INTERNATIONAL JOURNAL OF SOCIAL SCIENCE HUMANITY & MANAGEMENT RESEARCH
ISSN (print) 2833-2172, ISSN (online) 2833-2180
Volume 03 Issue 11 November 2024
DOI: 10.58806/ijsshmr.2024.v3i11n11 Impact Factor: 5.342
Page No.1460-1469

A Systematic Review of Research on the Application of Virtual Reality Technology in Primary Education

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ABSTRACT: Virtual reality technology is receiving increasing attention in education and research fields. Based on 10 high-impact journals in China and abroad, this study selected 26 empirical studies of virtual reality technology applications in primary education in the past 6 years (2018-2024), constructed a coding and analysis framework from several aspects of publication trends, research contexts, research methods, technology characteristics, advantages and challenges, and conducted a systematic literature review using content analysis. The literature focused on the application of virtual reality technology in elementary education, with a mixed-method approach combining quantitative and qualitative aspects, and a diverse trend of data collection and analysis. The findings indicate that VR technology has great potential in improving learning outcomes in various subjects such as science, mathematics, and social studies. Moreover, the application of virtual reality technology in primary education is mostly carried out in semi-immersive VR learning environments. However, the adaptability of hardware and software operation, the stability of real-time interaction, and the complexity of learning task design are new challenges for the application of this technology to primary education.

KEYWORDS: virtual reality; elementary education; systematic literature review; empirical study

1. INTRODUCTION

VR technology is a comprehensive technology that integrates various technologies such as stereoscopic display technology, scene modeling technology and natural interaction technology. It uses virtual environments to simulate the senses of vision, hearing and touch in the real world, and realizes natural interaction through computers, sensors and other means of human-computer interaction (Burdea & Coiffet, 2003). In the field of education, Virtual Reality (VR) is an emerging educational technology that allows students to experience different learning content, learning environment, learning style, and learning scenarios than traditional methods through immersive multi-channel perception. Its “3I” characteristics, i.e. Immersion, Interaction Imagination (Violante, n.d.; Y. Wang, 2020), can stimulate students' motivation, engagement and participation in learning, support meaningful learning in the learning process and bring students a new learning experience (Lau & Lee, 2015). In recent years, VR has been widely used in many educational fields such as engineering education, medical education, spatial technology and mathematics, liberal studies and special education, showing great potential to drive teaching reform and innovation (Kamińska et al., 2019). Its integration with the learning field will become a new trend in the future development of education, and more and more educators are now exploring its innovative applications in the field of education (Zhang et al., 2020).

Some previous studies on the application of VR technology to the field of education mostly start from a theoretical perspective, exploring the theoretical framework and design strategies for VR technology to support teaching and learning (Liu et al., 2020). In

recent years, more and more scholars have started to investigate the effects of VR applications in various educational contexts from an empirical perspective, such as studies on the effects of traffic safety education (Zhang et al., 2020) and studies on enhancing learning motivation (Gao et al., 2016). However, these empirical studies are fragmented, while many scholars have not clearly distinguished between virtual reality and Augmented Reality (AR) in their review studies, or even mixed the two together for research (Li et al., 2017), ignoring the impact of different technological features on the learning experience: VR immerses users in a completely virtual world AR presents virtual information in a rich context, embodies interaction with virtual content, and emphasizes the connection between the virtual and the real (M.-P. Chen et al., 2022). The differences in immersion, interactivity, and imagination between the two bring different audiovisual experiences to users, and therefore an undifferentiated overview of the application of VR and AR in education can lead to many problems such as generalization of conclusions.

In addition, most of the current review literature on VR education does not distinguish between primary education and higher education (Li B. et al., 2019), and primary education does not make a careful distinction between primary education and secondary education, although there are significant differences between these two in terms of teaching targets and teaching contents. Primary education mainly serves elementary school students aged 6 to 12 years old, who are less capable of self-care, less mature in thinking, and less capable of self-protection, and have uneven resources for basic education due to regional differences (Gao et al., 2016). Therefore, including the primary education and secondary and higher education fields together in a review study of VR education does not reflect the impact of educational contextual differences. Relatively speaking, the relatively few applications of VR in primary education, which started late, are more worthy of a systematic review and summary. To sum up, this paper focuses on VR technology and elementary education, attempts to sort out previous VR education application studies, explores the characteristics of teaching design, teaching strategies and teaching evaluation in the VR teaching process and its derivation trends, and tries to summarize existing experiences and promote the application process of VR technology in elementary education.

Specific research questions for this study include:

(1) What are the publication trends of relevant empirical studies in the last 6 years

(2) What are the common research methods and important findings so far?

(3) What are the advantages and challenges of applying VR technology in the field of elementary education?

(4) What are the characteristics of VR devices commonly used in the field of elementary education?

2. RESEARCH METHODOLOGY

This study was based on the Chinese and English literature of the last 6 years (2018-2024) to screen the empirical studies on the application of virtual reality technology in primary education. The screened literature was combined with the application of the systematic literature review method to conduct the study, which consists of the following steps: identifying the problem, developing criteria, searching the literature, screening literature, data extraction, statistical analysis, and writing a review (Evans & Benefield, 2001). As an emerging approach to literature research, systematic literature reviews use specific statistical analysis methods to generalize conclusions about the research topic from scattered research findings. After identifying the literature, the selected literature is quantitatively coded through a coding scale, and the content of the selected literature is further quantitatively analyzed and visually presented in terms of three dimensions: research context, research methods, and technical characteristics.

2.1 LITERATURE SCREENING METHOD

This paper reviews empirical research papers on VR applications in primary education published in Chinese as well as international academic journals in the past 6 years (2018-2024). At present, the number of empirical studies on the application of virtual reality technology in the field of primary education is limited, and this study mainly draws on the method of systematic literature review regarding journal screening and selects 10 academic journals with high influence at home and abroad. Among them from China

were five CSSCI-searchable journals, including Telephone Education Research, Chinese Electro-Chemical Education, Open Education Research, Modern Educational Technology, and Chinese Distance Education. The foreign journals are five SSCI-indexed journals, including British Journal of Educational Technology, Computers in Human Behavior, Educational technology research and development, Interactive Learning Environments, and Computers, Interactive Learning Environments, and Computers & Education (C&E). The literature published in these 10 academic journals has undergone rigorous review and is the top authoritative and representative academic journals in the field of educational technology.

Two sets of keywords were used as search strings in any combination. The first set of strings included virtualreality, VR, and the second set included the keywords "primary, elementary, education, teach, learn, etc.". The initial screening was performed by reading the titles and abstracts of the documents, and a total of 56 documents were obtained.

According to the purpose of the study, the initial screening was further selected as follows: (1) The research context must be primary education, excluding secondary education, higher education, special education, etc. (2) It must be an empirical study (quantitative, qualitative, and mixed studies, etc.), excluding review and theoretical articles. (3) Articles focused on VR technology, excluding research related to AR and MR; (4) Peer-reviewed journal articles were selected, excluding research results such as monographs and conference papers.

Table 1 Inclusion and exclusion criteria of the literature

No	Inclusion criteria	Exclusion criteria
1	Primary Education	Secondary Education, Higher Education, Vocational Education, Special Education
2	Empirical Research	Non-Empirical Research
3	Peer-reviewed journal article	Non-peer-reviewed journal article
4	Focus on VR	Non-VR (AR/MR)
5	Full text available	Full text not available

2.2 Coding analysis method

Table 2 Literature coding table

First Level Dimension	Second Level Dimension	Third Level Dimension
Research Situation	Types of Research	Experimental research, qualitative research, mixed research
	Study Period	Primary school grades 1-6
	Subjects of study	Chinese Language, Mathematics, English Language, Science, Physical Education, Music
	Number of research implementation	1 time, 2 times, 3 times, more than 3 times
Research method	Data collection methods	Questionnaire survey, interview, observation (video, audio), other
	Data analysis method	Correlation analysis (e.g., regression equation, correlation coefficient, structural equation modeling, etc.), analysis of variance (e.g., t-test, ANOVA, ANCOVA, MANOVA, etc.)
Technical feature	Hardware Devices	VR glasses, headgear, projection equipment, computers, other
	Immersion	Fully immersive, semi-immersive
	Interactivity	Virtual world, real world
	Imaginative	None, Low, High
	Teaching function	Attracting interest, content transfer, operation practice, teaching

		evaluation, others
	Exploration level	High, medium, low

In this paper, the final selection of 26 relevant papers was quantitatively coded (6 in Chinese and 20 in English) using the literature coding table in Table 2. The coding was divided into 3 dimensions: research context, research method, and technical characteristics.

3. RESEARCH FINDINGS

3.1 Overall posting trends

3.1.1 NUMBER OF PUBLICATIONS

In the literature over the past five years, 26 locations of empirical VR studies were reported (as shown in Figure 1), with 12 studies from China, indicating that Chinese scholars' research on VR applications in the field of basic education started early and became increasingly mature. Before 2018, especially from 2010-2017 due to the immaturity of VR technology and the complexity of its educational applications, its application and research in elementary school teaching gradually came to a standstill. In recent years, with the rapid development of VR technology and the continued reduction of equipment costs, fully immersive VR learning environments have re-attracted the interest of frontline primary and secondary school teachers and researchers, and related research peaked in 2019, as shown in Figure 1. The phenomenon is also in line with the prediction of the 2017 Horizon Report (Basic Education Edition) that VR technology will be introduced into basic education within 2 to 3 years (Luo et al., 2021).

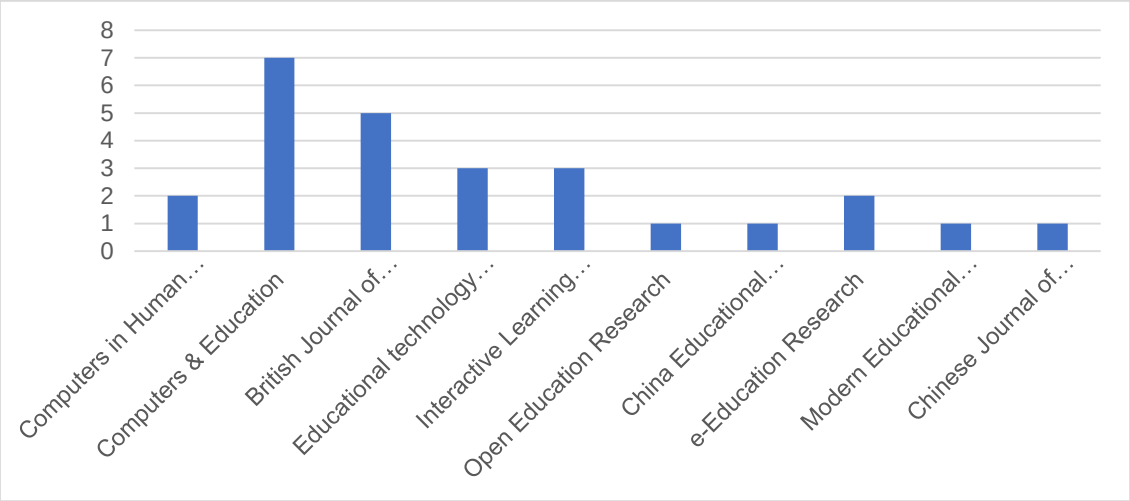

Figure 1 Total number of articles in 10 journals in the last 6 years

3.2 Types of research

3.2.1 Data collection

This paper compares the data collection methods used in the literature. The count of data collection methods is larger than the number of literatures reviewed in this paper because a single piece of literature may use multiple data collection methods. Based on (Creswell, 2013) 's framework for classifying research takes and research designs in educational research, the study summarized three categories of research takes and six categories of research designs based on 26 empirical studies. As shown in Table 3, two studies used qualitative research, including one case study and one study based on rooted theory. six studies used quantitative research, including six quasi-experimental studies. 18 used mixed methods, including three action research studies and 15 other types of mixed research designs. Mixed research accounts for a relatively large proportion of studies, reflecting the latest trends in educational research methods today. Mixed research can modify and make up for the deficiencies of using qualitative or quantitative research alone, and help researchers to answer research questions more comprehensively and deeply (Morse, 2016), which is more suitable for researchers to explore the dynamic and complex learning process of learners in a virtual reality environment.

Table 3 Research design of the empirical study

Research path	Research design	Number of Research
Qualitative research	Case study	1
	Rooted theory	1
Quantitative research	Quasi-experimental research	6
Mixed Research	Action Research	3
	Other mixed methods	15

As shown in Table 3, researchers used a variety of methods to investigate VR educational applications, including experimental studies, qualitative studies, survey studies, design studies, and mixed studies. Among them, experimental studies were the most common (22 articles), and researchers mostly verified the effectiveness of VR teaching through group comparisons and quantitative statistical analysis. This was followed by qualitative studies (2 articles), which explored the issues arising from VR classroom applications by conducting interviews with cases and combining video and audio data (Cheng & Tsai, 2019) and children's collaborative processes in the VR environment.

3.2.2 Data analysis

Among the 26 studies reviewed in the article, the researchers also used diverse data analysis methods. In terms of qualitative data, two papers conducted discourse analysis and interaction analysis based on corpus to explore the types and characteristics of interactions in virtual reality environments. As for the quantitative data analysis methods (see Figure 2), descriptive analysis mainly reported frequency, mean, and percentage, while other methods were mainly divided into difference analysis and correlation analysis. Among them, analysis of variance includes t-test, ANOVA, ANCOVA, MANOVA, non-parametric test, chi-square test, The Wilcoxon Paired Sign Rank Test and other methods, and correlation analysis includes correlation coefficient, regression model, structural equation model, factor analysis and other methods. Comparing differences between groups through experimental studies can test the effects of VR instruction, while modeling to analyze the complex relationships between variables can help explore the mechanisms and related influences on how VR instruction works. Of all 20 papers that used analysis of variance, 19 obtained significant between-group difference results, and one paper showed no significant difference due to VR instruction. This shows that the application of VR technology in the field of elementary education can generally enhance the effectiveness of teaching and learning and bring about a positive impact.

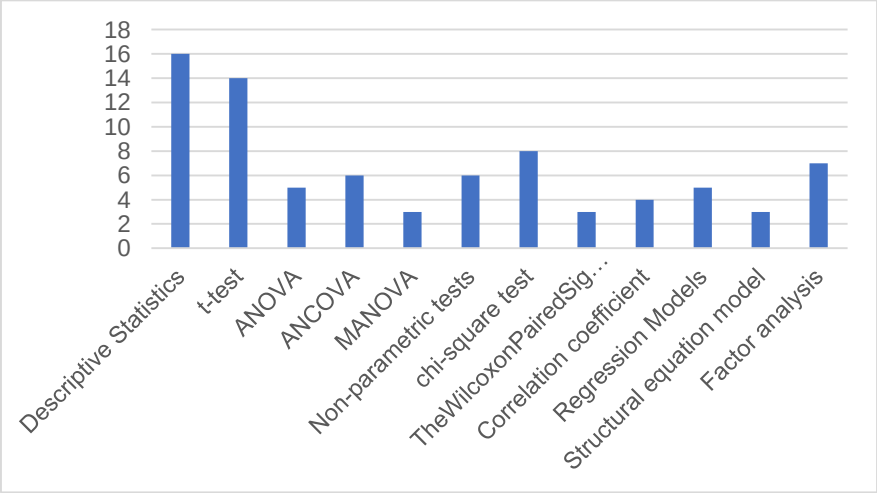

Figure 2 Frequency statistics of quantitative data analysis methods

3.3 Research Context

The subject distribution of VR applications in primary education is shown in Figure 3. The elementary school section mainly applies VR technology to mathematics, health education, and social science. Other subjects include informal subjects represented by STEAM education and creator education, such as exploring the behavior of teacher-student interaction in learning activities (Cheng & Tsai, 2019). Children's health education has always been a focus of social concern, and using VR technology to construct dangerous scenarios for skill training can avoid the potential dangers associated with real training. For example, students can enhance safety awareness and improve safety skills by practicing repeatedly in virtual scenarios such as simulated fire scenes (Çakiroğlu & Gökoğlu, 2019) and traffic intersections (Zhang et al., 2020). In addition, studies have begun to use VR in real classroom settings, such as music, English, and science classes (M.-P. Chen et al., 2022; Cheng & Tsai, 2019; Han, 2020; Liu et al., 2020), as well as to help students overcome public anxiety (Sülter et al., 2022).

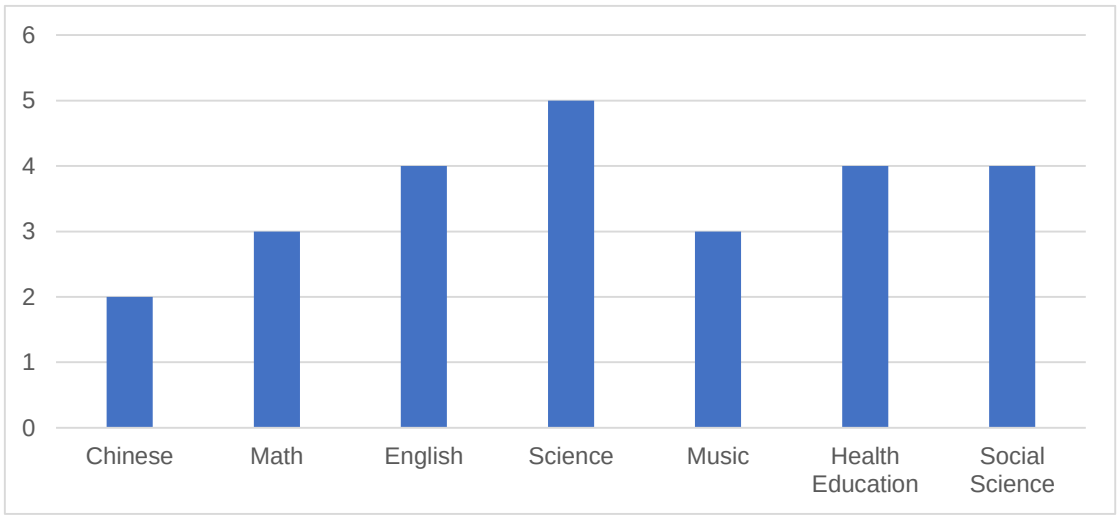

Figure 3 Statistics of VR application in basic education field by discipline

3.4 VR Technology Development

VR learning experience relies on devices such as computers, head-mounted displays and VR glasses, however, the learning experience brought by different devices varies greatly. In this paper, we analyzed the VR devices used in 26 papers. 2018 to date, VR glasses and head-mounted displays have rapidly developed and gradually become mainstream VR devices that support a fully immersive virtual experience (Pala et al., 2021). In addition to a high-quality immersive experience, portability is an important condition that determines the spread of VR devices in the classroom. However, there are only eight papers in the literature describing VR devices with portable features. VR teaching applications that satisfy immersion, interactivity, and portability simultaneously are relatively scarce and limited by high device prices. The imaginative nature of VR is reflected in the creation of virtual scenarios, such as historical events and dangerous scenarios, that are not available in real life or cannot be visited in person. However, 80% of VR scenarios in the literature are still based on the real world and do not take full advantage of the imaginative nature of VR. The reason for this may be that most VR teaching aims to develop students' ability to analyze and solve real problems, emphasizing the realism and relevance of problem situations.

4. ADVANTAGES AND CHALLENGES OF APPLYING VIRTUAL REALITY TECHNOLOGY IN PRIMARY EDUCATION

4.1 Advantages of virtual reality technology in primary education

The application of virtual reality technology in primary education includes four main advantages. First, the 3D immersive virtual

simulation user interface. The interface is conducive to enhancing the pleasure of learner participation (Makransky & Lilleholt, 2018) and the immersion of virtual scenarios (Ma, 2021), which enhances learners' interest and motivation in learning (Yang & Chen, 2020). Second, the anonymity of virtual images. This feature can reduce learners' learning anxiety, enhance learners' self-confidence, and thus promote interactive communication (Zhou et al., 2021). Third, the communication technology of real-time interaction. Learners can interact in real-time through various media such as voice, video, and text (Gao et al., 2016) to carry out social interaction and negotiation of meaning in real situations to enhance learning (Su & Zou, 2022). Fourth, task-oriented instructional design. Scientific and reasonable learning tasks will strengthen learners' practical and integrated application and enhance their interdisciplinary communication skills and learning outcomes.

4.2 Challenges of applying virtual reality technology in elementary school education

The main challenges faced by virtual reality technology in facilitating elementary school classroom teaching: First, the high requirements for network connectivity, the limitations of network broadband, and settings related to network security are likely to cause instability of network connectivity (Zheng et al., 2019) which in turn affects the effectiveness of real-time interaction. Second, the immersion and interactivity of VR technology applied to primary education are at a low level, and the high standard of software and hardware configuration, virtual reality technology to achieve a high degree of simulation, related software and hardware to achieve universal application, there is still a series of technical difficulties to overcome (Petersen et al., 2022). Third, new requirements for teachers. The fundamental condition for virtual reality technology to promote classroom teaching is the scientific and reasonable design of teaching activities, and the current operational difficulties of hardware and software and the complexity of learning task design require teachers to have stronger teaching design ability and higher technical literacy. Fourth, the cycle of VR teaching is generally short, its long-term teaching effect is unknown, and one-time teaching interventions are vulnerable to the novelty effect of VR technology (Wang & Huang, 2024). Whether students can continue to derive benefits from VR learning environments when VR becomes routine from new technology cannot be estimated. Therefore, in future studies, examining learning effects requires long-term observations to obtain more credible experimental results.

5. CONCLUSION AND REFLECTION

This study integrates empirical research on the application of virtual reality (VR) technology in primary education with an examination of the “3I” characteristics of VR immersion, interactivity, and imagination along with instructional design and evaluation trends over the past six years, to systematically analyze the relevant literature. Findings indicate that as VR technology and related equipment continue to advance, research interest in VR applications within elementary education has shown a marked upward trend. This research suggests that VR’s application in primary education generally enhances teaching effectiveness, creating more engaging and interactive learning environments. However, the study also identifies several limitations, including insufficient instructional guidance in current VR-based educational research, overly rigid teaching methods, and a narrow range of research approaches. These issues reduce the practical value of VR research findings as guidance for teaching practice in elementary education.

The effectiveness of VR technology in primary education ultimately depends on well-structured instructional design that aligns with specific teaching objectives, supporting a foundation for meaningful learning experiences (Ongoro & Fanjiang, 2024). Instructional designs should carefully consider differences in content and the characteristics of student groups, adjusting teaching strategies to fit these factors. For younger students, the focus of learning often centers on basic knowledge acquisition and the development of fundamental skills, making content presentation and hands-on practice more appropriate strategies for supporting these early-stage learning needs. In contrast, upper-grade students, who typically encounter more complex content requiring higher-order thinking, may benefit more from inquiry-based or collaborative learning strategies (Ješková et al., 2022; Lee et al., 2021). These approaches

are well-suited to students' growing abilities for independent exploration and group cooperation, enhancing engagement and deepening their understanding of the material (Chen, 2021; Saleh et al., 2022).

To enhance the robustness of future VR research in education, several methodological improvements could be implemented. Diverse data collection methods, standardized quantitative reporting, and thorough qualitative analyses can significantly enhance the reliability of findings, offering more scientifically grounded recommendations for VR's use in primary education. Through these measures, VR technology can be applied more effectively in educational contexts, supporting its broader adoption in ways that genuinely benefit students' learning and development.

6. LIMITATIONS OF THE STUDY

The findings from this systematic review should be approached with caution, as several limitations impact the overall robustness and applicability of the conclusions. First, the relatively small number of studies and the considerable diversity in their research designs, methodologies, and sample characteristics create challenges for synthesizing results. This diversity hinders the ability to establish a clear, consistent picture of the effectiveness of VR technology in primary education, making any generalizations tentative. Furthermore, with such methodological variability, comparing outcomes across studies is difficult, as each study may have used different metrics, instructional approaches, or VR platforms, which complicates an accurate assessment of VR's impact on learning outcomes.

Second, most of the studies reviewed were conducted within controlled laboratory environments, often under conditions that are not representative of typical classroom settings. Laboratory-based studies, while beneficial for isolating specific variables, may not capture the complexities, disruptions, and diverse learner needs present in real-world classrooms. Consequently, the findings observed in these controlled environments may not fully translate to primary education settings where logistical, behavioral, and environmental factors are more variable.

Lastly, practical barriers, such as the high cost associated with VR hardware and software, as well as the technical knowledge required for effective implementation, pose additional constraints on the adoption of VR in primary education. These financial and technical demands may place VR technology beyond the reach of many schools, particularly in underfunded or resource-limited settings. This limited accessibility could impede the equitable and widespread integration of VR technology into educational systems, potentially widening the gap between institutions with ample resources and those without.

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