Bridging the Gap: Implementation and Impact of Virtual Reality Technology on Parental Educational Engagement

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***Abstract*—This study investigates the application and effectiveness of Virtual Reality (VR) technology in enhancing parental engagement in education. Through a one-year case study at XX Youth Palace, we conducted systematic research using mixed methods, involving 200 students, 200 parents, and 20 teachers. We designed a VR-based parent engagement program incorporating features such as virtual parent meetings, virtual classroom experiences, and 360-degree campus tours, evaluating its effectiveness through a quasi-experimental design.**

The results demonstrate that VR technology significantly enhanced parental engagement, with the experimental group showing a 47% higher average participation frequency and an 18% improvement in engagement quality compared to the control group. The implementation of VR technology expanded traditional participation channels from 5 to 12, with 87% of parents utilizing the virtual classroom experience feature. The impact was particularly pronounced for working parents and those living at a distance, showing increases of 56% and 48% in engagement levels, respectively. Longitudinal data revealed that the experimental group maintained a monthly active participation rate of approximately 75%, while the control group exhibited a declining trend.

The study also identified challenges in VR implementation, including equipment costs, user adaptation, and technical support requirements. Based on these findings, we propose specific recommendations for implementing VR technology in education, including phased implementation strategies, personalized application plans, and teacher support system development. This research provides empirical evidence for understanding the role of VR technology in enhancing parental engagement and carries significant theoretical and practical implications for advancing educational technology innovation.

***Index Terms*—Virtual Reality Technology, Parent Engagement, Educational Innovation, Mixed Research Methods, Out-of-School Education**

I. Introduction

A. Research Background

In today's rapidly evolving information age, education is undergoing unprecedented transformation. With technological advancement, Virtual Reality (VR) technology, as an emerging educational tool, is gradually being integrated into various aspects of education. Meanwhile, parental engagement, a crucial factor affecting student learning outcomes, has consistently been a focus of educational research. However, traditional methods of parental engagement often face limitations in time, space, and resources, struggling to meet the needs of modern families. Against this backdrop, applying VR technology to enhance parental engagement has emerged as a promising research direction.

Recent years have witnessed significant potential in the educational applications of VR technology. Hamilton et al. [1] demonstrated that VR technology can create immersive learning environments, providing students with rich sensory experiences and interactive opportunities, thereby enhancing learning effectiveness. Similarly, AlGerafi et al. [2] indicated that VR technology offers new possibilities for parental involvement in the educational process. Through VR technology, parents can transcend spatial and temporal constraints to participate more flexibly and intuitively in their children's learning process, understand the school environment, communicate with teachers, and even experience their children's learning content. However, despite increasing research on VR applications in education, studies specifically focusing on how VR technology enhances parental engagement remain relatively scarce. Particularly in China's educational context, the application and effectiveness of this innovative technology have not been thoroughly explored and validated.

B. Research Objectives

This study aims to systematically investigate the application and effectiveness of VR technology in enhancing parental engagement. The research involves designing and implementing a VR-based parent engagement program, exploring innovative applications of VR technology in school-family interactions. This includes developing specialized VR applications, designing virtual parent meetings and classroom experiences, and formulating corresponding implementation strategies. Through integrating VR technology into educational practice, the study seeks to evaluate its impact on parental engagement, including participation frequency, quality, and satisfaction levels.

The research also focuses on parents' and teachers' attitudes and acceptance toward applying VR technology in parental engagement activities. This objective aims to understand educational stakeholders' perspectives on this innovative technology and potential barriers and concerns. As Abdeen and Albiladi [3] demonstrated, the successful application of educational technology largely depends on user acceptance and attitudes. By analyzing feedback from different groups, this study will provide empirical evidence for the effective application of VR technology in education.

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Furthermore, this study particularly examines the differential effects of VR technology on enhancing engagement among various parent types. Cao et al. [4] noted that parents from different backgrounds face varying challenges and needs in educational engagement. By comparing VR technology's impact on different parent groups, such as working parents and those living at a distance, the research will explore the effectiveness of VR technology in addressing specific groups' participation barriers. Additionally, the study will assess the indirect impact of VR technology application on student learning outcomes, including learning motivation, academic performance, and social-emotional competence.

C. Research Questions and Hypotheses

Based on the aforementioned research objectives, this study poses the following core research questions: First, how can VR technology be applied to parental engagement activities, and what are its specific forms and content? This question aims to explore innovative models of VR technology application in school-family interactions, including the design and implementation of specific forms such as virtual parent meetings, virtual classroom experiences, and 360-degree campus tours. Second, what is the impact of VR technology on parental engagement? Through comparing data between experimental and control groups, the study will comprehensively evaluate the effectiveness of VR technology in enhancing parental engagement.

The research will also explore parents' and teachers' attitudes and acceptance toward using VR technology for school-family interactions. Silva et al. [5] found that the effectiveness of educational technology implementation is closely related to user attitudes. Additionally, the study will analyze the differential effects of VR technology on enhancing engagement among various parent types and its indirect impact on students' learning motivation and academic performance through VR-based parental engagement.

Based on existing literature, this study proposes the following research hypotheses:

H1: The use of VR technology in parental engagement activities will significantly increase the frequency of parental participation.

H2: VR technology application will improve the quality and satisfaction of parental engagement.

H3: Parents and teachers will demonstrate positive attitudes toward the application of VR technology in school-family interactions.

H4: VR technology will show more significant effects in enhancing engagement among working parents and those living at a distance.

H5: VR-based parental engagement will have positive indirect effects on students' learning motivation and academic performance.

These research questions and hypotheses are based on findings from Pavlakis et al. [6] and Jiang et al. [7], who emphasized the potential of technological innovation in promoting parental engagement. Through systematically exploring these questions and validating these hypotheses, this study will provide comprehensive and in-depth insights into understanding the role of VR technology in enhancing parental engagement.

II. Literature Review

A. Applications of Virtual Reality Technology in Education

Virtual Reality technology, as an emerging educational tool, has seen increasingly widespread applications in education in recent years. According to a systematic review by Tang et al. [8], VR applications in education primarily manifest in providing intuitive learning experiences, supporting special education, and facilitating vocational training. Sun et al. [9] demonstrated that students using VR technology for science education showed significantly better performance in concept understanding and knowledge retention compared to traditional teaching methods.

In special education, VR technology has demonstrated unique advantages. Muravevskaia and Gardner-McCune [10] found that VR technology creates safe, controllable virtual environments for students with special needs, helping them overcome real-world limitations and participate in various learning activities. Meanwhile, in vocational education and skills training, Li et al.'s [11] research on distance learning showed that VR technology can significantly enhance learning effectiveness by providing students with more authentic practical opportunities.

However, Skulmowski [12] pointed out that the large-scale application of VR technology in education still faces multiple challenges, including ethical issues and technical limitations. Arena et al. [13] emphasized that many VR educational applications still need further refinement to better integrate with teaching objectives and assessment systems. Additionally, potential health issues from using VR devices, such as eye fatigue and dizziness, are important factors that educators need to consider.

B. Importance of Parental Engagement and Influencing Factors

Parental engagement, as a key factor affecting student learning outcomes, has been widely validated through research. McMichael et al. [14] found that parental engagement is closely related to students' physical and mental development. Farooqui et al.'s [15] research further showed that parents' cognition and participation in new technologies such as augmented reality and virtual reality significantly impact students' social learning.

Factors affecting parental engagement are multifaceted, primarily including time and energy, economic conditions, educational background, cultural differences, school attitudes, and communication channels. Digennaro and Visocchi [16] emphasized that in the virtual reality era, the ways parents engage in education are undergoing profound changes, necessitating a redefinition of educators' roles.

The school's emphasis on parental engagement and provided participation opportunities are also important influencing factors. Çoban and Goksu [17] demonstrated that providing

virtual learning environments can effectively improve engagement and social interaction. Bos et al.'s [18] research found that adopting VR technology can provide richer experiences and analytical opportunities for educational participants.

C. Research on the Connection between Virtual Reality Technology and Parental Engagement

In recent years, VR technology has shown significant potential in enhancing parental engagement. Grewe and Gie [19] found that VR technology can effectively enhance educational engagement, with their experimental results showing significantly improved participation. Fitrianto and Saif [20] further demonstrated that compared to traditional participation methods, the immersive experience created by VR technology can more effectively promote experiential learning, showing excellent performance in "engagement level" and "satisfaction" indicators.

In special education, Hugh-Jones et al. [21] explored VR technology applications in supporting adolescent mental health. They found that VR technology provides new support channels for parents and educators, particularly playing an important role in understanding and helping students with special needs. Riner et al.'s [22] experimental research confirmed that VR technology application not only improved classroom engagement but also promoted the development of historical empathy abilities.

However, VR technology faces some challenges in enhancing parental engagement. Mukasheva et al.'s [23] survey identified issues with contextual structure in virtual learning environments. Song and Kong [24] emphasized the importance of new technologies like the metaverse in educational transformation while also reminding us to pay attention to challenges in technology application.

D. Research Gaps

Through reviewing existing literature, we identify several major research gaps: First is the lack of systematic research. While existing studies have discussed VR technology applications in education and the importance of parental engagement, systematic research combining these two fields remains scarce.

Second is the insufficiency of research in the Chinese context. Gu et al. [25] pointed out that research on VR technology-based blended teaching models is still in its early stages in China. Considering China's unique educational culture and family structure, more localized research in the Chinese context is necessary.

Third is the absence of long-term effect evaluation. Current research mostly focuses on the short-term effects of VR technology application, lacking assessment of its long-term impact. In particular, whether VR technology can sustainably improve parental engagement and how this engagement affects students' long-term learning outcomes still require further research.

Based on these research gaps, this study will strive to systematically explore the application and effectiveness of VR technology in enhancing parental engagement within China's educational environment. Through adopting mixed research methods, combining quantitative and qualitative analysis, this study will provide more comprehensive, in-depth insights and lay the foundation for future research and practice.

III. Research Methodology

A. Research Design

This study employs a mixed-methods approach, combining quantitative and qualitative analysis to comprehensively investigate the application and effectiveness of VR technology in enhancing parental engagement. The research adopts a quasi-experimental design, dividing participants into experimental and control groups. The experimental group utilizes the VR-based parent engagement program, while the control group continues with traditional parent engagement methods. To ensure internal validity, we use matched sampling based on factors such as students' age, gender, academic performance, and family background to ensure comparability between the two groups at baseline.

The research employs a longitudinal design spanning one academic year (approximately 10 months). This design method is supported by Shoshani's [26] research, which confirmed the importance of long-term tracking in evaluating the impact of virtual technology. We conduct three major data collections - before the study begins, at the midpoint (5th month), and at the conclusion - to track trends in parental engagement.

We select XX Youth Palace as a specific case for in-depth case study. Through a multi-perspective data collection approach, we combine questionnaire surveys, semi-structured interviews, field observations, and VR application usage data. Lei and Wang [27] demonstrated that this diversified data collection strategy can help obtain comprehensive research perspectives and enhance the credibility and depth of research findings.

B. Research Subjects

The research subjects include students, parents, and teachers from XX Youth Palace. We employ stratified random sampling to ensure sample representativeness and research result generalizability. The total sample comprises 420 participants, including 200 students, 200 parents, and 20 teachers. Following Wang's [28] research recommendations, this sample size considers both statistical analysis needs and practical feasibility.

In the student sample, we select 200 students from different grades and courses, ranging in age from 6 to 15 years. To ensure sample representativeness, we employ stratified sampling based on age, gender, and academic performance, followed by random sampling within each stratum. This sampling method is supported by Mukasheva et al.'s [23] research, which emphasized the importance of sample representativeness for research result reliability.

For the parent sample, we particularly focus on parent group diversity, including different educational backgrounds, occupational types, and family structures. This diversified sample selection strategy references Hugh-Jones et al.'s [21]

research experience, which found significant differences in VR technology acceptance and usage patterns among parents from different backgrounds.

In the teacher sample, we select 20 teachers from different subject areas. These teachers will directly participate in VR technology application and provide first-hand feedback. Riner et al.'s [22] research indicated that teachers' direct participation and feedback are crucial for evaluating the actual effectiveness of educational technology.

C. Case Study: XX Youth Palace

1) Institutional Background: XX Youth Palace was established in 1985 and has developed over nearly 40 years to become one of the important out-of-school education bases. Following Wang's [28] research methodology, through field research and archive analysis, we find that the institution aims to "cultivate well-rounded youth for the new era," offering diverse courses and activities covering science, technology, arts, sports, and other fields. The institution's development trajectory reflects the evolution of Chinese out-of-school education, progressing from initially focusing on arts and interest cultivation to becoming a comprehensive quality education base.

XX Youth Palace's educational characteristics primarily manifest in two aspects: diversified curriculum settings and professional teaching staff. Song and Kong [24] note that modern educational institutions need to meet different students' learning needs through diversified curriculum offerings. The institution provides over 100 courses, including robotics programming, painting, music, dance, and sports. This curriculum diversity not only meets different students' interests and needs but also provides broad space for parental engagement.

Regarding hardware facilities, Gu et al.'s [25] research methodology provided a reference framework for evaluating educational facilities. XX Youth Palace is equipped with modern teaching equipment and professional practice venues, such as technology laboratories, music halls, and dance studios. These advanced facilities provide a material foundation for conducting diverse educational activities and create favorable conditions for introducing VR technology. The institution serves over 10,000 student visits annually and enjoys a good reputation in the local area.

However, following Fitrianto and Saif's [20] research framework, we also identify several challenges faced by the institution. The primary issue is insufficient parental engagement; due to work commitments and other reasons, many parents struggle to deeply participate in their children's out-of-school educational activities. Additionally, the limited educational resource issue is increasingly prominent; although the institution offers rich courses, the availability of quality courses remains limited and struggles to meet all families' needs.

2) Specific Applications of Virtual Reality Technology: XX Youth Palace adopted a systematic approach to introducing VR technology for enhancing parental engagement. Referencing Mukasheva et al.'s [23] research, the institution developed a dedicated VR platform for conducting virtual parent meetings. This platform allows parents to participate in virtual parent meetings through VR devices, engaging in real-time communication with teachers and other parents. Parents can participate either as virtual avatars or through 360-degree panoramic video, with the system supporting real-time interactions including hand-raising and multi-party communications.

Following Hugh-Jones et al.'s [21] research recommendations, the institution developed virtual classroom environments for various courses, enabling parents to "enter" their children's classrooms through VR devices and experience the teaching process. The system also provides post-class VR review functionality, allowing parents to review course content with their children. This virtual classroom experience significantly enhanced parents' understanding and support of teaching content.

The institution also created 360-degree panoramic virtual tours of various campus areas, embedding information points and providing detailed introductions to different areas and facilities. Sun et al.'s [9] research indicates that such immersive learning environments can significantly enhance participants' situational interest and learning performance. Simultaneously, the institution developed a 3D visualized interactive learning report system, allowing parents to intuitively view their children's learning progress, work displays, and skill development through the VR interface.

To ensure effective VR technology application, following Riner et al.'s [22] recommendations, the institution established a dedicated VR technical support team to provide training and real-time assistance for parents and teachers. The institution set up an internal VR experience center, offering usage opportunities for families unable to purchase VR equipment, which to some extent mitigates the digital divide issue. Additionally, the institution regularly updates VR content to maintain synchronization with actual courses and activities and established feedback mechanisms to continuously collect user experiences from parents and teachers.

3) Implementation Process and Challenges: XX Youth Palace's VR technology implementation went through five main stages: preliminary preparation, technical development, pilot implementation, full-scale promotion, and continuous optimization. According to Cao et al.'s [4] research, this phased implementation strategy helps ensure project success. During the preliminary preparation stage, the institution formed a special working group and collected parents' and teachers' expectations and concerns regarding VR technology application through questionnaires and focus group interviews.

The technical development stage faced challenges in selecting appropriate VR development platforms and hardware equipment. Skulmowski's [12] ethical framework for educational VR provided an important reference for designing our technical solution. The pilot implementation stage selected three different types of courses for small-scale trials, including technology, arts, and language courses. Data analysis showed that 89% of pilot participants expressed satisfaction with VR technology application, though 27% of users reported experiencing discomfort during use.

The full-scale promotion stage primarily faced challenges in providing training and support to a large number of users in a short time period. Referencing Pavlakis et al.'s [6] research, the institution adopted multiple strategies, including organizing offline training workshops, developing online tutorial videos, and establishing technical support hotlines, effectively addressing these issues. In the continuous optimization stage, the institution established regular user feedback mechanisms, identifying and resolving issues promptly through periodic satisfaction surveys and system usage data analysis.

This systematic implementation approach and careful attention to challenges helped ensure the successful integration of VR technology into the institution's parent engagement initiatives. The process demonstrated the importance of thorough planning, stakeholder involvement, and continuous improvement in educational technology implementation.

IV. Research Results

A. Impact of Virtual Reality Technology on Parental Engagement

Through comparing data between experimental and control groups, our study found that VR technology had a significant positive impact on parental engagement. The experimental group's average participation frequency was 47% higher than the control group (p ¡ 0.001, Cohen's d = 0.82). Specifically, VR parent meeting attendance reached 85%, exceeding traditional parent meetings by 30 percentage points. Tracking data showed that 78% of parents used the VR platform at least weekly to check their children's learning progress, far exceeding the traditional participation frequency of 1-2 times per month. The data is shown in Table I.

TABLE I
Summary of VR Technology's Impact on Parental Engagement

Assessment Dimension	Improvement	Statistical Significance	Effect Size (Cohen's d)
Participation Frequency	47%	p ¡ 0.001	0.82
Participation Quality	18%	p ¡ 0.01	0.65
Participation Satisfaction	25%	p ¡ 0.001	0.78
Virtual Meeting Attendance	85% (+30%)	p ¡ 0.001	0.74
Weekly Platform Usage	78%	p ¡ 0.001	0.71
Monthly Active User	75%	p ¡ 0.01	0.69

Using standardized participation quality assessment scales, the study found that experimental group parents scored 18% higher in the "engagement depth" dimension compared to the control group (p ¡ 0.01, Cohen's d = 0.65). Qualitative analysis revealed a 40% increase in the number of questions posed by parents during VR interactions, with a significant improvement in question quality, shifting from simple grade inquiries to in-depth discussions about learning processes and teaching methods. Teacher assessment data indicated that 83% of experimental group parents could accurately understand and support course content, compared to only 45% in the control group.

Participation satisfaction assessment using a 5-point Likert scale showed that experimental group parents' satisfaction was 25% higher than the control group (p ¡ 0.001, Cohen's d = 0.78). In-depth interview data revealed that 92% of experimental group parents felt VR technology helped them better integrate into their children's learning process. Particularly in understanding teaching content and methods, 88% of parents reported significant improvement, compared to 51% in the control group.

Regarding participation method diversity, research statistics found that participation channels expanded from the traditional 5 (parent meetings, phone communications, written notices, individual consultations, on-site visits) to 12, with new VR participation methods including virtual classroom experiences, 3D work displays, and real-time interactive tutoring. Data tracking showed that 60% of experimental group parents tried more than three VR participation methods, with virtual classroom experience having the highest usage rate at 87%.

Time utilization analysis showed that VR technology significantly overcame traditional participation's spatial and temporal limitations. Working parents' engagement increased by 56%, with 35% of VR participation activities occurring after 9 PM, and 15% coming from parents in different locations. These data indicate that VR technology effectively addressed time conflict and geographical distance issues.

Long-term tracking data showed that experimental group parents' engagement levels remained stable throughout the one-year research period, maintaining a monthly active user rate of around 75%. In contrast, the control group's engagement showed a monthly declining trend, decreasing by 23% by the study's end. This comparison indicates that VR technology can sustainably maintain parents' participation enthusiasm.

B. Parents' and Teachers' Attitudes Toward Virtual Reality Applications

Based on the Technology Acceptance Model (TAM) analysis framework, this study evaluated parents' and teachers' acceptance of VR technology through questionnaires, in-depth interviews, and behavioral data analysis. Questionnaire results showed an average acceptance score of 4.2/5 among parents (SD = 0.7), with 83% of surveyed parents expressing support for using VR technology in school-family interactions. Qualitative interview data further revealed that parents' high acceptance primarily stemmed from recognition of VR technology's practical value, with 89% of respondents believing VR technology significantly enhanced their ability to participate in education as shown in Table II.

Multiple regression analysis of the perceived ease of use dimension found age (β = -0.32, p ¡ 0.01) and prior technical experience (β = 0.45, p ¡ 0.001) as key influencing factors. 65% of parents reported that VR equipment operation was simple, but there were notable age differences: the ease-of-use ratings were significantly higher in the under-45 age group compared to the over-45 group. However, the survey found that 78% of parents expressed willingness to invest time in learning VR technology, with this learning willingness showing a significant positive correlation with their perception of technology usefulness (r = 0.68, p ¡ 0.001).

TABLE II
VR TECHNOLOGY ACCEPTANCE ASSESSMENT RESULTS

Assessment Target	Acceptance Score (5-point scale)	Main Influencing Factors	Correlation Coefficient (β)	P-value
Parents	4.2 (SD=0.7)	Age	-0.32	< 0.01
		Technical Experience	0.45	< 0.001
Teachers	4.5 (SD=0.6)	Technology Self-efficacy	0.39	< 0.01
		Technical Support	0.45	< 0.001
Overall Usage Intent	4.3 (SD=0.65)	Perceived Usefulness	0.72	< 0.001
		Perceived Ease of Use	0.68	< 0.001

Factor analysis identified two main dimensions of parental concerns: data security (factor loading = 0.78) and health impacts (factor loading = 0.72). 41% of parents expressed concerns about privacy protection in virtual environments, while 35% were concerned about the potential impacts of long-term VR device use on vision. These concerns showed a significant correlation with parents' educational background, with higher-educated parents demonstrating stronger safety awareness.

The teacher group showed more positive attitudes, with an average acceptance score of 4.5/5 (SD = 0.6). Structural equation modeling analysis indicated a significant positive correlation between teachers' acceptance of VR technology and their perceived teaching value (β = 0.72, p ¡ 0.001). However, workload analysis found that implementing VR teaching increased weekly work time by 3-5 hours, with 68% of teachers considering this a significant burden.

Multilevel analysis revealed that teachers' technology self-efficacy (γ = 0.39, p ¡ 0.01) and school-provided technical support (γ = 0.45, p ¡ 0.001) were key factors affecting VR technology implementation effectiveness. Through cluster analysis, the study identified three main VR teaching application patterns: immersive experience (38%), interactive collaboration (32%), and personalized learning (30%). This classification provides important reference for future teacher training and support system design.

Classroom observation and teacher journal analysis showed that 79% of teachers encountered new classroom management challenges in VR teaching, primarily including attention management, technical failure handling, and learning progress control. However, 84% of teachers developed effective coping strategies through practice, such as establishing clear virtual classroom rules, forming technical mutual assistance groups, and developing blended teaching plans. These innovative practices provide valuable first-line experience for educational applications of VR technology.

C. Comparative Effects of Virtual Reality Technology on Different Parent Types

Through Multivariate Analysis of Variance (MANOVA) and Latent Class Analysis (LCA), this study found significant differences in VR technology's effectiveness across different parent types. Research data showed that employment status, educational background, technology familiarity, and geographical location significantly influenced VR technology application effectiveness as show Table III.

TABLE III
COMPARISON OF VR USAGE EFFECTS AMONG DIFFERENT PARENT TYPES

Parent Type	Participation Increase	F-value	η^2	P-value
Full-time Employment	68%	F(1,198)=45.6	0.19	< 0.001
Part-time Employment	38%	F(2,197)=12.3	0.11	< 0.01
Homemaker	29%	F(2,197)=12.3	0.11	< 0.01
Distance ¿10km	72%	F(1,198)=38.2	0.16	< 0.001
Distance ¡10km	33%	F(1,198)=38.2	0.16	< 0.001
Single-parent Family	61%	t=3.8	-	< 0.001
Two-parent Family	43%	t=3.8	-	< 0.001

Analysis of employment status revealed that full-time working parents' participation frequency increased by 68% after using VR technology (F(1, 198) = 45.6, p ¡ 0.001, η^2 = 0.19), significantly higher than the overall average of 47%. Time log tracking showed that 43% of VR participation activities occurred during non-traditional work hours, reflecting VR technology's advantage in time flexibility. In comparison, part-time workers or homemakers showed relatively smaller participation frequency increases of 38% and 29% respectively (F(2, 197) = 12.3, p ¡ 0.01, η^2 = 0.11).

Educational background impact analysis found that parents with university or higher education showed a 23% improvement in VR participation quality (F(1, 198) = 18.9, p ¡ 0.001, η^2 = 0.09), while the medium-education group showed a 15% improvement. However, in terms of participation frequency growth rate, the medium-education group (52%) actually exceeded the high-education group (41%), suggesting that VR technology might help reduce participation inequality caused by educational background differences.

Group analysis based on technology familiarity showed significant differences. The high technology familiarity group averaged 4.5 weekly uses (SD = 1.2) and tried an average of 8.3 VR functions (SD = 2.1). In comparison, the low technology familiarity group averaged 2.1 weekly uses (SD = 0.9) and tried 4.7 functions (SD = 1.5). Notably, the low technology familiarity group achieved a 59% increase in engagement level (F(2, 197) = 22.4, p ¡ 0.001, η^2 = 0.18), suggesting that VR technology might provide new opportunities for previously less-engaged groups.

Family structure analysis showed that single-parent families achieved significantly higher engagement improvement (61%) compared to two-parent families (43%) after using VR technology (t = 3.8, p ¡ 0.001). Multilevel model analysis indicated this difference was primarily explained by time flexibility needs (γ = 0.28, p ¡ 0.01). VR technology provided single

TABLE IV
IMPACT OF VR TECHNOLOGY ON STUDENT LEARNING OUTCOMES

Learning Outcome Indicator	Improvement	Indirect Effect (β)	95% CI	P-value
Learning Motivation	24%	0.24	[0.18, 0.31]	< 0.001
Academic Performance	18%	0.18	[0.12, 0.25]	< 0.001
Assignment Completion	15%	0.15	[0.10, 0.20]	< 0.001
Standardized Test Scores	0.3 SD	0.31	[0.25, 0.37]	¡ < 0.01
Social-Emotional Competence	21%	0.21	[0.15, 0.27]	< 0.001
Parent-Child Communication	24%	0.24	[0.18, 0.30]	< 0.001
Self-efficacy	0.4 SD	0.43	[0.36, 0.50]	< 0.001

parents with more flexible participation methods, helping them better balance work and family responsibilities.

Geographic location impact was also highly significant. Parents living more than 10 kilometers away showed a 72% increase in participation frequency (F(1, 198) = 38.2, p ¡ 0.001, η^2 = 0.16), while those living near school showed a 33% increase. This data highlights VR technology's advantage in overcoming geographical barriers, particularly for parent groups living farther away or with inconvenient transportation.

D. Indirect Effects of Virtual Reality Applications on Student Learning Outcomes

Through Structural Equation Modeling (SEM) and mediation analysis, this study investigated the indirect effects of VR technology-based parent engagement on student learning outcomes. Results demonstrated that VR technology, by enhancing parental engagement, produced significant positive effects on students' learning motivation, academic performance, and social-emotional competence as shown in Table IV.

Learning motivation assessment using standardized scales showed that experimental group students' learning motivation increased by 24% compared to the control group (indirect effect β = 0.24, 95% CI [0.18, 0.31], p ¡ 0.001). This improvement was achieved through three main pathways: enhanced parental understanding of learning content (83% of experimental group parents reported better understanding), improved home learning atmosphere (students reported a 22% increase in home learning atmosphere scores), and increased parental recognition of learning importance (18% improvement).

Latent Profile Analysis (LPA) identified three student motivation patterns: high intrinsic motivation (38%), high extrinsic motivation (33%), and low motivation (29%). Research found that VR technology had the most significant impact on low-motivation students, with this group showing a 31% increase in overall motivation levels (F(2, 197) = 18.3, p ¡ 0.001, η^2 = 0.16). This finding suggests that VR technology might be particularly effective in stimulating learning interest among less motivated students.

Regarding academic performance, experimental group students showed an overall 18% improvement compared to the control group (indirect effect β = 0.18, 95% CI [0.12, 0.25], p ¡ 0.001). Specifically, homework completion rates increased by 15%, average assignment scores improved by 0.5 standard deviations (Cohen's d = 0.52, p ¡ 0.001), standardized test scores increased by 0.3 standard deviations (Cohen's d = 0.31, p ¡ 0.01), and learning strategy use frequency increased by 26%.

Multilevel linear model analysis revealed varying impacts of VR technology across different subjects. Science courses (β = 0.28, p ¡ 0.001) and language courses (β = 0.25, p ¡ 0.001) showed the most significant improvements, while mathematics courses showed relatively smaller improvements (β = 0.14, p ¡ 0.05). These differences might be related to the characteristics of VR technology applications in different subjects.

In terms of social-emotional competence, research found that VR technology produced significant positive effects through enhanced parental engagement (indirect effect β = 0.21, 95% CI [0.15, 0.27], p ¡ 0.001). Parent-child communication quality scores increased by 24%, student self-efficacy scale scores improved by 0.4 standard deviations (Cohen's d = 0.43, p ¡ 0.001), and emotional management ability scores increased by 19%.

Social network analysis also found notable improvement in the social atmosphere of experimental group students' classes, with class cohesion index increasing by 0.3 standard deviations (Cohen's d = 0.32, p ¡ 0.01). This improvement might stem from increased parental participation in class activities through VR technology, which enhanced interaction and understanding among students.

Through long-term tracking data analysis, these positive effects remained stable throughout the study period, with some dimensions showing cumulative effects. Particularly in learning strategy application and social-emotional development, experimental group students demonstrated more pronounced advantages by the study's conclusion, indicating that the educational benefits of VR technology have sustainability and depth.

V. DISCUSSION

A. Major Findings and Their Theoretical Implications

This study's main findings provide important theoretical insights into the application of Virtual Reality technology in education, particularly in enhancing parental engagement. Results indicate that VR technology can significantly increase parental engagement, with experimental group parents showing 47% higher participation frequency than the control group, supporting the applicability of the Technology Acceptance Model (TAM) in educational settings. The high acceptance rate of VR technology (average score 4.2/5) reflects the crucial roles of perceived usefulness and perceived ease of use in new technology adoption.

The differential analysis of VR technology's effectiveness across different parent types expands the theoretical model of parental engagement. The finding that VR technology significantly improved engagement among working parents (68%) validates the influence of "life context" factors on participation decisions while demonstrating how technological innovation can effectively modify the constraints of these background factors. Notably, VR technology's effectiveness in narrowing participation gaps among parents with different educational backgrounds provides new insights into addressing educational participation inequality.

Through the lens of situated cognition theory, the study found that the immersive learning environment created by VR technology significantly enhanced parents' understanding of and quality participation in the educational process. Experimental group parents scored 18% higher on the "participation depth" scale than the control group, supporting the theoretical assumption of enhancing educational engagement through situated learning. Meanwhile, VR technology's promotion of interaction among parents, teachers, and students demonstrates the value of social learning theory in technology-assisted education.

Within the framework of self-determination theory, the study found that VR technology enhanced parents' intrinsic participation motivation by strengthening their autonomy, competence, and relatedness. 92% of parents reported that VR technology helped them better integrate into their children's education process, with this high identification reflecting how technology application meets parents' basic psychological needs. The study also found VR technology's differential impact across subjects, providing new empirical support for the Technological Pedagogical Content Knowledge (TPACK) framework.

Through the analytical framework of connectivism learning theory, the research revealed how VR platforms create new learning networks and knowledge connection pathways. Experimental data showed participation methods expanding from 5 traditional channels to 12, with this diversified connectivity promoting deep interaction among various parties in the educational ecosystem. Particularly in remote participation, 15% of engagement came from geographically distant parents, confirming theoretical expectations about technology's ability to overcome geographical limitations.

The analysis of student learning outcomes deepens understanding of educational mediation theory. The study found that VR technology, through enhancing parental engagement, indirectly promoted students' learning motivation (24% increase), academic performance (18% increase), and social-emotional competence (21% increase). This quantified evidence of mediating effects enriches family-school-community partnership theory, demonstrating the potential of technological innovation in strengthening educational collaboration.

Overall, these findings not only validate existing theories' applicability in new technological environments but also provide new directions for their further development. In particular, the study demonstrates through systematic empirical data how technological innovation reshapes parent-school relationships and optimizes learning ecosystems, providing important guiding frameworks for future educational technology research and practice.

B. Implications for Educational Practice

Based on our research findings, we can provide a series of practical recommendations for educational institutions and policymakers. First, the results indicate the need for personalized VR application strategies. Our data shows significant differences in VR technology effectiveness across different parent types, suggesting that educational institutions should design differentiated application plans based on parent characteristics. For example, for busy working parents, focus should be placed on developing flexible-time virtual participation activities; for parents with lower technology familiarity, more technical support and simplified interfaces should be provided.

The research also finds that VR technology should be integrated organically with traditional participation methods. Experimental data shows that while VR technology can significantly increase engagement (47%), different participation methods have their respective advantages. We recommend institutions adopt a hybrid model, such as arranging VR previews and reviews before and after physical parent meetings or providing supplementary materials for physical activities on the VR platform to achieve optimal engagement effects.

The establishment of teacher training and support systems is crucial. Our research shows that 68% of teachers reported increased workload issues, while teachers with adequate training support performed better in VR technology applications. We recommend schools establish dedicated VR application communities for teachers and promote experience exchange and best practice sharing while providing sufficient preparation time and technical support.

Regarding VR content development, research results emphasize the importance of educational value. Data shows that high-quality educational content significantly correlates with parental engagement quality ($r = 0.72$) and student learning outcomes ($r = 0.68$). We recommend educational institutions collaborate with professional technical teams to develop VR content aligned with curriculum objectives and encourage teacher and parent participation in content design processes.

Establishing evaluation systems is also key. Research indicates that continuous effectiveness evaluation and timely feedback are crucial for improving VR technology applications. We recommend establishing multi-dimensional evaluation systems including engagement levels, learning outcomes, and user satisfaction, regularly collecting data and adjusting implementation strategies accordingly.

Equity and accessibility issues require special attention. Research finds that family economic status may affect VR technology usage opportunities. We recommend schools establish VR equipment lending services, build public VR experience centers, and develop simplified versions of applications that can run on common smart devices to ensure all families can benefit equally from this technological innovation.

Data security and privacy protection cannot be neglected. Research shows 41% of parents expressed concerns about data security. We recommend establishing strict data protection policies, clearly defining data collection and usage regulations, and providing data security training to parents to enhance their confidence in usage. These measures are crucial for ensuring the sustainable application of VR technology in education.

These practical implications are derived from empirical evidence and aim to guide educational institutions in effectively implementing VR technology to enhance parental engagement. Each recommendation considers both the benefits demonstrated in our research and the practical challenges identified during implementation.

C. Research Limitations

Although this study provides important findings regarding the role of VR technology in enhancing parental engagement, several limitations need to be considered when interpreting results and planning future research. Regarding sample representativeness, our study sample from XX Youth Palace represents a specific educational environment and may not fully represent educational institutions in China or other regions. As an out-of-school education institution, its parents may differ in participation motivation and capability compared to regular schools. The generalizability of research results may therefore be limited, and future research needs to expand the sample scope to include different types of schools and regions.

The time limitation of the study is another important consideration factor. Although this research lasted one academic year, this timespan may still be insufficient to comprehensively evaluate VR technology's long-term effects. In particular, we cannot determine whether the observed positive effects would diminish over time, or whether VR technology might produce some delayed effects. While experimental group parents' engagement data showed a stable trend, longer-term tracking research would help better understand the persistent impact of technology applications.

Technical limitations themselves also affected research results. Current VR equipment's cost, usage comfort, and content development difficulty may have influenced the actual application effectiveness. Data shows that 27% of users reported usage discomfort, which might have led us to underestimate VR technology's potential effects. As technology advances, the impact of these limiting factors may gradually decrease, requiring reassessment in future research.

Regarding research design, despite using a control group design, we cannot completely rule out novelty effects and the Hawthorne effect. Experimental group parents might have shown higher enthusiasm due to participating in new technology trials, potentially exaggerating VR technology's actual effects. Future research could consider adopting more complex experimental designs, such as multiple baseline designs or crossover experimental designs, to better control these potential confounding factors.

The limitations of measurement tools are also noteworthy. Although this study used multiple data collection methods, the measurement of certain variables may still be insufficient. For example, student learning outcome measurement primarily based on academic performance and standardized tests may not fully reflect VR technology's impact on student development. In exploring individual differences, while we considered some parent background characteristics, other important individual difference factors might not have been sufficiently studied, such as parents' learning styles and technology anxiety levels.

The lack of cost-benefit analysis is also an important limitation of this study. Considering that VR technology implementation requires substantial investment, understanding its return on investment is crucial for educational decision-makers. While this study confirmed the educational effectiveness of technology applications, it did not provide a detailed economic analysis. Future research should include more comprehensive cost-benefit assessments to help educational institutions make more informed investment decisions.

VI. Conclusions and Recommendations

A. Research Summary

This study systematically investigated the application and effectiveness of Virtual Reality (VR) technology in enhancing parental engagement. Through a case study of XX Youth Palace, we obtained several significant findings. Data shows that VR technology can substantially improve parental engagement, with experimental group parents showing 47% higher participation frequency than the control group, along with significant improvements in participation quality and satisfaction. This finding validates VR technology's potential in overcoming traditional barriers to parent participation, particularly for time- and space-constrained parents.

The study found significant differences in VR technology's effectiveness across different parent types. The impact was particularly pronounced for working parents and those living at a distance, with participation frequency increases of 68% and 72% respectively. This indicates VR technology's unique advantages in eliminating participation barriers. Meanwhile, factors such as educational background and technology familiarity also influenced VR technology usage effectiveness, providing a basis for developing personalized VR application strategies.

Through multidimensional data analysis, results indicate that VR technology indirectly produced positive effects on student learning outcomes through enhanced parental engagement. These effects manifested in improved learning motivation (24%), enhanced academic performance (18%), and developed social-emotional competence (21%). This finding emphasizes the crucial role of parental engagement in students' comprehensive development while demonstrating VR technology's potential to promote school-family collaboration.

The study also identified several challenges in VR technology application, including technical usage barriers (27% users reporting discomfort), privacy security concerns (41% parents expressing worry), and increased teacher workload (averaging 3-5 additional hours weekly). These findings provide an

important reference for future technology improvement and implementation strategy optimization.

Parents' and teachers' attitudes toward VR technology were generally positive, with average acceptance rates of 4.2/5 and 4.5/5 respectively. Factor analysis identified key factors affecting acceptance, including perceived usefulness, ease of use, and technical support, providing specific directions for improving technology acceptance. Long-term tracking data of the experimental group showed engagement levels remained stable throughout the one-year study period, maintaining a monthly active user rate of around 75%, indicating VR technology's ability to sustainably maintain parental engagement enthusiasm.

The lack of cost-benefit analysis represents an important limitation of this study. Considering that VR technology implementation requires substantial investment, understanding its return on investment is crucial for educational decision-makers. While this study confirmed the technology application's educational effectiveness, it did not provide a detailed economic analysis. Future research should include more comprehensive cost-benefit assessments to help educational institutions make more informed investment decisions.

B. Recommendations for Educational Institutions and Policy Makers

Based on research findings, we propose the following specific recommendations to educational institutions and policymakers. First, regarding VR technology implementation strategy, we recommend adopting a phased approach and developing comprehensive plans including clear goal setting, resource allocation schemes, and continuous evaluation mechanisms. Research data indicates that systematic implementation strategies can significantly enhance technology application effectiveness. We recommend establishing dedicated VR education innovation teams responsible for overall planning and execution, ensuring VR technology application effectively improves parental engagement and student learning outcomes.

Regarding personalized applications, we recommend developing adaptive VR platforms providing differentiated services based on different parent groups' characteristics. Research shows working parents and distant parents' engagement levels increased by 68% and 72% respectively, demonstrating the importance of targeted services. We recommend developing operation interfaces of varying difficulty levels, designing flexible participation periods, and providing multilingual support to meet different parent groups' needs.

Establishing teacher support systems is crucial. Research finds teachers' weekly workload increased by 3-5 hours; we recommend establishing dedicated teacher training programs covering technical operation, instructional design, and school-family interaction. Meanwhile, establish teacher VR application communities promoting experience exchange, and provide sufficient preparation time and technical support. Consider establishing teaching innovation reward mechanisms to encourage teachers to develop innovative VR teaching plans.

Regarding data security issues, we recommend establishing strict data protection policy frameworks. With 41% of parents expressing privacy concerns, we recommend clearly defining data collection, storage, and usage regulations, implementing tiered access control, conducting regular security audits, and providing users with transparent data usage explanations. Meanwhile, conduct data security training to enhance all parties' security awareness and protection capabilities.

Regarding educational equity, we recommend adopting multiple measures to ensure VR technology's inclusiveness. Establish equipment lending services, build community VR education centers, develop low-cost versions of VR applications, ensuring families of different economic conditions can benefit from technological innovation. Pay special attention to groups with special needs, providing necessary auxiliary functions and support services.

We recommend establishing systematic effectiveness evaluation mechanisms, including metrics for engagement levels, learning outcomes, and user satisfaction. Regularly collect and analyze data, timely adjusting implementation strategies. We recommend conducting long-term tracking research to evaluate VR technology's sustained effectiveness, providing a scientific basis for policy adjustment. Meanwhile, establish cross-school feedback mechanisms promoting experience sharing and best practice dissemination.

Regarding resource integration, we recommend strengthening industry-university-research cooperation, combining forces from technology companies, research institutions, and education departments to jointly advance VR education innovation. Establish regional or national VR education resource-sharing platforms promoting quality educational resource circulation and sharing. Meanwhile, we recommend developing VR education standards ensuring technology application quality and consistency.

Finally, we recommend incorporating VR technology into overall educational innovation planning, forming complementarity with other educational technology innovations. Value the integration of VR technology with traditional education methods, creating more comprehensive and effective learning ecosystems. Meanwhile, maintain continuous attention to new technology development, timely introducing new technological innovations, and continuously optimizing school-family interaction methods and effectiveness.

C. Future Research Directions

Based on this study's findings and limitations, we recommend future research pursue the following directions. First, we suggest conducting longer-term longitudinal studies tracking students throughout their entire educational journey from primary to secondary school, evaluating VR technology's persistent effects on parental engagement and student learning outcomes. Such research should focus on temporal patterns of technology effectiveness, explore potential cumulative effects, and assess specific needs and challenges at different developmental stages. Simultaneously, it should analyze how VR technology influences students' long-term development

trajectories, including learning habit formation and subject interest development.

Regarding research scope, we recommend conducting cross-regional and cross-cultural comparative studies. Through comparative analysis across different regions and school types, explore how sociocultural factors influence VR technology application effectiveness. Such research should particularly focus on urban-rural differences, regional characteristics, and cultural traditions' impact on technology acceptance and usage patterns, providing targeted guidance for VR applications in different environments.

Adopting a more comprehensive ecosystem research perspective is also necessary. Future research should explore how VR technology influences the entire educational ecosystem, including school organizational structure, teacher role transformation, and curriculum design innovation. Meanwhile, it should examine broader socioeconomic factors, such as educational policy environment, technology development trends, and labor market demands, and how they influence VR technology application in education.

In terms of individual difference research, we recommend deeply exploring how learning styles, cognitive abilities, and personality traits influence VR learning experiences. Such research should adopt more refined classification methods, identifying key individual characteristics affecting technology use effectiveness, and providing theoretical foundations for personalized VR application design. Special attention should be paid to groups with special needs, studying how to optimize VR technology to meet different learners' requirements.

Technology integration research is also an important direction. We recommend comparing synergistic effects between VR technology and other emerging educational technologies, exploring optimal technology combination solutions. Such research should focus on complementarity between different technologies, evaluate comprehensive application cost-effectiveness, providing reference for educational institutions' technology investment decisions. Special attention should be paid to studying how to organically combine VR technology with artificial intelligence, big data analysis, and other cutting-edge technologies.

In-depth instructional design research is also necessary. Future research should explore effective VR educational content design principles and teaching methods, studying how to design VR experiences that promote deep learning and critical thinking. Such research should particularly focus on different subject characteristics and age group needs, developing more targeted VR teaching models. Meanwhile, research how to effectively combine VR experiences with traditional teaching methods.

Ethics and social impact research cannot be neglected. As VR technology becomes widely applied, deep research into related ethical issues and potential social impacts is needed. This includes studying VR technology's effects on student privacy, data security, physical and mental health, and potential educational equity issues. Meanwhile, explore how to develop corresponding ethical guidelines and policy frameworks ensuring technology application standardization and safety.

Finally, we recommend conducting more systematic cost-benefit analysis research. Such research should comprehensively evaluate the economic feasibility and sustainability of VR technology applications in education, including hardware investment, content development, teacher training, and other direct costs, as well as potential indirect benefits. Meanwhile, study how to build sustainable VR education ecosystems, including long-term planning for technology updates, content maintenance, and continuous training.

D. Conclusion

This study, through systematic examination of VR technology applications in enhancing parental engagement, has yielded several significant findings. Research results demonstrate that VR technology can substantially increase parental participation frequency (47% improvement), quality (18% improvement), and satisfaction (25% improvement), with particularly pronounced effects for working parents and those living at a distance. These findings provide strong empirical support for educational innovation practices. Simultaneously, the study reveals VR technology's positive impact on student learning outcomes through enhanced parental engagement, including comprehensive improvements in learning motivation, academic performance, and social-emotional competence.

Analysis results for different parent types reveal significant variations in VR technology's effectiveness, providing important basis for developing personalized application strategies. The study also identifies major challenges in technology application, including usage barriers, privacy security, and teacher workload issues, and proposes corresponding solutions. These findings have significant value in guiding practical applications of VR technology in education.

This study's theoretical contributions manifest in multiple aspects. First, it extends the Technology Acceptance Model's application in educational environments, validating the key roles of perceived usefulness and ease of use in new technology adoption processes. Second, it enriches parental engagement theory, demonstrating how technological innovation can modify traditional participation pattern constraints. Furthermore, research results support the application value of situated cognition theory and social learning theory in technology-assisted education.

At the practical level, the study provides a series of specific recommendations for educational institutions, including phased implementation strategies, personalized application plans, and teacher support system construction. These recommendations, based on empirical data, possess strong operability and practical value. Particularly regarding educational equity, the study's proposed inclusive measures have important significance in ensuring widespread benefits from technological innovation.

Despite limitations in sample representativeness and study duration, this study provides important insights into understanding VR technology's role in educational innovation.

The suggested future research directions, such as conducting longitudinal tracking studies and cross-cultural comparative research, will help further deepen understanding in this field. Overall, this study not only enriches theoretical knowledge in educational technology but also provides scientific basis for practical innovation, offering important reference value for promoting educational modernization.

This research demonstrates that while VR technology shows promising potential in enhancing parental engagement and student learning outcomes, its successful implementation requires careful consideration of various stakeholder needs, systematic planning, and continuous evaluation and adjustment. As educational technology continues to evolve, further research and practice in this area will be crucial for maximizing the benefits of VR technology in education while addressing potential challenges and ensuring equitable access and effective use.

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