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Implementing virtual reality technologies to enhance digital literacy in primary education

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Abstract

Virtual reality (VR) technologies have shown promising results in the field of education. However, the number of studies directly examining the impact of VR technologies on digital literacy in primary education is limited. This study demonstrates the benefits of VR technologies and the potential of resources developed based on VR technology to support digital literacy acquisition in primary schools. The article conducted a study to examine the role of VR technologies in the development of the digital literacy of students in grades 2–4. The study involved 72 students from schools in Kazakhstan, divided into experimental and control groups. The results showed that the digital competencies of the experimental group improved compared to the control group. Students in the experimental group demonstrated improved problem-solving and information search abilities, indicating the effectiveness of using VR technologies. The results highlight the importance of implementing immersive learning technologies in primary education. These results demonstrate the potential of virtual reality to change primary education by developing basic digital skills, providing a basis for future research in this area.

Keywords: Digital literacy, Educational technology, Kazakhstan, Primary education, Virtual reality.

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1. Introduction

Digital literacy, the ability to effectively and critically engage with digital tools and technologies, is increasingly recognized as a crucial skill in modern education. In primary education, where foundational learning occurs, digital literacy plays a pivotal role in equipping young learners with the competencies needed to navigate a technology-driven world. By introducing digital literacy at an early stage, educators can foster critical thinking, problem-solving, and creativity, which are essential for academic success and lifelong learning.

In Kazakhstan, the importance of digital literacy is growing, as the country actively embraces digital transformation. Educational policies and initiatives reflect a commitment to integrating digital tools into classrooms to enhance teaching and learning. However, studies highlight a need for tailored approaches to digital literacy in primary education, considering the

developmental needs of young children and the unique challenges faced by teachers in implementing these strategies [1]. For instance, research shows variability in digital literacy levels among students and emphasizes the critical role of teacher training and resources in addressing these gaps [2].

In an era where digital skills are essential, integrating innovative technologies into education is crucial. In recent years, there has been growing interest in the use of virtual reality (VR) technology as a teaching tool in a variety of educational topics. Using VR in education helps students develop critical 21st-century skills such as creativity, critical thinking, and problem-solving. One particularly promising area of research is the use of VR to improve the digital literacy learning experience of primary school students. The development of VR technologies and their implementation in everyday life occur simultaneously with the rest of the digitalization processes, becoming part of the global digital transformation.

VR technologies offer transformative potential in this context by creating immersive, interactive learning environments that enhance engagement and understanding. In primary education, VR can make abstract concepts tangible, support experiential learning, and encourage collaboration among young learners. For example, VR simulations can help students explore digital tools in a hands-on manner, fostering early familiarity and confidence in using technology. VR stands out as a transformative tool, offering immersive experiences that can enhance digital literacy among primary school students. VR can make learning more engaging and enjoyable for students, increasing their motivation to participate in digital literacy activities. It allows students to visualize and interact with abstract concepts, making them easier to understand [3].

The use of VR technologies in the classroom contributes to the transformation of the teaching format, allowing for greater real individualization of learning due to variability in the pace of presentation, complexity, and volume of tasks. However, despite its potential, integrating VR into primary education presents challenges. High costs, limited content tailored for younger learners, and a lack of teacher preparedness are significant barriers. Additionally, ensuring accessibility and inclusivity in VR implementation remains a concern. These challenges necessitate focused efforts in professional development for teachers and the creation of localized, age-appropriate VR content [4]. Also, some authors have expressed concerns that if the material is presented incorrectly, the use of VR in teaching will obviously have negative consequences: for example, an overly detailed, very visual demonstration of the material in elementary schools may reduce the development of abstract concepts and make it difficult to form symbolic thinking [5, 6]. That is why, in order to effectively apply VR technologies, it is necessary to understand how to create the most acceptable content and what effect its use will have. We consider the preparation of schoolchildren for the use of virtual reality technology as an important task in the formation of digital literacy.

The purpose of this research is to present an overview of current studies on the potential of virtual reality technologies to enhance digital literacy acquisition among Kazakhstani students in elementary schools and to report on an experimental study conducted to determine the practical utility of VR in achieving this goal.

The remainder of this paper is as follows: Section 2 provides an in-depth review of the literature related to the research topic. Section 3 outlines the methodology employed in the study. Section 4 presents the key findings obtained. Section 5 offers a discussion of these findings. Finally, Section 6 concludes the study by summarizing the main outcomes and suggesting directions for future research.

2. Literature Review

Digital literacy refers to the ability to locate, evaluate, and utilize information effectively in digital formats. This encompasses various competencies, including critical thinking, digital communication, and online safety. According to Bawden [7], critical thinking in the digital realm involves analyzing online information for credibility, a skill that is increasingly important in today's information-rich environment. Furthermore, digital communication emphasizes understanding how to communicate safely and respectfully in online spaces. Online safety, as described by Bawden [7], involves recognizing potential dangers in the digital environment, an essential aspect of navigating the internet. Primary education, which serves as the foundation for lifelong learning, plays a critical role in developing these skills. Introducing digital literacy at an early stage ensures that students are equipped to navigate the complexities of the digital world, as highlighted by Bawden [7]. Early exposure to these concepts helps foster a generation of learners who are not only proficient in using digital tools but also capable of engaging critically and safely in the digital space.

VR has emerged as a powerful tool in educational settings, offering immersive learning experiences that can enhance digital literacy. According to Slater and Wilbur [8], VR creates a simulated environment where users can interact with specialized equipment, such as VR headsets. This technology has rapidly evolved and become more accessible, particularly in educational contexts. Huang and Liaw [9] argue that VR enables experiential learning, where students can practice skills in a safe, controlled environment. For example, VR can simulate online interactions, providing students with opportunities to learn about digital communication and safety in a practical setting.

The immersive nature of VR encourages critical thinking, as students are placed in realistic, simulated scenarios that require them to evaluate information and make decisions. As Mikropoulos and Natsis [10] suggest, this type of learning promotes deeper engagement and reflection, which enhances the ability of students to critically assess online content. This aligns with the objectives of digital literacy, where critical thinking plays a central role in navigating the digital world effectively. Research demonstrates the effectiveness of VR in improving learning outcomes. For example, Ibáñez and Delgado-Kloos [11] show significant improvements in digital literacy and critical thinking when VR is used in the classroom.

More longitudinal studies are needed to understand the long-term impacts of VR on digital literacy skills [12]. Investigating collaborative VR experiences can foster teamwork and communication skills, essential components of digital literacy [9]. As VR technology evolves, establishing best practices for its use in education will be crucial. Educators need clear guidelines on effective VR implementation.

Integrating VR into the curriculum, however, requires careful alignment with educational objectives. According to Dede et al. [13], a VR module could, for example, simulate an online forum where students must distinguish between safe and unsafe interactions. Effective integration of VR into the classroom requires not only the availability of VR equipment but also comprehensive teacher training. As noted by Dede et al. [13], educators must be familiar with both the technology and the pedagogical methods for effectively using VR in their teaching practices. Therefore, ongoing training sessions should be established in schools to help educators develop proficiency with VR technology. Collaborating with technology companies can provide schools with the resources required to implement VR effectively, ensuring that students can benefit from these immersive learning experiences. This collaborative approach can help bridge the gap between technological advancements and educational accessibility, facilitating the integration of VR into primary education. Furthermore, incorporating VR into digital literacy education presents significant opportunities for enhancing critical thinking, communication, and online safety.

The integration of VR into digital literacy instruction is particularly compelling for several reasons. First, VR enables students to engage in experiential learning by immersing them in realistic, simulated environments where they can practice using digital tools without fear of failure. This hands-on approach not only increases engagement but also reinforces retention of knowledge and skills [14]. Second, VR supports diverse learning styles by providing visual, auditory, and kinesthetic experiences, making digital literacy instruction more accessible to all students. Third, VR can help bridge the gap between theory and practice, allowing students to apply abstract concepts in practical scenarios, such as creating digital content, navigating virtual spaces, and collaborating in simulated digital projects [11]. Finally, the use of VR can inspire curiosity and innovation among young learners, preparing them for the evolving demands of a digital-first society [15].

Kazakhstan's commitment to digital transformation is reflected in its policies and initiatives aimed at promoting digital literacy. The government has supported the development of digital literacy curricula and infrastructure. In Kazakhstan, the integration of Virtual Reality technologies into education is an emerging field, with several studies highlighting its potential and challenges. Research by Daineko et al. [16] examined the use of augmented and virtual reality in teaching physics within Kazakhstan's secondary educational institutions. The study found that VR applications enhanced students' understanding of complex physical concepts through interactive simulations, leading to improved engagement and learning outcomes. A study conducted at Astana International School explored the development of digital literacy skills among teachers for effective integration of computer science and design education [17]. Despite these advancements, gaps such as the lack of region-specific studies, limited exploration of the role of VR in primary education compared to secondary or higher education, and the insufficient research on teacher training programs for VR integration persist.

3. Research Methodology

This study employed a quasi-experimental design with an experimental group and a control group to investigate the impact of Virtual Reality (VR) technologies on enhancing digital literacy among primary school students. The study involved a total of 72 primary school students, aged 7-10 years, enrolled in grades 2-4 at 81 Astana English School, Astana, Kazakhstan. The participants were evenly distributed across the three grade levels, with each grade comprising 24 students. 36 students were divided evenly across grades 2, 3, and 4, with 12 students in the experimental group and 12 in the control group per grade. The balanced distribution across grades ensured comparability between the experimental and control groups, allowing for a consistent evaluation of the impact of VR technologies on digital literacy across different age levels.

The participants were randomly assigned to one of two groups: an experimental group and a control group. The experimental group consisted of 36 students who were exposed to a digital literacy curriculum enhanced with VR tools, while the control group comprised 36 students who followed a traditional, non-VR digital literacy curriculum. The intervention for the experimental group lasted for six weeks, with 1 session per week. Each VR lesson lasted approximately 45 minutes. The study followed a structured methodology to evaluate the impact of VR technologies on digital literacy. The experimental and control groups underwent distinct interventions, as summarized in Table 1.

Table 1.
Process of experiment.

Experimental Group	**Control group**
Week 1: Pre-Test	
Students in the experimental group completed a baseline digital literacy assessment. The test included sections on online safety, digital communication, and evaluating online content.	Students in the control group completed the same baseline digital literacy assessment as the experimental group.
Weeks 2-5: VR-Based Activities	
Students participated in interactive learning sessions using headsets.	Students participated in lessons using textbooks, worksheets, and group discussions.
Week 6: Post-Test	
After the intervention, the experimental group repeated the digital literacy assessment to measure improvements. Observations and interviews were also conducted to understand student experiences with the VR tools.	The control group also repeated the digital literacy assessment. Observations focused on engagement levels and the application of digital skills learned during the sessions.

As shown in Table 1, the procedure consisted of three main stages. At the outset, all participants completed a baseline assessment designed to evaluate their digital literacy skills. This pre-test covered critical areas, including online safety, digital communication, and evaluating online content.

In an intervention, students in the experimental group engaged in immersive, VR-based activities using Oculus Quest 2, HTC Vive, and Vive Pro headsets. These activities included simulated environments for practicing online safety, interactive tasks to enhance digital communication skills, and virtual problem-solving scenarios to develop critical evaluation of online content. While students in the control group engaged in traditional activities, such as textbook-based lessons, video tutorials, and group discussions, these sessions focused on the same digital literacy components but without the use of immersive technologies.

At the conclusion of the program, all participants completed the same digital literacy assessment administered during the pre-test. This post-test provided comparative data on the effectiveness of VR-based versus traditional methods in the digital literacy subject.

The VR modules were designed to complement the Digital Literacy curriculum, focusing on key areas such as:

Basic computing skills: understanding hardware components (including the processor, hard drive, printers, speakers, and their structure), operating systems, and basic software applications.

1. Online safety: recognizing safe websites, understanding privacy settings, and learning how to prevent cyberbullying.
2. Digital communication: using email appropriately, social media etiquette, and understanding digital footprints.
3. Information literacy: assessing the credibility of online sources and understanding the basics of online research.

In contrast, the control group's curriculum was based on traditional learning materials such as textbooks, printed worksheets, and online educational resources, and their lessons did not use immersive learning tools.

In this study, Meta Quest 2 HMDs, also known as Oculus Quest 2, with hand controllers, which are among the most affordable HMDs available in the market, and HTC Vive devices were used. The HTC Vive and Oculus Quest 2 are both immersive VR systems, but they differ in design and functionality. The HTC Vive consists of a headset connected to a computer through cables, along with two base stations that monitor the user's movements within a defined space. It also includes a pair of handheld controllers, each equipped with multiple buttons for different functions depending on the application. On the other hand, the Oculus Quest 2 is a standalone VR system that does not require a computer or external sensors. Instead, it uses an array of integrated cameras to track user movement in real time. The system comes with two wireless controllers that feature buttons to interact with various applications. As part of the onboarding process, students participated in training sessions to learn key actions like grabbing virtual objects, navigating environments, and adjusting the headset for optimal comfort and clarity. The reason for choosing these devices is that they have already been used in studies and have shown their benefits. For example, Laime used and demonstrated the key positive impacts of HTC Vive in K-12 education in their study. Additionally, we can see studies conducted using the Oculus device that have shown positive results; for example, in the study by Karelhan et al. [18], a study conducted about digital literacy showed that about 80 students mastered the topic by 80% and showed great interest.

As part of our research into awareness and attitudes toward virtual reality (VR) technologies in education, we conducted a survey among parents of primary-grade students to understand the current situation and their familiarity with these technologies. The survey was created using Google Forms, a platform that is accessible to everyone, ensuring convenience and inclusivity for participants. To make the survey understandable for all parents, it was conducted in two languages (Kazakh and Russian) based on the preferences of the respondents. Figure 1 presents three pie charts summarizing the survey responses. The first chart illustrates that a significant majority of parents (86.1%) have heard about VR technologies, while only 13.9% indicated they had not. The second chart focuses on parents' awareness of using VR technologies in education. The results show that a smaller proportion of parents (25%) are familiar with the application of VR in educational settings, whereas the majority (75%) are not aware of its use in this context. The third chart highlights parents' attitudes toward the use of VR headsets or glasses during lessons. An overwhelming majority of 94.4% expressed support for using such technologies in the classroom, while only 5.6% were opposed. These findings suggest that while most parents are generally aware of VR technologies, there is limited knowledge about their specific use in education. However, parents demonstrate strong approval of integrating VR into classroom learning for their children.

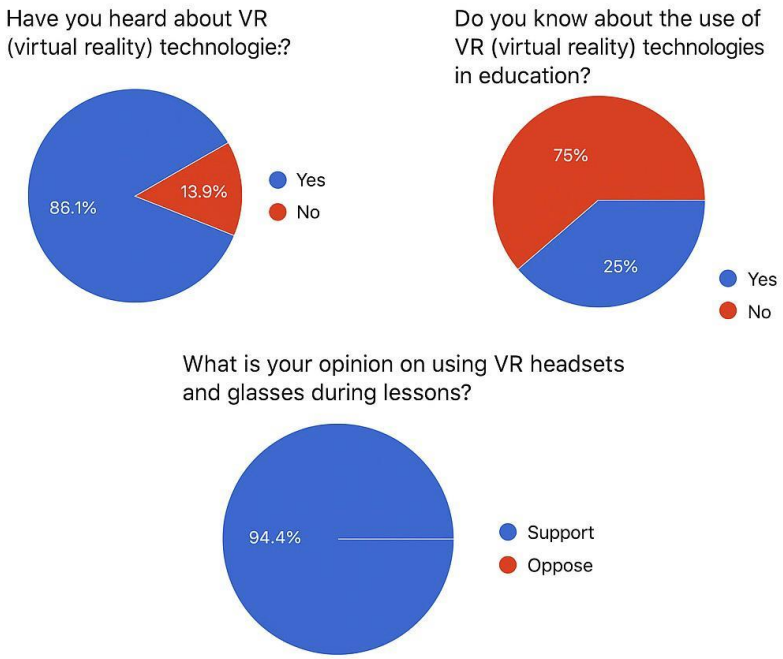

Figure 1.
Survey Responses of Parental Awareness and Attitudes Toward VR Technologies in Education.

4. Research Findings

To assess effectiveness, we conducted pre-tests, post-tests, and follow-up tests to measure knowledge improvement, engagement levels, and retention rates. As shown in Table 2, statistical analysis showed that students in the VR group demonstrated a significant increase in digital literacy scores compared to the control group.

Table 2.
Comparison Scores Across Testing Phases.

Test Phase	VR Group (M ± SD)	Control Group (M ± SD)	t(70)	p-value
Pre-Test	55.3 ± 5.2	54.8 ± 4.9	0.29	0.77
Post-Test	78.6 ± 6.4	65.2 ± 7.1	4.89	<0.001
Follow-Up	76.4 ± 6.8	63.1 ± 7.6	4.23	<0.01

The pre-test scores of both groups were nearly identical (55.3 ± 5.2 for VR vs. 54.8 ± 4.9 for Control), with no statistically significant difference ($p = 0.77$). This confirms that both groups started at a comparable level, ensuring that subsequent differences in scores are attributable to the intervention rather than pre-existing differences in digital literacy skills. After the intervention, the VR group showed a substantial increase in scores (78.6 ± 6.4) compared to the control group (65.2 ± 7.1), with a highly significant difference ($p < 0.001$). This indicates that the VR-based digital literacy program was markedly more effective in improving students' understanding and skills than the traditional approach. Even six weeks after the intervention, the VR group maintained a higher performance level (76.4 ± 6.8) compared to the control group (63.1 ± 7.6), with a statistically significant advantage ($p < 0.01$). The small drop from the post-test scores in the VR group suggests some forgetting over time, but the retention of knowledge and skills was still significantly better than that of the control group. The long-term advantage observed in the VR group highlights the potential of immersive learning technologies in reinforcing digital literacy concepts. VR provides an interactive and engaging learning environment, which may contribute to better comprehension, memory retention, and practical skill application compared to traditional teaching methods.

Student engagement was assessed through surveys and observational data.

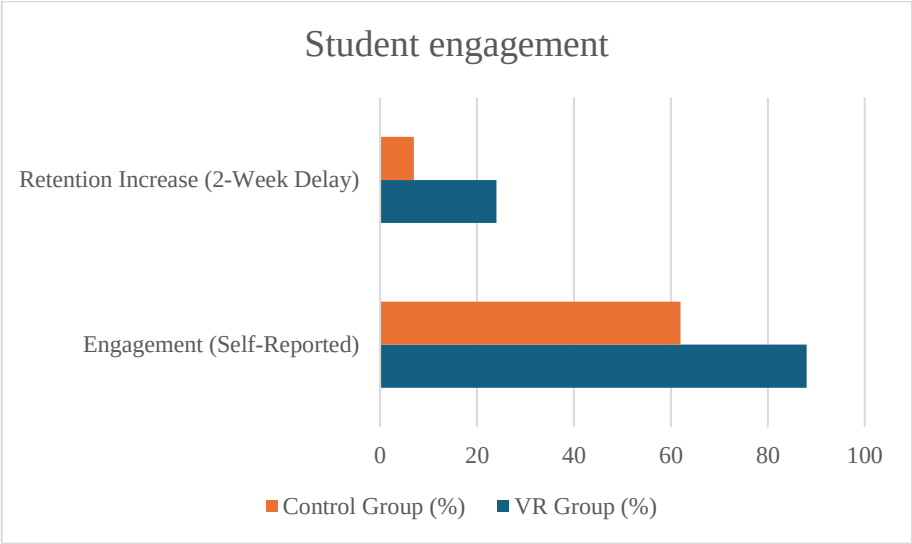

Figure 2.
Impact of VR-Based Instruction on Student Engagement, Retention, and Distraction.

The Figure 2 shows that VR-based instruction resulted in a significant increase in student engagement (88% vs. 62% in the control group), led to a 24% retention increase after two weeks compared to a modest 7% improvement in the control group, and resulted in distraction incidents that were three times lower (9% vs. 27%), suggesting that VR-based instruction not only captures student attention more effectively but also enhances long-term retention of digital literacy concepts.

We also interviewed students to gather their experiences with VR-based learning activities. The results of the interviews are presented in Table 3. The responses were organized around four main themes: knowledge, understanding, technology-based learning activities, and interaction. Students reported that they acquired new information (knowledge) and were able to understand and compare ideas related to the content of the lesson (understanding). They expressed high satisfaction with the immersive and authentic learning activities supported by the technology, and they appreciated the interaction with their classmates and teachers, who helped them ask questions and seek clarification. Table 3 contains some of the students' responses:

Table 3.
Example Student Responses on Interview Themes.

Theme	Example Student Responses
Knowledge	- "I learned many new things about the lesson that I had never seen before through the VR experience." - "I discovered interesting facts that made the lesson more exciting and fun."
Understanding	- "The activity helped me understand the lesson better by showing me different ways to look at the information." - "It made the lesson clear and helped me see how the ideas fit together."
Technology-Supported Learning Activities	- "The VR tools made learning so much fun and exciting; it felt like the lesson was right in front of me!" - "Using the VR headset made the lesson come alive and was very engaging."
Interaction	- "Talking with my classmates during the VR session helped me ask questions and get answers quickly." - "The teacher and my friends explained things to me when I was confused, which made learning easier."

These qualitative findings highlight the positive impact of the VR-based learning activity on primary grade students. The immersive technology not only enhanced their acquisition of new knowledge and deepened their understanding of the lesson content but also promoted meaningful interactions that enriched their overall learning experience. These results underline the potential of VR-based instruction to not only engage students more effectively but also to enhance their digital literacy and overall learning experience in a cross-cultural context.

Our findings align with Martarelli et al. [19], who found that VR improves long-term retention in science education. Unlike Makransky and Petersen [20], who reported cognitive overload in younger learners, our study demonstrated that primary-grade students adapted well with structured guidance. Similar to Liu et al. [21], this study confirmed that immersive VR fosters engagement and motivation, leading to stronger conceptual understanding. These comparisons emphasize that VR is a promising tool for early digital literacy instruction, provided that implementation is age-appropriate and well-structured.

Despite promising results, our study has limitations, including a small sample size from one school (n = 72), short-term retention measured only over six weeks, and a brief technical adaptation period during which 14% of students experienced motion sickness; future research should expand to multiple schools for broader generalizability, examine long-term effects

over one year, and explore varying levels of VR interactivity, while practical implications for educators include gradually integrating VR into digital literacy curricula with developmentally appropriate content, providing specialized teacher training, and addressing technical considerations such as setup time, motion sickness prevention, and effective lesson structuring.

5. Discussion and Conclusion

Including virtual reality technologies in digital literacy instruction has great potential to transform the course of digital literacy. The paper stresses the possible advantages and disadvantages of this fresh strategy. Still, given the difficulties, the advantages of increased involvement, experiential learning, and the sharpening of critical thinking abilities make virtual reality technology worthy of investment. The complete development of VR training possibilities calls for more study and cooperation. Finally, even though Kazakhstan is still in the process of incorporating virtual reality technology into the field of education, ongoing research and development open bright prospects.

A total of 72 sixth-grade students from two classes were randomly assigned to the experimental and control groups. The experimental group engaged in the science lessons using Head-Mounted Displays, whereas the control group learned the same material through traditional teaching methods. The results revealed that the experimental group obtained significantly higher academic achievement and engagement scores than the control group. Moreover, the experimental group had a high level of technology acceptance for VR usage in classrooms. Our study provides empirical evidence for the use of VR technology in digital literacy subjects in primary education.

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