional reconstruction," followed by "genetic algorithms." Other large keywords include "virtual design," "point cloud," "point cloud registration," "species recognition," "dynamic modeling," "design optimization," and "artificial intelligence," while "feature matching" is represented in the smallest font, and "liver reconstruction" is in a smaller font.

At the next lower level, keywords include "machine vision," "face modeling," and "object detection," with "neural networks" standing out with a larger font, while "one-dimensional images,"

Figure 4
Number of CNKI publications from 2003 to 2023

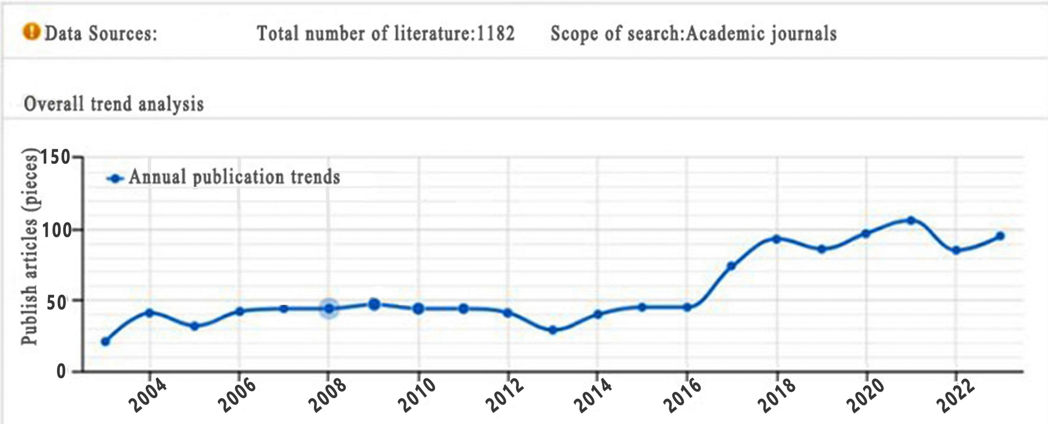
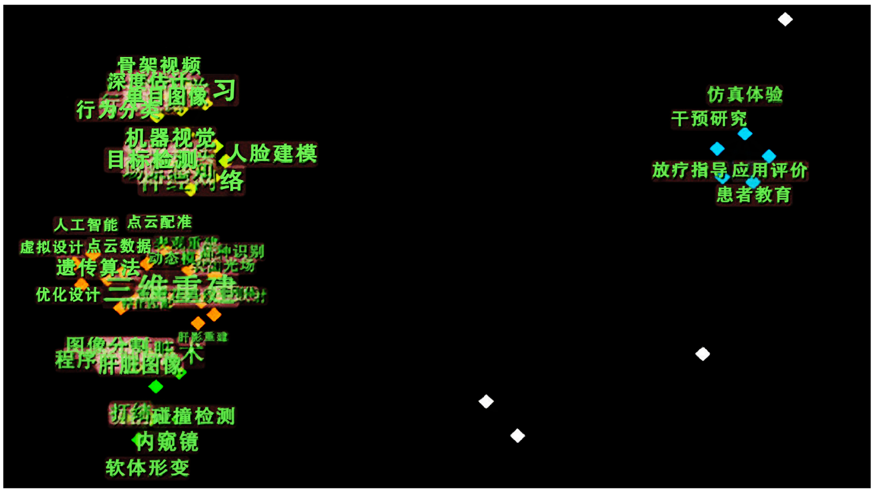


Figure 5
CiteSpace analysis results



"depth evaluation," "behavior classification," and "skeleton video" are shown in smaller font.

Below this level of technical orange color is the green area, which includes keywords such as "liver images," "image segmentation," and "program decomposition." Besides, there is some space allocated for keywords such as "endoscope," "collision detection," and "soft tissue formation."

At the lowest level are blue-colored keywords such as "experience simulation," "interventional studies," "radiation therapy guidance," "application evaluation," and "patient education." The last level is represented in white, indicating its low importance in the analysis.

From the graph, it can be seen that researchers' focus in the field of VR is mainly directed toward such aspects as three-dimensional reconstruction, genetic algorithms, virtual design, and point cloud processing. This indicates a broad interest in applying and developing VR technologies in various areas. Particularly noteworthy is the widespread use of methods such as machine vision, face modeling, and object detection, highlighting their significance in this research area.

4.1.3. Study of key areas of virtual reality based on CiteSpace analysis and CNKI database

According to the CiteSpace analysis, we found that four aspects – three-dimensional reconstruction, genetic algorithms, virtual design, and point cloud processing – are highly correlated with VR, demonstrating high levels of research activity and popularity. We conducted a full-text search of articles in the CNKI database for each of these four terms from 2003 to 2023 and visualized the number of published articles each year.

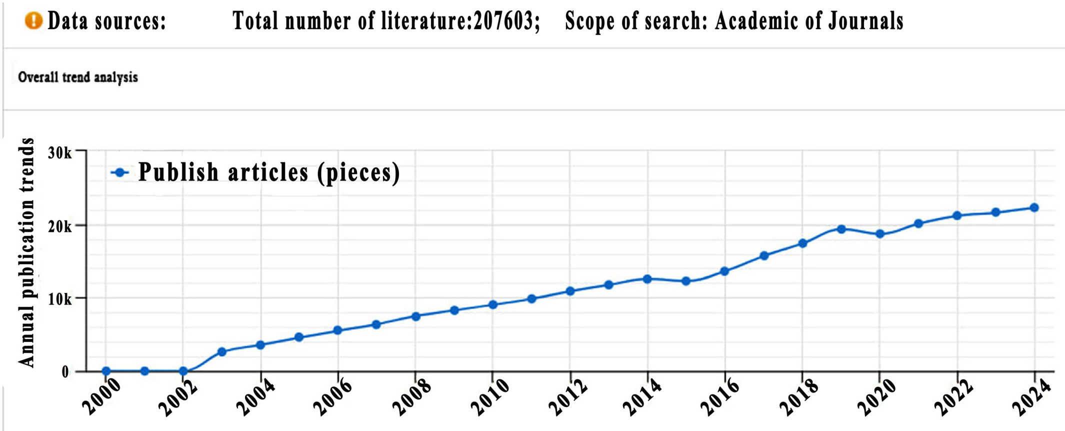
Our analysis using CiteSpace identified four aspects – three-dimensional reconstruction, genetic algorithms, virtual design, and point cloud processing – that show high correlation with VR, as well as high levels of research activity and popularity.

Three-dimensional reconstruction:

Graph description (Figure 6): 207,603 articles were found on the topic of three-dimensional reconstruction. The graph shows a steady growth in the number of publications from 2003 to 2023, with slight declines in 2015 and 2020.

Analysis: The steady growth in the number of publications on three-dimensional reconstruction indicates sustained interest in this technology. Three-dimensional reconstruction is an important aspect of VR, allowing for the creation of accurate and realistic models of objects and scenes. This is crucial for various applications such as architecture, medicine, industrial design, and others. Declines in 2015 and 2020 may be related to some shifts in research priorities or the economic factors affecting research funding.

Figure 6
Trends in the number of publications on three-dimensional reconstruction from 2003 to 2023



Three-dimensional reconstruction remains an important area of research in VR, with continued interest and innovation in this field. To maintain this trend, it is important to continue developing technologies and methods, as well as adapting them to new requirements and challenges.

Virtual design:

Graph description (Figure 7): 26,790 articles were found on the topic of virtual design. The graph shows a sharp increase in the number of publications from 2003 to 2006, followed by stabilization from 2006 to 2009, a decline from 2009 to 2012, subsequent growth from 2012 to 2015, and stabilization again until 2017, followed by a gradual decline.

Analysis: The dramatic increase in publications in the field of virtual design between 2003 and 2006 can be explained by an active integration of VR technologies into various industries such as architecture, engineering design, and medicine. New opportunities offered by VR stimulated interest in this area and attracted the attention of researchers and practitioners.

The stabilization and subsequent decline in the number of publications after 2009 may indicate market saturation and a decrease in the novelty of technologies. However, the increase in interest after 2012 is associated with the emergence of new applications and improvements in VR hardware, stimulating new research in virtual design. The emergence of new applications such as virtual educational environments, training simulators, and gaming platforms has driven the increase in the number of publications. Improvements in the quality of VR equipment, including the development of more powerful and affordable VR headsets, have expanded the user base and attracted new researchers to the field of virtual design.

However, the subsequent decrease in interest in this area may be due to several factors. Possible reasons may include market saturation in China, shifting focus to other technological directions, or the impact of external factors such as economic changes. For further development, it is important to focus efforts on integrating VR into new areas and improving the user experience. This may include creating more innovative

Figure 7
Trends in the number of publications on virtual design from 2003 to 2023

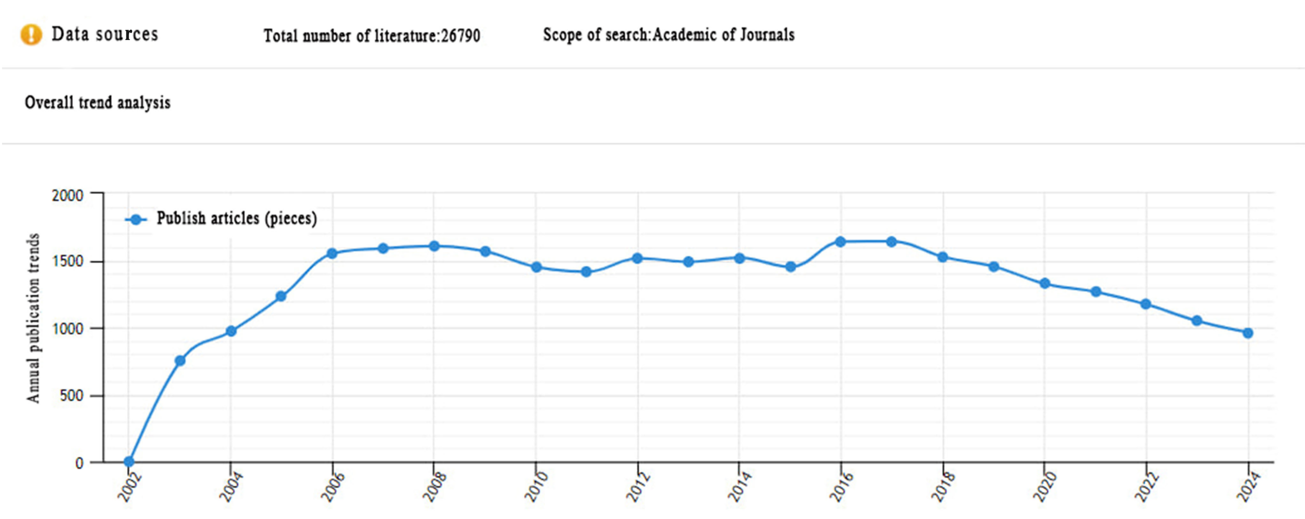
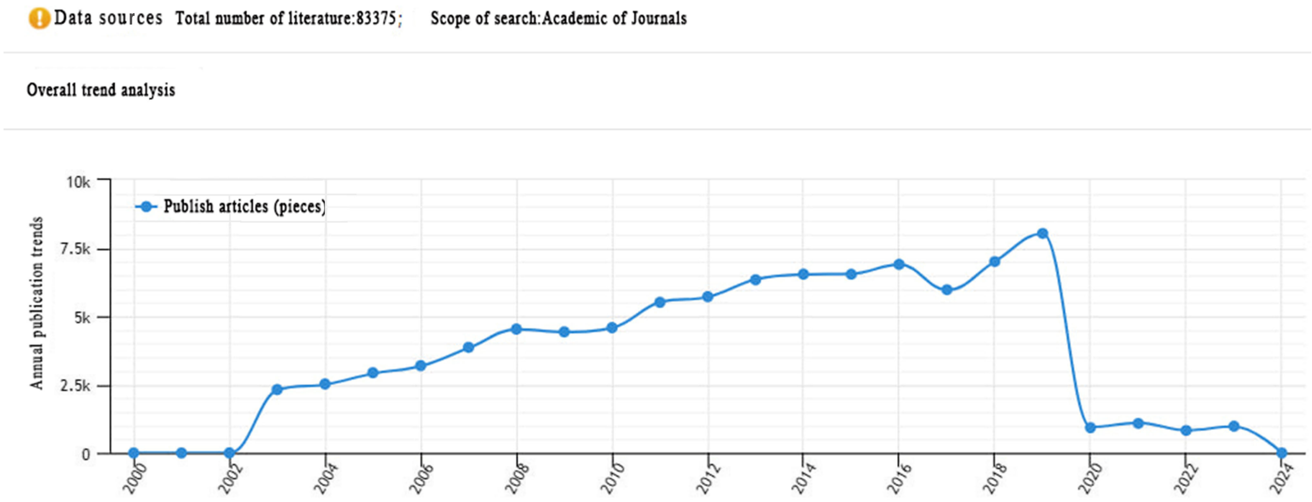


Figure 8
Trends in the number of publications on genetic algorithms from 2003 to 2023



applications, developing new virtual design methods, and actively engaging users in the use of VR technologies in various fields of activity.

Genetic algorithms:

Graph description (Figure 8): 83,375 articles were found on the topic of genetic algorithms. The graph shows steady growth in the number of publications from 2003 to 2016, followed by a slight decline in 2017, growth until 2019, and a sharp decline in 2020, after which the number of publications stabilized.

Analysis: Genetic algorithms are an important tool for optimizing and solving complex problems in VR. The growth in publications until 2016 reflects active research and application of these algorithms in various aspects of VR, such as agent behavior management, rendering process optimization, and the creation of photorealistic virtual environments.

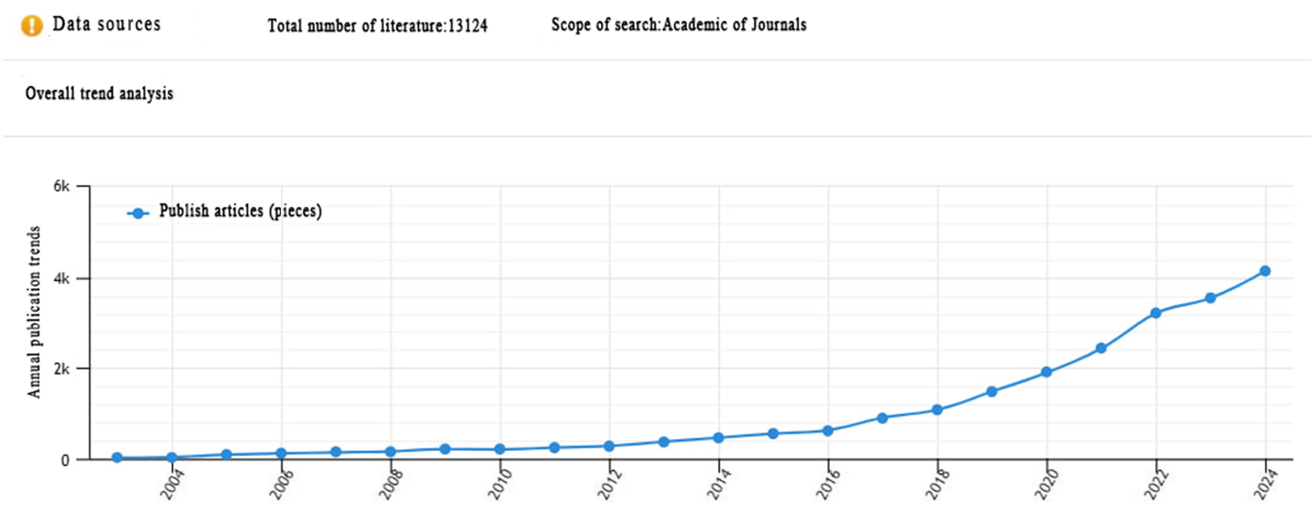
The decline in 2017 may be due to researchers shifting toward more modern methods such as machine learning and deep learning, which are also widely used in VR application development. However, the sharp decline in 2020 may be related to the global economic and social impact of the COVID-19 pandemic, as many research projects were slowed or delayed due to work constraints and limited access to resources. Nevertheless, genetic algorithms are still relevant and offer unique opportunities for optimizing VR processes, such as the automatic creation of virtual worlds and the optimization of scene and model parameters. To sustain interest in this field, it is important to integrate genetic algorithms with modern VR technologies and explore new applications, such as developing intelligent VR systems or using them in virtual learning and training.

Point cloud processing:

Graph description (Figure 9): 13,124 articles were found on the topic of point cloud processing. The graph shows steady growth in the number of publications from 2003 to 2023, starting with 23 publications in 2003 and gradually increasing until 2023.

Analysis: Point cloud processing plays a key role in the field of VR technologies, especially 3D scanning and reconstruction. The steady growth in the number of publications from 2003 to 2023 demonstrates the continued interest in this topic and the

Figure 9
Trends in the number of publications on point cloud processing from 2003 to 2023



progressive development of point cloud processing methods. This growth can be explained by improvements in scanning technologies, photogrammetry, and machine learning methods that have expanded the capabilities and accuracy of reconstructing 3D models from point cloud data.

Point cloud processing is an integral part of the process of creating virtual environments and models, so the continued focus on this area reflects its importance to a wide range of industries, including architecture, surveying, medical diagnostics, and even the film industry.

For further development in this area, it is important to continue improving data processing methods and algorithms, as well as actively seeking new ways to apply them in various fields. This may include improving segmentation and filtering algorithms for point clouds, developing efficient methods for visualizing 3D models, and creating new applications based on point cloud data to enhance the user experience in VR.

Analysis of the publications in various aspects of VR allows us to observe their dynamics and significance in technological development. Three-dimensional reconstruction, virtual design, genetic algorithms, and point cloud processing stand out as the key areas demonstrating stable interest and research activity growth. These aspects play an important role in various fields, from architecture to medicine, and their development requires constant improvement of methods and algorithms. Integration of new technologies, development of innovative applications, and active research direction will help to continue sustainable progress in the field of VR.

Detailed analysis:

Technological advances and accessibility: From 2016 to 2018, there was a sharp increase in publications, which can be explained by significant technological advances in the field of VR and increased accessibility. The emergence of new devices and platforms, such as cheaper VR headsets and content development tools, stimulated the interest of researchers in studying the possibilities and applications of these technologies.

Impact of investments: Significant investments from Chinese companies, government, and startups have also contributed to the increase in research on VR. This highlights the strategic importance of VR as an innovative technology for China. Support programs and investment projects can serve as examples of successful financial impact on scientific research development.

Fluctuations and stability: Despite minor fluctuations in the number of publications in 2019, the overall trend remains upward, indicating sustained interest in VR. These fluctuations may be due to reassessment of current research directions or changes in funding priorities, but they do not detract from the overall positive trend in the development of this field.

Research areas identified: Analysis conducted using CiteSpace software identified major research directions in the field of VR. Key themes such as three-dimensional modeling, computer vision, and simulation reflect key technical aspects and VR applications. These areas are critical to the development of VR technologies and their integration into various fields.

Interdisciplinary collaboration: One of the keys to the further development of VR technologies is interdisciplinary collaboration. Collaboration between experts in different fields such as information technology, engineering, medicine, and psychology can lead to the creation of more effective and innovative solutions in the field of VR.

Conclusion and recommendations:

Continued investment and support: For the further development of VR technologies in China, it is important to continue investments and support for scientific research. State and private initiatives should focus on incentivizing innovation and interdisciplinary collaboration.

Focus on priority areas: Considering the identified priority directions – three-dimensional modeling, computer vision, and simulation experience – efforts should be concentrated on their development. This will help to improve the quality of VR products and expand their applications.

Analysis and reassessment: The periodic decline and fluctuations in the number of publications indicate the need for regular analysis and reassessment of current research. This will help to identify new promising directions and adjust development strategies.

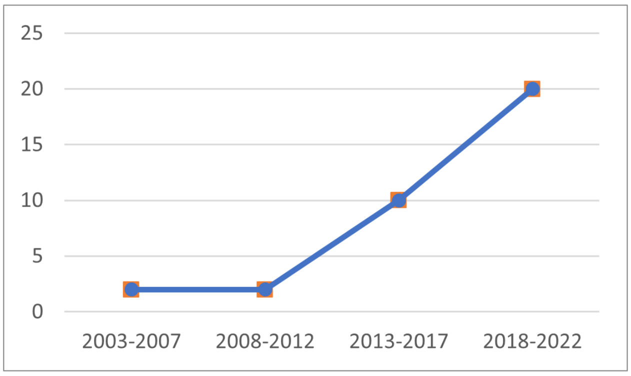
Thus, analysis of publications in the CNKI database shows that VR technologies continue to evolve and remain an important area of research in China. Continued investment, support for prior areas, and international cooperation will contribute to further progress and innovation in this field.

4.1.4. Analysis of selected 37 articles from the Web of Science database

As Figure 10 shows, the number of published articles on VR increases every year, with identifiable cycles of development every five years. Over the period from 2003 to 2023, VR has progressed through four stages of development:

1) (2003–2012): The primary research interest was focused on theoretical assumptions, utilizing basic VR devices, and models of rough quality.
2) (2013–2015): Technical progress and expanded applications began. VR technologies gradually improved, with systems increasingly using various simulators to achieve virtual effects, albeit with a low level of immersion. The research scope expanded to include broader domains such as clinical practice. Most studies concentrated on technical development and system validation, emphasizing results and modeling realism.
3) (2016–2020): Ubiquitous dissemination and technological diversification commenced. Lowered costs of VR headsets, increased accessibility, and maturity of other VR devices such as VR headphones. The Unity3D development platform gained popularity, alongside such modeling programs as MAYA and 3ds MAX, leading to enhanced modeling quality. Researchers shifted focus toward user experience, immersion, and integration of virtual and real environments. VR applications became more diverse.
4) (2021–2023): Innovations and future perspectives. Emerging technologies such as AR and MR gained more attention, converging with VR. Research has increasingly focused on

Figure 10
Trends in the number of published works from 2003 to 2022



personalized learning, AI applications in virtual tutoring, and assessing long-term effects. Significant attention was given to technical feasibility, economic efficiency, and practical applications. Some studies also considered specific factors such as the deployment of 5G networks and the COVID-19 pandemic.

The trend of VR technology development gradually moves toward personalized learning experiences, combining AI with VR to provide personalized guidance and more targeted feedback. VR technology also promotes collaboration across various professional fields including medicine, engineering, computer science, and others. In the future, new VR systems introduced for use will undergo more rigorous evaluation and certification to ensure compliance with applicable efficiency standards. VR technology will contribute to providing broader, more comprehensive, and targeted services.

Recommendations:

1) Promoting the development of personalized learning experiences

It is recommended to further intensify research on the integration of VR technology and AI and develop systems capable of providing tailored learning guidance and precise feedback. By enhancing the application of AI in VR, a more efficient personalized learning experience can be achieved.

2) Strengthening the evaluation and certification of VR systems

It is recommended to conduct more rigorous evaluation and certification before the launch of new VR systems to ensure they meet relevant efficiency standards and safety requirements. This will not only enhance the user experience but also increase industry trust in VR technology.

3) Promoting the deep integration of AI and VR

It is recommended to focus on researching the integration of AI and VR, exploring its broader applications in personalized learning and training. AI can dynamically adjust learning paths in real-time, providing users with customized learning experiences, thus improving learning effectiveness and efficiency.

4) Establishing VR technology standards and certification systems

It is recommended to establish a comprehensive VR technology standard and certification system as soon as possible to ensure the safety and effectiveness of VR applications. By developing industry regulations and quality standards, the healthy development of VR technology across various industries can be promoted.

4.2. RQ2: what is the development and current state of the use of VR devices?

4.2.1. Types of VR devices used in the selected 37 articles

Virtual reality in these articles utilizes various types of devices, including:

1) VR headsets (HMD): The use of VR headsets such as Oculus Rift and HTC Vive is crucial for providing high-quality and immersive VR experiences. These headsets have become the key elements not only in the gaming industry but also in education, healthcare, and industry. The increased interest in VR headsets demonstrates their growing popularity and significance across various fields.
2) Standalone devices: Standalone VR devices, such as the Oculus Quest and Oculus Quest 2, open new possibilities for using VR without the need to connect to a computer or console, making the technology more accessible and convenient for a broader audience. This contributes to its widespread application across various sectors.
3) Mobile virtual reality: The use of smartphones to access VR through dedicated headsets or simplified VR devices enhances the technology's accessibility. This is particularly important for education and entertainment, as many people already own smartphones.
4) Different sensors: The integration of various sensors, such as 3D magnetic sensors and haptic feedback, enhances the virtual experience and increases interactivity. This is especially crucial in the fields where precision and responsiveness are critical, such as medicine and engineering.

The use of different VR devices is a key factor in expanding VR applications across various fields. Further development of more affordable, convenient, and technologically advanced devices, as well as their integration with various sensors and technologies, will expand VR's capabilities and enhance the user experience. Moreover, ongoing research on VR and the exchange of expertise across different disciplines will further optimize the application of this technology, maximizing both efficiency and user satisfaction.

4.2.2. Stages of VR equipment usage

Pre-VR headset era:

During this period, VR technology was primarily used through various types of simulators. These simulators, used in experiments, collectively created an immersive effect for users. The primary method of achieving virtual experiences is by combining different technologies and devices, which were not always specialized for VR.

Post-VR headset era:

With the advent and widespread adoption of VR headsets, these headsets primarily became the method of choice for using VR. Specialized modeling programs such as MAYA or 3ds MAX and popular engines like Unity 3D or UE4 were used in developing virtual scenes and environments. This enabled developers to create higher quality and more realistic virtual worlds.

The distribution and improvement of VR headsets led to changes in approaches to using VR technology. The application of VR expanded to include more diverse fields, with a focus on user experience and immersion. This also spurred the development of software and tools for creating high-quality virtual scenes and environments. For further development and successful use of VR technology, it is important to continue improving the quality of devices and development tools, as well as actively researching and implementing of new methods for creating immersive and realistic virtual experiences.

4.2.3. Conclusion and recommendations

In conclusion, the development and use of VR devices have advanced significantly across various sectors, offering more immersive and interactive experiences. The variety of VR devices, including VR headsets, standalone devices, mobile VR solutions, and sensor integration, plays a crucial role in expanding VR applications and increasing its accessibility. The shift from the pre-VR headset era to the post-VR headset era has marked a significant transformation in the way VR technology is utilized, leading to the creation of more realistic and high-quality virtual environments. However, continued improvements are necessary to fully realize VR's potential across diverse fields.

In terms of recommendations, it is essential to focus on several key areas to maximize the impact of VR technology:

1) Enhance device affordability and accessibility: As standalone VR devices like the Oculus Quest have made VR more accessible, further development of affordable and user-friendly devices is recommended. This would ensure broader adoption and allow VR to reach a wider audience, particularly in education, healthcare, and entertainment sectors.
2) Focus on sensor integration and interactivity: Further integration of advanced sensors, such as 3D magnetic sensors and haptic feedback, will enhance the interactivity and immersion of VR experiences. These technologies should continue to be developed and incorporated into more devices to improve precision and responsiveness, particularly in fields such as medicine and engineering.
3) Improve software and development tools: Specialized software tools such as MAYA, 3ds MAX, Unity 3D, and UE4 have been crucial in developing high-quality virtual environments. There should be continued emphasis on improving these software platforms, making them more user-friendly, and encouraging the development of high-quality, realistic virtual scenes and experiences.

4.3. RQ3: what are the needs and the current state of content development for virtual scenarios?

A comparison of these illustrations (Figures 11–13) reveals the following trends in the development of VR content: Year 2003 (Figure 11): During this period, scene content was mainly represented by hand-drawn illustrations. The models were simplistic and lacked pronounced volume or realism. This marked the initial stage of VR content development, where the primary focus was on creating virtual worlds and attempting to visualize them. It is noteworthy that computer graphics began to play a significant role in this process, providing tools to create a sense of volume and realism in virtual scenes.

Year 2013 (Figure 12): By this period, VR models had already possessed a certain degree of volume and realism. Some models might still have depended on real objects. Human–machine interactions began to occur in virtual environments, although fully immersive experiences had not yet been realized. This era was characterized by experimentation and the search for optimal ways to present virtual content. A significant milestone was the development of 3D reconstruction, which enabled the creation of more realistic and scalable VR models.

Year 2023 (Figure 13): By this period, VR systems have fully realized an immersive experience. All interactions are performed using controllers, and all objects are presented as completely virtual models, without any real-world objects. The quality of the virtual environments has significantly improved, with models becoming more voluminous and realistic. This era is marked by a high level of technological maturity and widespread application of VR content

Figure 11
Scene content illustrations presented in literature from the year 2003

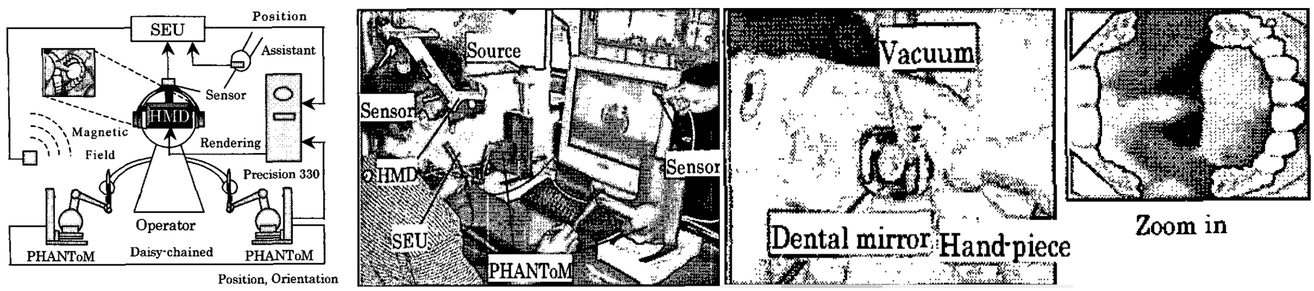


Figure 12
Scene content illustrations presented in literature from the year 2013

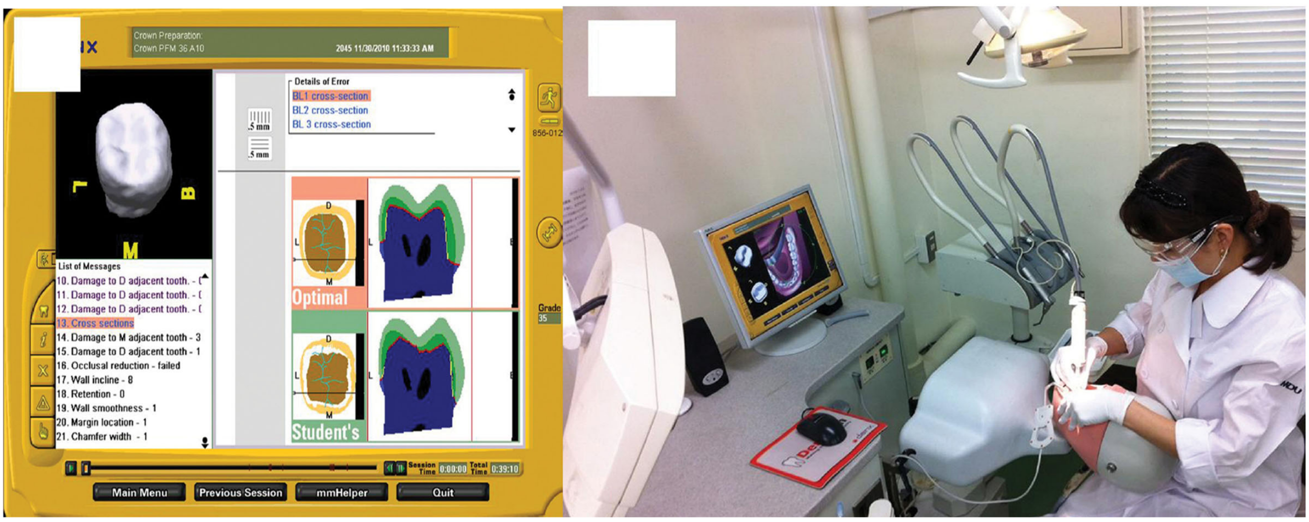
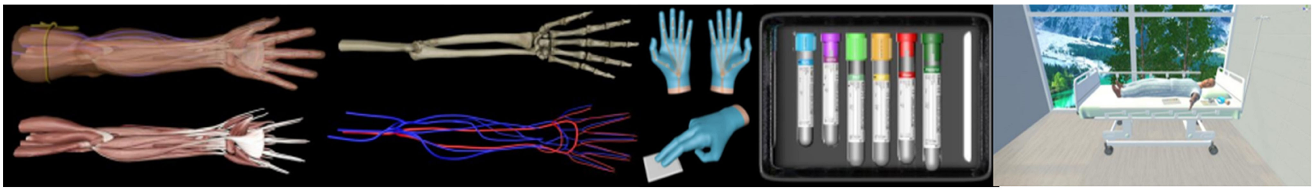


Figure 13
Illustrations of scene content presented in literature from the year 2023



across various domains. The degree of integration between computer graphics, 3D reconstruction, and scene creation in VR has become incredibly tight, allowing for high levels of realism and interactivity in virtual worlds.

Based on the analysis of VR content development trends from 2003 to 2023, several key insights emerge. These trends highlight the evolution of VR technology and the growing sophistication of content development. Here are some recommendations for further advancing VR content development:

1) Exploring realism and immersion

As VR continues to evolve, there seems to be a growing interest in creating more realistic and immersive experiences. While impressive strides have already been made in visual fidelity, further exploration into advanced graphics, AI integration, and photorealistic rendering could continue to improve the sense of immersion. Enhancements in areas like textures, lighting, and shading might also play a significant role in making virtual environments feel more lifelike.

2) Enhancing human–machine interaction

In recent years, VR has incorporated more intuitive human–machine interactions, but there's still room to refine these interfaces. Future developments could focus on making interactions even more seamless and natural, perhaps through the use of gesture recognition, haptic feedback, or eye-tracking technology. These advancements may offer users a more fluid and intuitive way to engage with virtual environments.

3) Advancing 3D reconstruction techniques

The use of 3D reconstruction has already provided a solid foundation for more realistic VR models, but there may be continued potential in this area. Advancements in 3D scanning technologies could help create even more accurate and immersive virtual environments. This could be especially valuable for industries like architecture, education, and healthcare, where creating realistic, real-world models could have practical applications.

4) Expanding interactivity and user engagement

While VR systems today offer impressive interactivity, there may be opportunities to push this further. Exploring ways to allow users to manipulate objects and environments in more complex and dynamic ways could lead to more engaging experiences. Additionally, fostering greater social interaction within virtual worlds may open up new possibilities for shared experiences and collaborative activities.

5) Fostering accessibility and usability

As VR continues to mature, making these technologies more accessible and usable for a wider range of users could be an important goal. This might include developing more intuitive systems that can be used by people with varying levels of technical knowledge or physical abilities. Making VR applications more inclusive could help reach a broader audience and ensure that the technology serves diverse needs.

In summary, the journey from the simple 2D illustrations of 2003 to the immersive 3D environments of 2023 reflects a remarkable progress in VR content development. While significant advancements have been made, the path forward offers plenty of opportunities for continued innovation. Areas such as realism and interactivity could play the key roles in shaping the future of VR, helping to refine and expand its capabilities across various sectors.

4.4. RQ4: what are the effects of user experience when using VR technology?

Out of the 37 studies, 27 included an assessment of the user experience with VR systems. This assessment covered two aspects: learning effectiveness and user experience.

1) Learning effectiveness assessment: This included measuring the level of knowledge, skills, and their application in practical situations. Such an approach allowed for the evaluation of professional knowledge and skills of learners in a virtual environment.
2) User experience assessment: This involved assessing the level of satisfaction, interactivity, and immersion. This provided feedback from users on the quality of learning in VR systems and their feelings about interaction.
3) Assessment results: The majority of participants recognized the positive impact of VR technology, considering its effectiveness for learning and offering a good user experience. However, some encountered issues such as control difficulties, dizziness, and other negative feelings are still remaining for a lot of users.
4) Assessment methods: These included group and individual experiments, as well as various methods such as surveys and testing of educational outcomes.
5) Conclusions and recommendations: It is important to continue research and development in VR technologies, considering the positive feedback from most users regarding their effectiveness and satisfaction with the experience. Attention should be given to issues arising from use, such as control difficulties and dizziness, and efforts should be made to improve them. Future research should delve deeper into the effects of immersive environments on user experience to develop more comfortable and effective VR systems.

5. Discussion

5.1. Theoretical significance

This study offers a deep analysis of several aspects of VR technology based on developer experiences. It particularly focuses on the trends in development, hardware usage, scene content, user experience, and learning effectiveness. Compared to previous research, our study pays special attention to specific challenges developers face in creating and utilizing VR systems, providing more concrete and practical recommendations. Our approach is innovative in emphasizing the crucial role of developers in the application of VR technology, offering them deeper theoretical support and practical guidance, which contributes to further advancements in this technology.

5.2. Limitations

Despite the valuable insights of this study, some limitations should be noted. First, the study only used the articles from English-language peer-reviewed journals spanning from 2003 to 2023, which may have limited the scope by excluding works in other languages and non-peer-reviewed sources. Second, this research focuses exclusively on VR technology, omitting exploration of related technologies such as AR, MR, etc. In addition, the sample size is relatively small, with only 37 articles selected for analysis, which may not fully represent the overall situation of VR technology applications. Therefore, for a more comprehensive study, expanding the sample, diversifying languages, and deeper exploration of interrelationships and differences between various VR technologies could be considered.

5.3. Future perspectives

In the future, VR technology will continue to play a pivotal role and be widely applied across various fields. With advancements in technology and innovations in VR hardware performance, scene quality will improve, facilitating deeper immersion of users into virtual spaces. Concurrently, there will be more in-depth research into user experience and learning effectiveness, which will be critical to optimizing and further enhancing VR technology. Long-term prospects include combining VR technology with other cutting-edge technologies such as Artificial Intelligence and the Internet of Things, leading to the creation of more intelligent and personalized virtual experiences for users.

Thus, despite its limitations, our work makes a significant contribution to the understanding and development of VR technology. Its findings can serve as a foundation for further research, including expanding into other areas of VR and AR, in-depth exploration of user experience, and the development of new research methods. Furthermore, recommendations derived from our analysis can be valuable for developers and engineers working in the VR technology field to improve the quality and effectiveness of VR products and applications.

6. Conclusion

In conclusion, our research confirms that VR technology has undergone significant changes over the past two decades, transitioning from an initial slow growth to rapid expansion in recent years, highlighting widespread interest and importance in this area for researchers and the industry alike. Particularly impressive has been the diversity in the use of VR devices, with VR headsets occupying a central role and becoming the standard. Concurrently, VR scene content has become more complex and detailed, enhancing realism and user immersion of virtual worlds.

Our research also confirms the positive impact of VR technology on improving user experience and learning effectiveness, despite some challenges and limitations. With these factors in mind, we are confident in the optimistic future of VR technologies. Advances in this field will continue, providing users with increasingly captivating and personalized virtual experiences and opening new perspectives in various fields including education, entertainment, and medicine.

In conclusion, our study is an important contribution to the understanding and development of VR technology. The results can be used as a basis for further research and recommendations for developers and engineers working in this field to enhance the quality and effectiveness of VR products and applications.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Author Contribution Statement

Wenli Shang: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Kazlova Alena:** Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration.

References

[1] Lee, H. G., Chung, S., & Lee, W. H. (2013). Presence in virtual golf simulators: The effects of presence on perceived enjoyment, perceived value, and behavioral intention. *New Media & Society*, *15*(6), 930–946. https://doi.org/10.1177/1461444812464033

[2] Behmadi, S., Asadi, F., Okhovati, M., & Ershad Sarabi, R. (2022). Virtual reality-based medical education versus lecture-based method in teaching start triage lessons in emergency medical students: Virtual reality in medical education. *Journal of Advances in Medical Education & Professionalism*, *10*(1), 48–53. https://doi.org/10.30476/JAMP.2021.89269.1370

[3] Oyelere, S. S., Bouali, N., Kaliisa, R., Obaido, G., Yunusa, A. A., & Jimoh, E. R. (2020). Exploring the trends of educational virtual reality games: A systematic review of empirical studies. *Smart Learning Environments*, *7*(1), 31. https://doi.org/10.1186/s40561-020-00142-7

[4] Ihamäki, P., & Heljakka, K. (2021). Developing interactive company presentations in the 3D Glue virtual reality environment: A collaborative educational approach. In *Proceedings of the AHFE 2021 Virtual Conferences on Usability and User Experience, Human Factors and Wearable Technologies, Human Factors in Virtual Environments and Game Design, and Human Factors and Assistive Technology*, 185–196. https://doi.org/10.1007/978-3-030-80091-8_22

[5] Jin, C., Dai, L., & Wang, T. (2021). The application of virtual reality in the training of laparoscopic surgery:

A systematic review and meta-analysis. *International Journal of Surgery*, *87*, 105859. https://doi.org/10.1016/j.ijsu.2020.11.022

[6] Egger, J., Gall, M., Wallner, J., Boechat, P., Hann, A., Li, X., . . . , & Schmalstieg, D. (2017). HTC Vive MeVisLab integration via OpenVR for medical applications. *Plos One*, *12*(3), e0173972. https://doi.org/10.1371/journal.pone.0173972

[7] de Buck, S., van de Bruaene, A., Budts, W., & Suetens, P. (2022). MeVisLab-OpenVR prototyping platform for virtual reality medical applications. *International Journal of Computer Assisted Radiology and Surgery*, *17*(11), 2065–2069. https://doi.org/10.1007/s11548-022-02678-0

[8] Mukasheva, M. U., Baiburin, A. M., Sarsimbayeva, S. M., & Mukhiyadin, A. U. (2022). Virtual and augmented reality in education: State and prospects. *Bulletin of Abai KazNPU. Series of Physical and Mathematical Sciences*, *77*(1), 247–255. https://doi.org/10.51889/2022-1.1728-7901.33

[9] Zikas, P., Kateros, S., Lydatakis, N., Kentros, M., Geronikolakis, E., Kamarianakis, M., . . . , & Papapagiannakis, G. (2022). Virtual reality medical training for COVID-19 swab testing and proper handling of personal protective equipment: Development and usability. *Frontiers in Virtual Reality*, *2*, 740197. https://doi.org/10.3389/frvir.2021.740197

[10] Zhang, R. (2023). Research on the progress of VR in game. *Highlights in Science, Engineering and Technology*, *39*, 103–110. https://doi.org/10.54097/hset.v39i.6507

[11] Wickramasinghe, N., Thompson, B. R., & Xiao, J. (2022). The opportunities and challenges of digital anatomy for medical sciences: Narrative review. *JMIR Medical Education*, *8*(2), e34687. https://doi.org/10.2196/34687

[12] Nassar, A. K., Al-Manaseer, F., Knowlton, L. M., & Tuma, F. (2021). Virtual reality (VR) as a simulation modality for technical skills acquisition. *Annals of Medicine and Surgery*, *71*, 102945. https://doi.org/10.1016/j.amsu.2021.102945

[13] Li, N., Sun, N., Cao, C., Hou, S., & Gong, Y. (2022). Review on visualization technology in simulation training system for major natural disasters. *Natural Hazards*, *112*(3), 1851–1882. https://doi.org/10.1007/s11069-022-05277-z

[14] Tatiana, B., Anna, B., & Elena, K. (2023). Visualization in the context of motivation development within the framework of corporate training. *International Journal of Media and Information Literacy*, *8*(1), 4–13. https://doi.org/10.13187/ijmil.2023.1.4

[15] Zhao, G., Fan, M., Yuan, Y., Zhao, F., & Huang, H. (2021). The comparison of teaching efficiency between virtual reality and traditional education in medical education: A systematic review and meta-analysis. *Annals of Translational Medicine*, *9*(3), 252. https://doi.org/10.21037/atm-20-2785

[16] Choi, J., Thompson, C. E., Choi, J., Waddill, C. B., & Choi, S. (2022). Effectiveness of immersive virtual reality in nursing education: Systematic review. *Nurse Educator*, *47*(3), E57–E61. https://doi.org/10.1097/nne.0000000000001117

[17] Tursø-Finnich, T., Jensen, R. O., Jensen, L. X., Konge, L., & Thinggaard, E. (2023). Virtual reality head-mounted displays in medical education: A systematic review. *Simulation in Healthcare*, *18*(1), 42–50. https://doi.org/10.1097/sih.0000000000000636

[18] Wu, Q., Wang, Y., Lu, L., Chen, Y., Long, H., & Wang, J. (2022). Virtual simulation in undergraduate medical education: A scoping review of recent practice. *Frontiers in Medicine*, *9*, 855403. https://doi.org/10.3389/fmed.2022.855403

[19] Lahti, J., Akkihal, K., Ordovich-Clarkson, R., Kosako Yost, K., & Varkey, T. C. (2023). Virtual reality experiences in medical education: A systematic literature review. *Yemen Journal of Medicine*, *2*(2), 68–74. https://doi.org/10.32677/yjm.v2i2.4070

[20] Soliman, M., Pesyridis, A., Dalaymani-Zad, D., Gronfula, M., & Kourmpetis, M. (2021). The application of virtual reality in engineering education. *Applied Sciences*, *11*(6), 2879. https://doi.org/10.3390/app11062879

[21] Xie, B., Liu, H., Alghofaili, R., Zhang, Y., Jiang, Y., Lobo, F. D., . . . , & Yu, L. F. (2021). A review on virtual reality skill training applications. *Frontiers in Virtual Reality*, *2*, 645153. https://doi.org/10.3389/frvir.2021.645153

[22] Guo, Z., Zhou, D., Zhou, Q., Zhang, X., Geng, J., Zeng, S., . . . , & Hao, A. (2020). Applications of virtual reality in maintenance during the industrial product lifecycle: A systematic review. *Journal of Manufacturing Systems*, *56*, 525–538. https://doi.org/10.1016/j.jmsy.2020.07.007

[23] Ng, Y. L., Ma, F., Ho, F. K., Ip, P., & Fu, K. W. (2019). Effectiveness of virtual and augmented reality-enhanced exercise on physical activity, psychological outcomes, and physical performance: A systematic review and meta-analysis of randomized controlled trials. *Computers in Human Behavior*, *99*, 278–291. https://doi.org/10.1016/j.chb.2019.05.026

[24] Chen, L. Y., Fujimoto, H., Miwa, K., Abe, T., Sumi, A., & Ito, Y. (2003). A dental training system using virtual reality. In *Proceedings 2003 IEEE International Symposium on Computational Intelligence in Robotics and Automation. Computational Intelligence in Robotics and Automation for the New Millennium, 1*, 430–434. https://doi.org/10.1109/CIRA.2003.1222128

[25] Kikuchi, H., Ikeda, M., & Araki, K. (2013). Evaluation of a virtual reality simulation system for porcelain fused to metal crown preparation at Tokyo Medical and Dental University. *Journal of Dental Education*, *77*(6), 782–792. https://doi.org/10.1002/j.0022-0337.2013.77.6.tb05530.x

[26] Kim, J. S., Kim, K. W., Yang, S. W., Chung, J. W., & Moon, S. Y. (2023). Immersive VR (Virtual Reality) simulator for vein blood sampling. *Technologies*, *11*(6), 158. https://doi.org/10.3390/technologies11060158

[27] Mayrose, J., & Myers, J. W. (2007). Endotracheal intubation: Application of virtual reality to emergency medical services education. *Simulation in Healthcare*, *2*(4), 231–234. https://doi.org/10.1097/sih.0b013e3181514049

[28] Trelease, R. B., & Rosset, A. (2008). Transforming clinical imaging data for virtual reality learning objects. *Anatomical Sciences Education*, *1*(2), 50–55. https://doi.org/10.1002/ase.13

[29] Brown, R., Rasmussen, R., Baldwin, I., & Wyeth, P. (2012). Design and implementation of a virtual world training simulation of ICU first hour handover processes. *Australian Critical Care*, *25*(3), 178–187. https://doi.org/10.1016/j.aucc.2012.02.005

[30] Djukic, T., Mandic, V., & Filipovic, N. (2013). Virtual reality aided visualization of fluid flow simulations with application in medical education and diagnostics. *Computers in Biology and Medicine*, *43*(12), 2046–2052. https://doi.org/10.1016/j.compbiomed.2013.10.004

[31] Ojala, S., Sirola, J., Nykopp, T., Kröger, H., & Nuutinen, H. (2022). The impact of teacher's presence on learning basic surgical tasks with virtual reality headset among medical students. *Medical Education Online*, *27*(1), 2050345. https://doi.org/10.1080/10872981.2022.2050345

[32] Choi, K. S., He, X., Chiang, V. C. L., & Deng, Z. (2015). A virtual reality based simulator for learning nasogastric tube placement. *Computers in Biology and Medicine*, *57*, 103–115. https://doi.org/10.1016/j.compbiomed.2014.12.006

[33] Huang, Y., Zhai, X., Ali, S., & Liu, R. (2016). Design and implementation of traditional Chinese medicine education visualization platform based on virtual reality technology. In *2016 8th International Conference on Information Technology in Medicine and Education*, 499–502. https://doi.org/10.1109/ITME.2016.0119

[34] Torner, J., Gómez, S., Alpiste, F., & Brigos, M. (2016). Virtual reality application applied to biomedical models reconstructed from CT scanning. In *24th Conference on Computer Graphics, Visualization and Computer Vision*, 21–23.

[35] Wang, F., Liu, Y., Tian, M., Zhang, Y., Zhang, S., & Chen, J. (2016). Application of a 3D haptic virtual reality simulation system for dental crown preparation training. In *2016 8th International Conference on Information Technology in Medicine and Education*, 424–427. https://doi.org/10.1109/ITME.2016.0101

[36] Omori, K., Shigemoto, N., Kitagawa, H., Nomura, T., Kaiki, Y., Miyaji, K., . . . , & Ohge, H. (2023). Virtual reality as a learning tool for improving infection control procedures. *American Journal of Infection Control*, *51*(2), 129–134. https://doi.org/10.1016/j.ajic.2022.05.023

[37] Qi, F., Gan, Y., Wang, S., Tie, Y., Chen, J., & Li, C. (2021). Efficacy of a virtual reality–based basic and clinical fused curriculum for clinical education on the lumbar intervertebral disc. *Neurosurgical Focus*, *51*(2), E17. https://doi.org/10.3171/2021.5.FOCUS20756

[38] Seo, J. H., Smith, B. M., Cook, M., Malone, E., Pine, M., Leal, S., . . . , & Suh, J. (2018). Anatomy builder VR: Applying a constructive learning method in the virtual reality canine skeletal system. In *Proceedings of the AHFE 2017 International Conference on Human Factors in Training, Education, and Learning Sciences*, 245–252. https://doi.org/10.1007/978-3-319-60018-5_24

[39] Haerling, K. A. (2018). Cost-utility analysis of virtual and mannequin-based simulation. *Simulation in Healthcare*, *13*(1), 33–40. https://doi.org/10.1097/sih.0000000000000280

[40] Schild, J., Misztal, S., Roth, B., Flock, L., Luiz, T., Lerner, D., . . . , & Herpers, R. (2018). Applying multi-user virtual reality to collaborative medical training. In *2018 IEEE Conference on Virtual Reality and 3D User Interfaces*, 775–776. https://doi.org/10.1109/VR.2018.8446160

[41] Süncksen, M., Bendig, H., Teistler, M., Wagner, M., Bott, O. J., & Dresing, K. (2018). Gamification and virtual reality for teaching mobile x-ray imaging. In *2018 IEEE 6th International Conference on Serious Games and Applications for Health*, 1–7. https://doi.org/10.1109/SeGAH.2018.8401364

[42] Dyer, E., Swartzlander, B. J., & Gugliucci, M. R. (2018). Using virtual reality in medical education to teach empathy. *Journal of the Medical Library Association*, *106*(4), 498–500. https://doi.org/10.5195/jmla.2018.518

[43] Dhanasree, K. S., Nisha, K. K., & Jayakrishnan, R. (2018). Hospital emergency room training using virtual reality and leap motion sensor. In *2018 Second International Conference on Intelligent Computing and Control Systems*, 924–928. https://doi.org/10.1109/ICCONS.2018.8662900

[44] Wang, Q., Li, C., Xie, Z., Bu, Z., Shi, L., Wang, C., & Jiang, F. (2020). The development and application of virtual reality animation simulation technology: Take gastroscopy simulation system as an example. *Pathology & Oncology Research*, *26*(2), 765–769. https://doi.org/10.1007/s12253-019-00590-8

[45] Chheang, V., Saalfeld, P., Huber, T., Huettl, F., Kneist, W., Preim, B., & Hansen, C. (2019). Collaborative virtual reality for laparoscopic liver surgery training. In *2019 IEEE International Conference on Artificial Intelligence and Virtual Reality*, 1–17. https://doi.org/10.1109/AIVR46125.2019.00011

[46] Liu, L., Zhou, R., Yuan, S., Sun, Z., Lu, X., Li, J., . . . , & Wang, L. (2020). Simulation training for ceramic crown preparation in the dental setting using a virtual educational system. *European Journal of Dental Education*, *24*(2), 199–206. https://doi.org/10.1111/eje.12485

[47] Arents, V., de Groot, P. C., Struben, V. M., & van Stralen, K. J. (2021). Use of 360 virtual reality video in medical obstetrical education: A quasi-experimental design. *BMC Medical Education*, *21*(1), 202. https://doi.org/10.1186/s12909-021-02628-5

[48] Serrano, C. M., Wesselink, P. R., & Vervoorn, J. M. (2020). First experiences with patient-centered training in virtual reality. *Journal of Dental Education*, *84*(5), 607–614. https://doi.org/10.1002/jdd.12037

[49] Dhawan, D., Barlow, M., & Lakshika, E. (2019). Prosthetic rehabilitation training in virtual reality. In *2019 IEEE 7th International Conference on Serious Games and Applications for Health*, 1–8. https://doi.org/10.1109/SeGAH.2019.8882455

[50] O'Connor, M., Stowe, J., Potocnik, J., Giannotti, N., Murphy, S., & Rainford, L. (2021). 3D virtual reality simulation in radiography education: The students' experience. *Radiography*, *27*(1), 208–214. https://doi.org/10.1016/j.radi.2020.07.017

[51] Couperus, K., Young, S., Walsh, R., Kang, C., Skinner, C., Essendrop, R., . . . , & Gorbatkin, C. (2020). Immersive virtual reality medical simulation: Autonomous trauma training simulator. *Cureus*, *12*(5), e8062. https://doi.org/10.7759/cureus.8062

[52] Li, L., & Li, T. (2022). Animation of virtual medical system under the background of virtual reality technology. *Computational Intelligence*, *38*(1), 88–105. https://doi.org/10.1111/coin.12446

[53] Chang, C. Y., Sung, H. Y., Guo, J. L., Chang, B. Y., & Kuo, F. R. (2022). Effects of spherical video-based virtual reality on nursing students' learning performance in childbirth education training. *Interactive Learning Environments*, *30*(3), 400–416. https://doi.org/10.1080/10494820.2019.1661854

[54] Stepan, K., Zeiger, J., Hanchuk, S., del Signore, A., Shrivastava, R., Govindaraj, S., & Iloreta, A. (2017). Immersive virtual reality as a teaching tool for neuroanatomy. *International Forum of Allergy & Rhinology*, *7*(10), 1006–1013. https://doi.org/10.1002/alr.21986

[55] Gloy, K., Weyhe, P., Nerenz, E., Kaluschke, M., Uslar, V., Zachmann, G., & Weyhe, D. (2022). Immersive anatomy atlas: Learning factual medical knowledge in a virtual reality environment. *Anatomical Sciences Education*, *15*(2), 360–368. https://doi.org/10.1002/ase.2095

[56] Yi, Z., Yang, Y., He, N., & Lou, Y. (2021). Design and key technology research of virtual training system for new coronavirus detection. In *2021 16th International Conference on Computer Science & Education*, 587–591. https://doi.org/10.1109/ICCSE51940.2021.9569517

[57] Harrison, B., Oehmen, R., Robertson, A., Robertson, B., de Cruz, P., Khan, R., & Fick, D. (2017). Through the eye of the master: The use of Virtual Reality in the teaching of surgical hand preparation. In *2017 IEEE 5th International Conference on Serious Games and Applications for Health*, 1–6. https://doi.org/10.1109/SeGAH.2017.7939269

[58] Vrillon, A., Gonzales-Marabal, L., Ceccaldi, P. F., Plaisance, P., Desrentes, E., Paquet, C., & Dumurgier, J. (2022). Using virtual reality in lumbar puncture training improves students

learning experience. *BMC Medical Education*, *22*(1), 244. https://doi.org/10.1186/s12909-022-03317-7

[59] Hamizi, M. A. A. M., Mokmin, N. A. M., & Ariffin, U. H. (2023). Design and development of a virtual reality anatomy medical classroom by utilizing cognitive load theory and the virtual medical technology acceptance model (VMEDTAAM). *Journal of Information and Communication Technology Education*, *10*(1), 1–13. https://doi.org/10.37134/jictie.vol10.1.1.2023

How to Cite: Shang, W., & Alena, K. (2025). Advancements in Virtual Reality Technology: A Systematic Review of User Experience and Application Trends. *Artificial Intelligence and Applications*, *3*(4), 341–358. https://doi.org/10.47852/bonviewAIA52024327