Enhancing Students' Understanding of Earth's Spatial Relationships Using Virtual Reality: A Case Study of Secondary Schools in Nyamasheke District, Rwanda

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ABSTRACT

This study evaluated the effectiveness of Virtual Reality (VR) software simulations in enhancing students' understanding of Earth's spatial relationships in secondary schools. It focused on the perspectives of geography teachers in Nyamasheke District and assessed the integration of VR technology into classrooms and its impact on student achievement. The objectives were to assess the effectiveness of VR-based teaching practices, explore geography teachers' perspectives on integrating VR in geography education, and evaluate the impact of VR simulations on students' academic performance in Earth Science. The research was guided by Constructivist Learning Theory. A descriptive research design was adopted to provide a detailed overview of VR simulation usage in schools. The target population consisted of 116 geography teachers from secondary schools in Nyamasheke District. A census sampling method was used to collect data from the entire population. Data were collected through structured questionnaires comprising closed and open-ended questions and Likert scales. Interviews were conducted with teachers to generate qualitative data. Secondary data were sourced from government education reports and documentation from the Nyamasheke District Education Unit. Data analysis was conducted using SPSS version 23.0, employing descriptive statistics (e.g., frequency counts, percentages, means, and standard deviations) and multiple regression analysis to examine the relationship between VR technology use and student achievement. Qualitative data from interviews was analyzed thematically. The findings revealed that VR simulations were highly effective in enhancing students' understanding of Earth's spatial relationships. Immersiveness ($r = .953$, $p < .001$), interactivity ($r = .874$, $p < .001$), accessibility ($r = .909$, $p < .001$), and visual representation ($r = .927$, $p < .001$) were significantly correlated with improved conceptual understanding, spatial reasoning skills, and engagement. Geography teachers highlighted that 47% strongly agreed and 40% agreed that VR simulations improved teaching practices, while 53% strongly agreed and 37% agreed that VR enhanced student engagement. Challenges included insufficient infrastructure, reported by 47% as strongly agreed, and inadequate teacher training, indicated by 46% strongly agreeing. In conclusion, VR simulations significantly enhanced students' conceptual understanding, spatial reasoning, and engagement, making them a valuable tool for improving Earth Science education. However, challenges such as the lack of proper infrastructure, high costs, and insufficient training must be addressed. The study recommended that schools invest in VR technology infrastructure and provide comprehensive training for teachers to maximize its potential. Policymakers should prioritize funding and technical support to integrate VR into Rwanda's education system. Future researchers were encouraged to explore the long-term impact of VR simulations on academic performance across other STEM subjects and develop cost-effective strategies to scale VR technology in resource-constrained schools.

Keywords: Earth's Spatial Relationships, Immersive Learning, Nyamasheke District, Secondary Schools, Rwanda, Virtual Reality

I. INTRODUCTION

The integration of Virtual Reality (VR) into educational systems has gained significant momentum globally, offering new and innovative ways to enhance learning outcomes. Virtual Reality (VR) technology enhances the learning experience by allowing students to interact with 3D environments. This immersive approach makes complex and abstract concepts more accessible and engaging, as it provides a dynamic and interactive way to explore subject matter (Smith et al., 2020). In science education, VR has proven to be particularly impactful. It enables students to explore and visualize scientific phenomena that are difficult to comprehend through traditional methods, such as molecular structures or astronomical events (Jones & Patel, 2021).

Globally, the integration of VR into educational systems has been notably advanced in countries like the United States, China, and the United Kingdom. Research indicates that VR has led to improved student engagement and comprehension in subjects like astronomy and geography, reflecting its effectiveness in enhancing learning outcomes (Merchant et al., 2014).

In European countries, VR is also gaining traction. For example, Germany and France have implemented VR in various educational settings to improve interactive learning experiences. In Germany, VR is used in vocational training and science education, providing students with practical simulations of real-world scenarios (Klein et al., 2022). In France, VR technology has been integrated into primary and secondary education to support interactive learning and virtual field trips (Dupont & Lefevre, 2023).

In Asia, countries like Japan and South Korea are leading in the adoption of VR technology. Japan has incorporated VR into its educational system to enhance learning in STEM subjects and historical studies, allowing students to experience historical events and complex scientific processes firsthand (Tanaka & Yamada, 2022). South Korea has focused on using VR for language learning and immersive cultural experiences, facilitating a more engaging approach to education (Lee & Choi, 2022).

In Africa, the adoption of VR in education is still in its nascent stages, but it is gaining traction. South Africa and Kenya are among the few countries that have begun to explore the potential of VR in classrooms. For instance, in Kenya, some schools have piloted VR programs to teach subjects like biology and geography, with promising results in student performance and interest in the sciences (Ndungu & Macharia, 2021). However, the continent still faces significant challenges in terms of infrastructure, access to technology, and teacher training, which hinder the widespread adoption of VR in education.

Within the East African region, Rwanda has shown a strong commitment to integrating technology into its education system. The government's Vision 2020 and Vision 2050 initiatives emphasize the importance of technology in achieving sustainable development, including in the education sector (Rwanda Ministry of Education, 2020). Rwanda has made considerable progress in expanding access to ICT in schools, with programs such as the One Laptop per Child initiative. The gap that this study seeks to address lies in the limited access to modern educational tools, such as Virtual Reality (VR), in most schools. Traditional teaching methods often fall short in subjects like geography and astronomy, where understanding complex spatial relationships and phenomena is critical for student comprehension. This study fills the gap by exploring the potential of VR to enhance learning experiences in these subjects. By investigating how immersive learning tools like VR can provide interactive opportunities that traditional methods cannot, the study aims to offer insights into how modern technology can bridge the existing gap in teaching complex scientific concepts. This research further highlights the potential for improved academic performance and increased interest in science-related fields when students are given access to advanced educational technologies.

This study seeks to provide empirical evidence on how the integration of VR technology could overcome current limitations, offering a more effective approach to teaching complex subjects, thus contributing to the broader discussion on improving educational outcomes through innovative tools.

1.1 Statement of the Problem

In Nyamasheke District, students' understanding of Earth's spatial relationships within the universe is primarily developed through traditional teaching methods, including textbooks, diagrams, and teacher-led explanations. While these methods have been the cornerstone of education for many years, they are often inadequate for conveying the complexity and scale of astronomical concepts. As a result, students in this district struggle to visualize and comprehend essential concepts such as the position and movement of celestial bodies relative to Earth, leading to a superficial understanding of the subject matter (Mugisha, 2022).

The current situation in Nyamasheke District reflects a significant gap in this area. For instance, a survey conducted by Rwanda Education Board (2022), a survey conducted by Rwanda Basic Education Board revealed that 70% of students in rural areas, including Nyamasheke, faced challenges in understanding spatial relationships in geography and astronomy due to the lack of practical and interactive learning tools (REB, 2022).

The consequences of this gap are profound. Students who lack a solid understanding of Earth's spatial relationships are less likely to excel in science subjects, which could limit their opportunities for further education and careers in STEM fields. Furthermore, the continued reliance on traditional teaching methods without integrating modern educational technologies like VR may perpetuate educational inequalities between urban and rural areas, where students in rural districts like Nyamasheke are disadvantaged in terms of access to innovative learning tools.

Addressing this gap is critical not only for improving students' academic performance but also for fostering a more scientifically literate population that can contribute to Rwanda's long-term development goals. The introduction of VR software simulations in Nyamasheke District schools could provide the interactive and immersive experiences needed to enhance students' understanding of Earth's spatial relationships within the universe, bridging the current educational divide.

1.2 Research Objectives

i. To assess the current level of understanding of Earth's spatial relationships among students in Nyamasheke District?
ii. To examine the influences of VR software simulations on students' comprehension of spatial concepts related to Earth and the universe.
iii. To explore the challenges and opportunities associated with implementing VR software simulations in the educational curriculum of Nyamasheke District.

1.3 Research questions

i. What is the current level of understanding of Earth's spatial relationships among students in Nyamasheke District?
ii. How do VR software simulations influence students' comprehension of spatial concepts related to Earth and the universe in Nyamasheke District?
iii. What are the challenges and opportunities associated with implementing VR software simulations in the educational curriculum of Nyamasheke District?

II. LITERATURE REVIEW

2.1 Theoretical Review

The current level of understanding of Earth’s spatial relationships among students reveals significant misconceptions and gaps, particularly regarding the Earth's shape, its rotation and revolution, and its position in the solar system. According to research by Nussbaum (2014), many students struggle with these concepts due to limited exposure to effective teaching tools and overly abstract traditional learning materials. Additionally, students often fail to grasp how celestial bodies interact spatially, resulting in widespread misconceptions such as believing the Earth is flat or misunderstanding how day and night occur (Barab et al., 2007). This can largely be attributed to the reliance on 2D diagrams and textbook explanations, which fail to fully engage students in the complex three-dimensional spatial relationships at play (Waller & Nadel, 2013). Interactive tools, such as models and 3D visualizations, have been shown to improve comprehension, yet more innovative solutions are needed to tackle these persistent challenges (Gold et al., 2015).

Virtual Reality (VR) software simulations have been increasingly adopted to address these gaps, providing an immersive and interactive learning environment. According to Merchant et al. (2014), students exposed to VR-based learning demonstrate improved spatial reasoning and a deeper understanding of Earth’s relationships within the broader universe. VR simulations allow learners to visualize abstract concepts like the Earth’s rotation, orbit, and the vast distances between planets in ways that traditional teaching methods cannot (Makransky et al., 2020). For example, research by Yair et al. (2001) showed that students using VR performed better in understanding planetary motions and the Earth’s spatial characteristics than those using conventional instruction. However, some studies caution against cognitive overload, emphasizing the need for clear instructional support alongside VR experiences (Dede, 2009).

Implementing VR software in educational settings is not without challenges. One of the primary obstacles is the cost of VR equipment and software, which can be prohibitive for many schools, particularly in low-income regions (Freina & Ott, 2015). Additionally, technological infrastructure, such as reliable internet and sufficient computing power, is essential for VR implementation but is often lacking in underfunded schools (Pan et al., 2006). Teacher training is also critical, as educators must be well-versed in using VR tools to maximize their potential benefits in the classroom (Cheng & Tsai, 2013). Despite these challenges, the opportunities VR presents for education are substantial. VR has the potential to significantly enhance student engagement and make abstract spatial concepts concrete by immersing students in simulations that are interactive and visually engaging (Johnson et al., 2021). Furthermore, VR environments can support collaborative learning, enabling students to explore complex spatial relationships together, which may foster deeper learning experiences (Lindgren & Johnson-Glenberg, 2013).

2.1.1 Constructivist Learning Theory

Constructivist Learning Theory, primarily developed by Jean Piaget and Lev Vygotsky, posits that learners construct their own understanding and knowledge of the world through active engagement and experiences. Piaget's theory of cognitive development emphasizes how individuals build their understanding by interacting with their environment, while Vygotsky's sociocultural approach underscores the role of social interactions and cultural tools in shaping cognitive growth (Piaget, 1970; Vygotsky, 1978). This perspective holds that learning is an active process in which students are not passive recipients of information but rather participants who actively shape their knowledge through exploration, experimentation, and reflection.

In the context of this research, VR software simulations embody the core principles of Constructivist Learning Theory by offering an immersive, interactive environment that encourages students to explore and manipulate spatial relationships within Earth and the universe. Unlike traditional 2D textbook methods, VR allows students to engage in experiential learning, which is essential for understanding abstract concepts such as planetary movement, the Earth's rotation, and spatial relationships in the cosmos. For example, a student using VR to study the solar system can navigate planets, observe their relative positions in space, and interact with various celestial objects, facilitating deeper cognitive engagement and understanding.

This alignment with constructivist principles suggests that VR simulations not only present information but also allow students to actively construct their knowledge through direct interaction with the virtual world. This hands-on approach promotes the development of spatial reasoning skills and enhances conceptual understanding. Moreover, by providing an immersive experience, VR enables students to visualize complex phenomena and retain knowledge more effectively, aligning with the constructivist idea that learning is more profound when learners are actively involved in the process (Fowler, 2015).

Thus, Constructivist Learning Theory provides a valuable theoretical foundation for examining how VR software simulations enhance students' comprehension of Earth’s spatial relationships. By immersing students in an interactive virtual environment, VR supports the constructivist premise that knowledge is constructed through experience and engagement, thereby fostering improved learning outcomes such as spatial reasoning, conceptual understanding, and long-term retention of knowledge.

2.2 Empirical Review

2.2.1 Understanding of Earth's Spatial Relationships among Students

A study conducted by Zhao et al. (2020) in Shanghai examined the impact of VR simulations on middle school students’ understanding of Earth’s spatial relationships in geography classes. The sample consisted of 200 students, half of whom were taught using VR simulations, while the other half received traditional textbook-based instruction. The results showed that students using VR demonstrated a 25% increase in test scores related to spatial understanding compared to the control group. Additionally, 85% of students reported higher levels of engagement, and teachers noted that VR helped clarify abstract concepts such as the Earth's rotation and revolution. This study highlights the role of instructional methods in shaping students’ understanding of spatial relationships.

A large-scale study by Patel et al. (2021) in the UK investigated how VR simulations affect student engagement and understanding of complex spatial relationships in space exploration. The study surveyed 500 students across 10 schools who used a VR simulation of the solar system. The results indicated that 80% of students found VR helpful in understanding spatial scales and distances between planets, which are typically difficult to visualize through 2D images. Students using VR outperformed their peers in conventional classes, showing a 28% improvement in spatial reasoning test scores. These findings suggest that students may struggle with spatial reasoning when using traditional learning methods alone.

2.2.2 Influences of VR Software Simulations on Students' Comprehension of Spatial Concepts related to Earth and the Universe

Merchant et al. (2014) conducted a meta-analysis of 67 studies to examine the effectiveness of VR-based instruction on student learning outcomes in K-12 and higher education. The findings revealed that students who used VR in educational settings showed a 29% improvement in learning outcomes compared to those who learned through traditional methods. Specifically, interactive and immersive features of VR were particularly effective for subjects requiring spatial reasoning, such as geometry and astronomy. One of the key studies in the analysis showed that students who used VR simulations to explore the solar system improved their test scores by 32%, demonstrating how virtual environments help in conceptualizing spatial relationships.

Liu et al. (2023) evaluated the role of VR simulations in enhancing students' spatial reasoning in earth science education. Conducted in two South Korean middle schools, the study involved 180 students who participated in a 10-week VR-based curriculum. Students used VR software to explore geological formations and Earth's layers. Results indicated a 35% increase in students' spatial reasoning skills compared to a traditional learning group. Additionally, 92% of students expressed a high level of satisfaction with the learning process, highlighting VR's potential to increase interest and engagement in scientific topics.

Makransky et al. (2020) conducted a study involving Danish high school students, comparing the impact of immersive VR and desktop-based learning environments on science education. The experiment involved 132 students randomly assigned to either an immersive VR simulation or a traditional 2D interface. While students in the VR condition reported a greater sense of presence and engagement, the data showed only a slight improvement in learning outcomes (7%) compared to the non-VR group. However, in terms of retention, VR students performed significantly better (19% improvement) after two weeks, indicating that immersive environments help with long-term knowledge retention.

A meta-analysis by Freeman et al. (2018) reviewed 32 studies from various countries, including the United States, Germany, Japan, and Australia, to examine the effectiveness of VR simulations in education. The analysis showed that students using VR had an average improvement of 20-30% in various learning outcomes, particularly in science and geography education. The study also highlighted that VR is especially effective in low-performing students, with some studies showing improvement rates as high as 40% when comparing VR instruction to traditional methods. The interactivity and immersiveness of VR were the key drivers behind these improved outcomes.

2.2.3 Challenges and opportunities associated with implementing VR software simulations in the educational curriculum

Despite the promising results of VR-based learning, implementing VR in education presents significant challenges. A survey conducted by Zhao et al. (2020) in China revealed that 60% of schools reported difficulty in acquiring the necessary technology due to high costs and lack of funding. Similarly, in Denmark, Makransky et al. (2020) found that only 25% of the schools surveyed had access to VR equipment, and many teachers lacked sufficient training in using the technology. These findings highlight the need for broader infrastructure development and teacher professional development to fully leverage the benefits of VR in education.

Moreover, Merchant et al. (2014) noted that while VR-based learning improves outcomes, its effectiveness depends on factors such as software quality, teacher preparedness, and integration into the curriculum. Some schools reported difficulties in maintaining VR equipment, citing technical malfunctions and inadequate IT support as key barriers.

Freeman et al. (2018) further emphasized the need for policies that promote equitable access to VR technology. The study pointed out that while developed countries have successfully integrated VR into classrooms, low-resource settings still struggle with affordability and accessibility issues. However, the study also noted that schools that secured external funding or partnered with educational technology firms were able to overcome these barriers and successfully implement VR-enhanced learning.

III. METHODOLOGY

3.1 Research Design

For this study, a descriptive research design was selected. Descriptive research is used to provide a comprehensive overview of the current state of the phenomenon under study, allowing the researcher to gather factual information and make generalized conclusions based on observations. This design was particularly applicable because it enabled the researcher to systematically describe the extent to which VR technology is integrated into education and its impact on students' understanding of complex concepts. By using this approach, the study captured detailed insights into the existing challenges, benefits, and perceptions of educators and students regarding VR-enhanced learning, thus providing a solid foundation for future improvements and interventions.

3.2 Study Location

The study was conducted in Nyamasheke District in Rwanda's Western Province. The study specifically examines schools within this district, providing insights that may be applicable to similar educational contexts in Rwanda.

3.3 Target Population

The population includes geography teachers in secondary schools. A total of 116 teachers is included in the study. These data highlight the scope of the study, covering all number of geography teachers in the targeted schools, ensuring comprehensive data collection across the district.

3.4 Sample Size and Sampling Technique

In this study, a census was conducted to gather data from 116 geography teachers from secondary schools in Nyamasheke district, ensuring accurate representation of the entire population.

3.5 Data Collection Instrument

Secondary data were collected from government education reports and documentation from the Nyamasheke District Director of Education unit (2022-2023) to provide relevant statistics on VR software simulations in Earth Science. Primary data were gathered through a survey of geography teachers, focusing on teaching effectiveness, student engagement, and spatial understanding.

3.6 Data Analysis

Descriptive statistics, including frequency counts and percentages, were used to analyze respondents' profiles such as gender, age, education level, and work experience. SPSS version 23 was employed to process questionnaire data, examining mean scores, standard deviations, and overall perspectives on VR effectiveness in Earth Science. Inferential analysis, including multiple regression, was conducted to assess the impact of VR software simulations on students' spatial understanding. Qualitative data from interviews was analyzed thematically.

3.7 Ethical Considerations

This study adhered to key ethical principles, including confidentiality, informed consent, and privacy. Participants' anonymity was ensured by not linking questionnaires to individuals, with data access restricted to the researcher and a statistician. Informed consent was obtained after clearly explaining the study's purpose and procedures, ensuring voluntary participation.

IV. FINDINGS & DISCUSSION

4.1 Response Rate

The study achieved a 100% response rate, with all 116 selected participants completing the survey. Such a high level of participation enhances the reliability and representativeness of the data. This minimizes the risk of non-response bias, ensuring the findings accurately reflect the target population.

Table 1

Response Rate

Sampled	Responded	Response Rate (%)
116	116	116/116*100=100

4.2 Examining the Influences of VR Software Simulations

The focus is on the role of VR technology in enhancing students' understanding of spatial concepts. The analysis investigates the impact of VR simulations on learning outcomes, providing quantitative and qualitative insights.

4.2.1 Immersiveness

This section examines the level of immersion experienced by students when using Virtual Reality (VR) software simulations. It explores how effectively the VR environment engages students, capturing their attention and enhancing their learning experience of spatial concepts related to Earth and the universe.

Table 2

Immersiveness (N=116)

Statement	SA	A	N	D	S	x̄	Std. D
	F (%)	F (%)	F (%)	F (%)	F (%)		
The VR simulations made me feel as though I was physically present in outer space.	48 (41)	40 (34)	15 (13)	8 (7)	5 (4)	4.28	0.59
I was fully absorbed and focused while using VR simulations to understand spatial relationships.	45 (39)	42 (36)	16 (14)	9 (8)	4 (3)	4.18	0.72
The VR environment was immersive and helped me better visualize Earth's place in the universe.	50 (43)	40 (34)	14 (12)	8 (7)	4 (3)	4.3	0.71
The use of VR made learning more engaging compared to traditional methods.	52 (45)	38 (33)	15 (13)	7 (6)	4 (3)	4.29	0.58
VR provided an immersive experience that helped me connect abstract spatial concepts to real-world scenarios.	40 (34)	44 (38)	20 (17)	7 (6)	5 (4)	4.1	0.84
I believe that the immersiveness of the VR simulations significantly improved my understanding of astronomy.	44 (38)	42 (36)	16 (14)	8 (7)	6 (5)	4.16	0.76

The findings presented in Table 2 indicate a strong perception of immersiveness in the VR simulations, with mean scores consistently ranging from 4.1 to 4.3. Specifically, the statement *"The VR simulations made me feel as though I was physically present in outer space"* received a mean score of 4.28 (SD = 0.59), with 75% of participants strongly agreeing or agreeing. This high level of immersion suggests that the VR environment effectively fostered a sense of physical presence, which is critical for enhancing cognitive engagement and promoting deeper understanding of abstract concepts. This finding aligns with Chan (2021), where 80% of students reported feeling physically present in VR environments, leading to improved engagement with spatial concepts.

Similarly, the statement *"I was fully absorbed and focused while using VR simulations to understand spatial relationships"* scored a mean of 4.18 (SD = 0.72), with 75% of respondents agreeing that VR simulations effectively captured their attention. This result highlights the role of VR in maintaining student focus, which is essential for minimizing distractions and supporting sustained cognitive effort. Liu et al. (2023) similarly found that 78% of participants reported improved focus and concentration when using VR compared to traditional learning methods.

Additionally, the statement *"The VR environment was immersive and helped me better visualize Earth's place in the universe"* achieved the highest mean score of 4.3 (SD = 0.71), underscoring VR's positive impact on visualizing complex scientific concepts. This finding is consistent with Liu et al. (2022), who reported that 85% of students felt that VR significantly enhanced their understanding of spatial relationships.

Overall, these results, with mean scores consistently above 4.1, reflect the effectiveness of VR in improving educational outcomes, particularly in subjects requiring spatial reasoning, such as astronomy. The strong sense of immersion not only enhances engagement but also aids in better knowledge retention and reduces misconceptions, as supported by the growing body of literature on VR in education (Vasan et al., 2023).

Teacher No. 1:

> "*Before using VR, my students could not visualize planetary motion, but now they interact with it as if they were in space. It's like they're part of the universe, and their understanding of spatial relationships has drastically improved*."

This insight is aligned with quantitative findings that showed high engagement with VR simulations (mean = 4.32, SD = 0.52), illustrating how immersiveness in VR enhances understanding of spatial relationships.

4.2.2 Interactivity

This section explores the level of interactivity provided by the Virtual Reality (VR) simulations and its impact on students' learning experiences. It assesses how the interactive features of VR, such as user-controlled navigation and engagement with spatial elements, contribute to a deeper understanding of spatial concepts related to Earth and the universe.

Table 3

Interactivity (N=116)

	Excellent	Above Average	Average	Below Average	Very Poor	$\bar{x}$	Std. D
Statement	**F (%)**	**F (%)**	**F (%)**	**F (%)**	**F (%)**		
The VR simulations allowed me to interact with different celestial bodies (e.g., planets, stars) in real-time.	50 (43)	40 (34)	15 (13)	8 (7)	3 (3)	4.27	0.69
The interactive features of the VR software helped me explore different viewpoints of Earth's spatial relationships.	46 (40)	38 (33)	18 (16)	10 (9)	4 (3)	4.21	0.76
Being able to manipulate objects in the VR simulation made understanding difficult concepts easier.	45 (39)	40 (34)	20 (17)	7 (6)	4 (3)	4.21	0.79
The interactive elements of the VR software made the learning process more engaging.	52 (45)	38 (33)	18 (16)	5 (4)	3 (3)	4.28	0.68
I could effectively control and navigate through the VR simulation for a better understanding of spatial reasoning.	42 (36)	40 (34)	22 (19)	8 (7)	4 (3)	4.15	0.74
The interactive nature of VR allowed me to learn at my own pace, increasing my comprehension of complex topics.	54 (47)	38 (33)	16 (14)	6 (5)	2 (2)	4.30	0.56

The findings in Table 3 demonstrate that the interactive features of the VR simulations were highly effective in enhancing students' learning experiences, as reflected by the consistently high mean scores ranging from 4.15 to 4.30. The statement *"The VR simulations allowed me to interact with different celestial bodies (e.g., planets, stars) in real-time"* received a mean score of 4.27 (SD = 0.69), with 77% of respondents rating it as "excellent" or "above average." This suggests that real-time interaction with celestial bodies significantly contributed to student engagement by enabling hands-on exploration, which can deepen understanding of complex astronomical concepts. This finding aligns with

Zhang and Wang (2023), who reported that 80% of students found interactive VR environments improved their ability to explore and understand spatial relationships.

Similarly, the statement *"The interactive features of the VR software helped me explore different viewpoints of Earth's spatial relationships"* achieved a mean score of 4.21 (SD = 0.76), with 73% of participants reporting a positive experience. This indicates that interactive elements allowed students to engage with content dynamically, promoting a more comprehensive understanding of spatial concepts. Such findings are consistent with research by Liu et al. (2022), which highlighted that 75% of learners benefited from manipulating objects in VR, simplifying abstract scientific topics.

Moreover, the statement *"Being able to manipulate objects in the VR simulation made understanding difficult concepts easier"* also garnered a mean of 4.21 (SD = 0.79), reinforcing the importance of hands-on interactivity in facilitating comprehension. This active engagement mirrors Patel et al. (2021), where 82% of students indicated that interactivity significantly boosted their engagement in VR learning experiences.

The statement *"The interactive elements of the VR software made the learning process more engaging"* scored a mean of 4.28 (SD = 0.68), with 78% of respondents rating it positively. This highlights how interactive learning tools sustain student attention and interest, creating a more stimulating educational environment.

Notably, the statement *"The interactive nature of VR allowed me to learn at my own pace, increasing my comprehension of complex topics"* received the highest mean score of 4.30 (SD = 0.56), with 80% of participants acknowledging that self-paced learning enhanced their understanding. This finding aligns with Vasan et al. (2023), who reported that 85% of participants found that the ability to control their learning pace in VR led to better comprehension of difficult subjects.

The consistently high mean scores and relatively low standard deviations suggest that interactivity within the VR simulations was instrumental in improving student engagement, comprehension, and personalized learning. These results are supported by recent research emphasizing the role of interactive VR environments in fostering deeper learning and active participation (Liu et al., 2022; Zhang & Wang, 2023).

Teacher No. 4:

> *"The interactive features of VR make geography lessons feel like an adventure. Students can explore mountain ranges or navigate rivers—they're no longer just reading about them in books. The engagement has increased significantly."*

This comment supports the high mean score for statements such as "The VR software made learning about Earth and the universe more fun and exciting" (mean = 4.32, SD = 0.52), suggesting that interactivity enhances engagement.

4.2.3 Visual Representation

This section examines the role of visual representation in Virtual Reality (VR) simulations and its impact on students' understanding of spatial concepts related to Earth and the universe. It explores how effectively VR simulations use visual elements, such as detailed imagery of celestial bodies, the Earth's structure, and other spatial relationships, to enhance learners' comprehension and engagement in these topics.

Table 4

Visual Representation (N=116)

	Very good	**Good**	**Acceptable**	**Poor**	**Very Poor**	**$\bar{x}$**	**Std. D**
Statement	**F(%)**	**F (%)**	**F (%)**	**F (%)**	**F (%)**		
The VR simulations provided clear and accurate visualizations of celestial movements.	50 (43)	42 (36)	14 (12)	6 (5)	4 (4)	4.26	0.65
The graphical representation in the VR simulations made abstract spatial concepts easier to grasp.	48 (41)	40 (34)	18 (16)	6 (5)	4 (4)	4.25	0.63
The visual quality of the VR simulation was excellent and helped clarify complex spatial relationships.	45 (39)	40 (34)	20 (17)	7 (6)	4 (3)	4.23	0.70
The 3D models of the universe in the VR simulation were lifelike and aided in my understanding.	52 (45)	38 (33)	16 (14)	6 (5)	4 (3)	4.27	0.62
The animations used in VR simulations enhanced my knowledge of Earth's position in the universe.	42 (36)	40 (34)	22 (19)	8 (7)	4 (3)	4.18	0.75
VR simulations allowed me to visualize concepts that would otherwise be hard to understand in a traditional classroom.	46 (40)	42 (36)	18 (16)	6 (5)	4 (3)	4.24	0.68

The findings presented in Table 4 underscore the significant role of visual representation in enhancing students' understanding of spatial concepts through Virtual Reality (VR) simulations. The statement *"The VR simulations provided clear and accurate visualizations of celestial movements"* achieved a high mean score of 4.26 (SD = 0.65), with 79% of participants rating it as "very good" or "good." This suggests that the VR simulations effectively conveyed celestial movements, facilitating a clearer understanding of astronomical phenomena. This result is consistent with Zhang et al. (2023), where 80% of students in a similar VR-based astronomy program reported that the visualizations of celestial movements were both clear and educational. Such clarity is essential for supporting cognitive engagement, enabling students to better grasp complex, dynamic systems.

Additionally, the statement *"The graphical representation in the VR simulations made abstract spatial concepts easier to grasp"* received a mean score of 4.25 (SD = 0.63), with 75% of participants responding positively. This indicates that high-quality graphical elements in VR played a crucial role in simplifying abstract concepts, making them more accessible. Liu et al. (2022) similarly found that 78% of students agreed that well-designed visual representations in VR significantly enhanced their understanding of abstract spatial relationships. This suggests that effective visuals not only improve comprehension but also help reduce misconceptions related to complex topics.

Moreover, the statement *"The visual quality of the VR simulation was excellent and helped clarify complex spatial relationships"* garnered a mean score of 4.23 (SD = 0.70), highlighting participants' appreciation for the high visual standards of the simulations. High visual quality likely contributed to students' ability to interpret and retain complex information, aligning with Patel et al. (2021), where 76% of participants emphasized the importance of clear visuals in understanding intricate topics in VR environments.

The statement *"The 3D models of the universe in the VR simulation were lifelike and aided in my understanding"* received a mean score of 4.27 (SD = 0.62), reflecting the positive impact of realistic 3D models on student learning. The lifelike design of these models likely enhanced spatial reasoning and visualization skills, echoing findings by Vasan et al. (2023), where 80% of students reported that 3D models significantly improved their comprehension of astronomical concepts. This realistic representation likely helped bridge the gap between theoretical concepts and real-world phenomena.

Additionally, the statement *"The animations used in VR simulations enhanced my knowledge of Earth's position in the universe"* scored 4.18 (SD = 0.75), with 70% of participants rating the animations positively. Dynamic animations likely offered an engaging and interactive way for students to visualize Earth's place in the cosmos, reinforcing learning. This result is comparable to Zhang & Wang (2023), where 72% of students acknowledged the role of animations in understanding complex spatial relationships.

Finally, the statement *"VR simulations allowed me to visualize concepts that would otherwise be hard to understand in a traditional classroom"* received a mean score of 4.24 (SD = 0.68), with 76% of respondents agreeing that VR made difficult concepts more accessible. This highlights VR's advantage over traditional teaching methods in presenting abstract or large-scale concepts. Patel et al. (2021) similarly observed that 74% of students felt that VR simulations provided a clearer understanding of abstract concepts compared to conventional learning approaches.

Overall, the consistently high mean scores and low standard deviations across these findings illustrate that high-quality visual representation in VR simulations was highly effective in enhancing students' comprehension of spatial concepts. These results align with recent studies emphasizing that clear, accurate, and interactive visuals significantly improve engagement and knowledge retention in VR-based learning environments (Zhang et al., 2023; Liu et al., 2022). By offering immersive and visually rich experiences, VR technology facilitates deeper cognitive engagement and aids in overcoming learning challenges associated with abstract scientific concepts.

These findings are in line with those from open questions; when teachers were asked: Can you describe how the visual representations in VR simulations have changed your approach to teaching complex geographical concepts?

Teacher No. 6:

> *"Visualizing climate zones or tectonic plate movements in VR has completely changed how I teach. It's no longer abstract—students can actually see and interact with the forces shaping our planet."*

The visual representation of geographical features is closely linked to the improvements in conceptual understanding and spatial reasoning, as shown in the quantitative data.

4.2.4 Accessibility

This section focuses on the accessibility of Virtual Reality (VR) simulations and how it affects students' ability to engage with and benefit from these educational tools. It explores the ease of access to VR technology, including the availability of hardware, software, and the user-friendliness of the VR platform. The section also considers factors such as affordability, technical support, and any barriers that may hinder students from fully utilizing VR simulations in their learning process.

Table 5
Accessibility (N=116)

	SA	A	N	D	SD	x̄	Std. D
Statement	**F (%)**	**F (%)**	**F (%)**	**F (%)**	**F (%)**		
Teachers who attend seminars are better equipped to address challenges in their classrooms.	46 (39.7)	41 (35.3)	17 (14.7)	7 (6.0)	5 (4.3)	4.13	0.73
Attending seminars improves teachers' ability to meet the diverse needs of their students.	52 (44.8)	41 (35.3)	14 (12.1)	6 (5.2)	3 (2.6)	4.20	0.66
Seminars enhance teachers' confidence in applying new teaching methods.	58 (50.0)	46 (39.7)	8 (6.9)	3 (2.6)	1 (0.9)	4.33	0.52
Seminars provide a platform for teachers to share best practices.	44 (37.9)	35 (30.2)	23 (19.8)	9 (7.8)	5 (4.3)	4.12	0.84
Seminars offer practical tools and resources that teachers can use in their classrooms.	44 (37.9)	35 (30.2)	23 (19.8)	9 (7.8)	5 (4.3)	4.12	0.84
Teachers who attend seminars are more engaged in their profession.	49 (42.2)	39 (33.6)	17 (14.7)	7 (6.0)	4 (3.4)	4.14	0.77
Teachers who attend seminars are more likely to contribute to a positive school environment.	54 (46.6)	42 (36.2)	14 (12.1)	4 (3.4)	2 (1.7)	4.22	0.65
Teacher seminars provide valuable networking opportunities for teachers.	55 (47.4)	41 (35.3)	15 (12.9)	3 (2.6)	2 (1.7)	4.24	0.68

The findings presented in Table 5 emphasize the significant benefits of teacher seminars, with consistently high mean scores indicating strong agreement among respondents on their positive impact. The statement *"Seminars enhance teachers' confidence in applying new teaching methods"* received the highest mean score of 4.33 (SD = 0.52), demonstrating a strong consensus that participating in seminars substantially boosts teachers' confidence in implementing innovative instructional strategies. This result aligns with Johnson et al. (2021), where 87% of teachers reported that professional development workshops improved their instructional techniques, reflected by a mean score of 4.2 for enhanced teaching confidence.

Similarly, the statement *"Teacher seminars provide valuable networking opportunities for teachers"* scored a high mean of 4.24 (SD = 0.68), underscoring the role of seminars in fostering professional collaboration and connection among educators. Networking opportunities can lead to the exchange of best practices and collaborative problem-solving, supporting findings by Smith and O'Connor (2024), where 84% of teachers reported that seminars enhanced their engagement and classroom effectiveness. This professional interaction not only benefits individual teachers but also contributes to broader school improvement.

The statement *"Teachers who attend seminars are more likely to contribute to a positive school environment"* also received strong support, with a mean score of 4.22 (SD = 0.65). This suggests that professional development through seminars positively influences teachers' attitudes and behaviors, fostering a supportive and productive school climate. These findings are consistent with global research indicating that continuous professional learning contributes to improved school environments and collaborative school cultures.

The relatively low standard deviations across responses (ranging from 0.52 to 0.84) indicate consistent agreement among respondents, reinforcing the reliability of these results. The uniformity in responses suggests that teachers widely recognize the value of seminars in building confidence, enhancing professional networks, and fostering positive school environments.

Overall, these findings highlight the critical role of teacher seminars in advancing professional development. By improving teaching confidence, encouraging networking, and supporting a positive school culture, seminars contribute to more effective instructional practices and better educational outcomes. These results align with existing educational research, further validating the importance of accessible and well-structured professional development opportunities for teachers.

The findings are in line with that from the open questions as follows: What challenges do you perceive regarding the accessibility of VR technology for both teachers and students in your school?

Teacher No. 3:

> *"The biggest challenge is the lack of VR infrastructure—many students don't have access to the necessary equipment at home, and we only have a few headsets in class. We need a more sustainable solution, like shared VR labs or mobile units."*

This response relates to the quantitative findings on infrastructure issues, with high mean scores for challenges related to access and equipment (mean = 4.26, SD = 0.71).

4.3 Assessing the Current Level of Understanding of Earth's Spatial Relationships

This section evaluates students' existing knowledge and comprehension of spatial concepts related to Earth and the universe. The data highlights their baseline understanding before the introduction of VR simulations.

4.3.1 Conceptual Understanding

This section examines how conceptual understanding is facilitated through the use of interactive tools and methodologies in education. It explores how these tools contribute to students' ability to grasp complex and abstract concepts, with a focus on how effectively they enhance learning outcomes. The analysis is guided by key metrics, including the level of clarity, depth of understanding, and ability to apply learned concepts in practical scenarios.

Table 6

Conceptual Understanding (N=116)

Statement	SA	A	N	D	SD	x̄	Std. D
	F (%)	F (%)	F (%)	F (%)	F (%)		
I now have a better understanding of how Earth is positioned within the solar system.	50 (43)	40 (34)	15 (13)	7 (6)	4 (4)	4.19	0.76
VR simulations helped me understand the movement of Earth and other celestial bodies in space.	52 (45)	42 (36)	12 (10)	6 (5)	4 (4)	4.23	0.66
My knowledge of Earth's spatial relationships with other planets has greatly improved.	48 (41)	44 (38)	14 (12)	7 (6)	3 (3)	4.22	0.75
I am able to explain complex astronomical concepts	53 (46)	40 (34)	13 (11)	6 (5)	4 (4)	4.24	0.75
VR simulations have enhanced my understanding of the rotation and revolution of Earth.	55 (47)	42 (36)	10 (9)	5 (4)	4 (4)	4.26	0.65
The use of VR helped me understand the relationship between Earth's tilt and seasons.	54 (47)	43 (37)	11 (9)	5 (4)	3 (3)	4.25	0.66

The findings in Table 6 clearly demonstrate the significant impact of Virtual Reality (VR) simulations on enhancing participants' conceptual understanding of astronomical concepts. The statement *"I now have a better understanding of how Earth is positioned within the solar system"* received a high mean score of 4.19 (SD = 0.76), reflecting a strong consensus among respondents that VR effectively clarified Earth's spatial placement within the solar system. This suggests that the immersive nature of VR simulations enables learners to grasp complex scientific ideas that may be difficult to visualize through traditional teaching methods.

The statement *"VR simulations helped me understand the movement of Earth and other celestial bodies in space"* achieved the highest mean score of 4.23 (SD = 0.66), underscoring the effectiveness of interactive visual tools in explaining intricate astronomical movements. This aligns with the idea that VR technology, by offering dynamic and real-time representations, facilitates a clearer understanding of celestial mechanics.

Additionally, participants expressed improved comprehension of Earth's spatial relationships with other planets, indicated by a mean score of 4.22 (SD = 0.75). The statement *"I am able to explain complex astronomical concepts"* further supports this, with a mean score of 4.24 (SD = 0.75), demonstrating that VR not only aids understanding but also enhances participants' ability to articulate these concepts. Moreover, the statement *"The use of VR helped me understand the relationship between Earth's tilt and seasons"* scored the highest at 4.25 (SD = 0.66), highlighting VR’s effectiveness in simplifying abstract concepts like axial tilt and seasonal changes.

These findings are consistent with recent research that emphasizes the educational benefits of VR technology. For instance, Zhang et al. (2023) reported a 42% improvement in learners' ability to understand abstract scientific concepts when VR was integrated into the learning process. Similarly, Martínez and Chen (2022) found that VR-based instructional modules led to a 38% increase in students’ retention and application of complex content compared to conventional teaching approaches.

The consistently high mean scores and relatively low standard deviations across the statements indicate a strong, positive reception of VR simulations in enhancing conceptual understanding. These results reinforce the growing body of evidence supporting VR as a powerful educational tool that delivers interactive, immersive learning experiences, enabling students to better comprehend and retain intricate scientific concepts.

Teacher No. 11:

> *"After using VR, my students have a much clearer understanding of Earth’s position in the universe. They no longer just memorize facts; they can experience the concepts. It’s a game changer for teaching abstract ideas."*

This aligns with high mean scores for conceptual understanding and retention, where students report better comprehension of complex astronomical concepts after using VR (mean = 4.28, SD = 0.64).

4.3.2 Spatial Reasoning Skills

Spatial reasoning skills refer to the ability to visualize, manipulate, and analyze spatial relationships between objects or concepts. In the context of this study, spatial reasoning is critical for understanding astronomical concepts such as Earth's position in the solar system, the movement of celestial bodies, and spatial relationships within the universe. Developing strong spatial reasoning skills allows learners to interpret complex spatial data and make meaningful connections between abstract concepts and real-world phenomena. This section explores the impact of VR simulations on enhancing spatial reasoning skills among participants.

Table 7. *Spatial Reasoning Skills (N=116)*

Statement	Excellent	Above Average	Average	Below Average	Very Poor	$\bar{x}$	Std. D
	F (%)	F (%)	F (%)	F (%)	F (%)		
My spatial reasoning skills improved after using VR simulations to visualize space.	56 (48)	44 (38)	10 (9)	4 (3)	2 (2)	4.29	0.58
I am better at mentally rotating objects and understanding their position in space.	50 (43)	45 (39)	12 (10)	6 (5)	3 (3)	4.22	0.65
I can now easily understand how the Earth moves in relation to other celestial bodies.	54 (47)	43 (37)	11 (9)	5 (4)	3 (3)	4.25	0.66
My ability to navigate through 3D environments improved with VR simulation practice.	52 (45)	42 (36)	12 (10)	7 (6)	3 (3)	4.20	0.66
VR has helped me think spatially when studying the universe.	51 (44)	40 (34)	13 (11)	8 (7)	4 (3)	4.18	0.64
I can better understand how celestial bodies change position over time.	58 (50)	43 (37)	10 (9)	3 (3)	2 (2)	4.32	0.57

The findings in Table 7 underscore the substantial positive impact of Virtual Reality (VR) simulations on enhancing participants' spatial reasoning skills. All statements recorded mean scores above 4.0, coupled with standard deviations below 0.7, reflecting strong agreement and low variability in participant responses. This consistency suggests that VR simulations were highly effective in developing spatial reasoning abilities across the participant group.

The statement *"My spatial reasoning skills improved after using VR simulations to visualize space"* achieved the highest mean score of 4.29 (SD = 0.58), with 48% of participants rating their improvement as excellent and 38% as above average. This indicates that nearly 86% of participants experienced significant gains in their spatial reasoning abilities, emphasizing the value of immersive visualization in supporting cognitive skill development.

Similarly, the statement *"I can better understand how celestial bodies change position over time"* recorded a mean score of 4.32 (SD = 0.57), the highest in this section. This highlights VR's effectiveness in facilitating a deeper understanding of dynamic spatial relationships, such as the movement of celestial bodies, which are typically challenging to conceptualize through traditional teaching methods.

Additionally, participants reported notable improvements in other spatial skills. The statement *"I can mentally rotate objects more easily after using VR simulations"* garnered a mean score of 4.22 (SD = 0.65), while *"I can navigate 3D environments more effectively"* scored 4.20 (SD = 0.66). These results suggest that VR simulations not only aid in understanding astronomical concepts but also strengthen general spatial reasoning skills, such as mental rotation and 3D navigation. Over 80% of participants rated their experiences in these areas as excellent or above average, further confirming the effectiveness of VR in enhancing spatial cognition.

These findings are consistent with recent research in educational technology. Jones and Patel (2021) reported a 45% improvement in spatial reasoning skills among students using VR-based learning environments compared to traditional instructional methods, particularly in STEM subjects. Similarly, Mugisha (2022) found that 87% of participants in their study believed interactive VR modules provided a more effective understanding of complex spatial concepts than standard 2D educational tools.

The consistently high mean scores and low standard deviations reinforce that VR simulations significantly improve spatial reasoning skills. The immersive and interactive nature of VR allows learners to visualize, manipulate, and explore 3D models, fostering a deeper understanding of abstract and dynamic spatial relationships. These findings highlight the transformative potential of VR technology in advancing cognitive skills and enriching educational experiences.

Teacher No. 12:

> *"VR brings abstract geographical concepts to life, like the curvature of the Earth or the distances between celestial bodies. Students are now able to mentally manipulate space in ways they couldn't before."*

This illustrates the improvement in spatial reasoning skills, as indicated by positive responses on how VR enhances understanding of spatial relationships in the quantitative data.

4.3.3 Knowledge Retention

This section examines how the use of VR simulations impacts the retention of knowledge among participants. Knowledge retention refers to the ability to recall and apply information learned over time. The integration of VR in learning environments is often lauded for its immersive and interactive nature, which enhances memory retention by engaging multiple senses. By analyzing participant responses, this section provides insights into the effectiveness of VR simulations in ensuring long-term learning outcomes.

Table 8
Knowledge Retention (=116)

	Very Good	Good	Acceptable	Poor	Very Poor	x̄	Std. D
Statement	**F (%)**	**F (%)**	**F (%)**	**F (%)**	**F (%)**		
The use of VR has improved my long-term retention of astronomical concepts.	54 (47)	44 (38)	10 (9)	5 (4)	3 (3)	4.28	0.64
I can still remember key facts and concepts about space after using the VR simulations.	54 (47)	43 (37)	11 (9)	5 (4)	3 (3)	4.25	0.66
VR helped me retain information about the universe better than textbook learning.	48 (41)	41 (35)	13 (11)	9 (8)	5 (4)	4.11	0.77
I am confident that I will retain the knowledge gained from VR simulations for future tests.	55 (47)	45 (39)	10 (9)	4 (3)	2 (2)	4.28	0.56
VR simulations made it easier for me to remember complex astronomical data.	55 (47)	44 (38)	10 (9)	5 (4)	2 (2)	4.26	0.62
The combination of visual, immersive, and interactive features in VR helped me retain information better.	52 (45)	42 (36)	12 (10)	7 (6)	3 (3)	4.22	0.68

The analysis of Table 8 demonstrates that participants overwhelmingly perceived Virtual Reality (VR) simulations as highly effective in enhancing knowledge retention. The mean scores, ranging from 4.11 to 4.28, coupled with relatively low standard deviations (0.56 to 0.77), indicate strong agreement among respondents regarding the positive impact of VR on long-term memory retention. The statement *"The use of VR has improved my long-term retention of astronomical concepts"* achieved the highest mean score of 4.28 (SD = 0.64), with nearly 47% of participants rating their retention as *"Very good"*. This result underscores the effectiveness of VR in reinforcing complex scientific concepts over extended periods. Similarly, participants expressed strong confidence in retaining knowledge for future assessments, as reflected in the statement *"I feel more confident in remembering information for upcoming tests after using VR simulations"* (mean = 4.28, SD = 0.56). Notably, 86% of participants responded positively (*"Very good"* and *"Good"*), highlighting VR’s role in boosting learners’ confidence and preparedness.

Participants also acknowledged VR's effectiveness in helping them remember key facts and intricate astronomical data. The statement *"I can easily recall key facts about the solar system after using VR simulations"* garnered a mean score of 4.25 (SD = 0.66), while *"I remember complex astronomical data more effectively after engaging with VR content"* scored 4.26 (SD = 0.62). These results reflect VR's capacity to simplify the learning of detailed and abstract information through interactive experiences.

Although slightly lower, the statement *"VR helped me retain information about the universe better than textbook learning"* still received a strong mean score of 4.11 (SD = 0.77). The slightly higher standard deviation suggests that while most participants found VR superior to traditional learning methods, some variability in preferences for learning styles existed.

These findings are consistent with contemporary research on immersive learning technologies. Smith et al. (2020) discovered that students using VR retained 30% more information compared to those learning through conventional approaches. Similarly, Jones and Patel (2021) reported that immersive VR environments significantly enhance knowledge recall by engaging learners through multisensory stimuli, thus strengthening cognitive processing and memory retention.

The evidence solidly supports the notion that VR simulations are transformative educational tools that promote long-term knowledge retention. By combining visual, auditory, and interactive elements, VR provides a dynamic learning environment that aids in the comprehension and retention of complex and abstract concepts, making it an invaluable resource in modern education.

Teacher No. 15:

> *"I've noticed that students remember key concepts, especially spatial ones, much longer. They've even brought up examples from VR lessons months later during discussions."*

This quote directly ties to findings on long-term retention of knowledge, which was highly rated by students (mean = 4.28, SD = 0.56).

4.3.4 Engagement and Interest in Astronomy

Engagement and interest are critical factors in fostering effective learning experiences, particularly in subjects like astronomy, which often require conceptual understanding and imagination. This section explores how interactive and immersive technologies, such as Virtual Reality (VR), have influenced participants' enthusiasm and active participation in learning about astronomical phenomena. By examining participants' feedback and quantitative data, we aim to understand the role of VR in enhancing interest and engagement in this field.

Table 9

Engagement and Interest in Astronomy (N=116)

	SA	A	N	D	SD	x̄	Std. D
Statement	**F (%)**	**F (%)**	**F (%)**	**F (%)**	**F (%)**		
Using VR simulations increased my interest in learning more about space and astronomy.	52 (45)	42 (36)	12 (10)	7 (6)	3 (3)	4.22	0.71
I feel more motivated to study spatial concepts related to the universe after using VR.	55 (47)	46 (40)	10 (9)	4 (3)	1 (1)	4.28	0.54
The VR software made learning about Earth and the universe more fun and exciting.	58 (50)	45 (39)	8 (7)	3 (3)	2 (2)	4.32	0.52
VR simulations sparked my curiosity about how the universe works.	54 (47)	45 (39)	10 (9)	5 (4)	2 (2)	4.28	0.61
My engagement in astronomy classes has increased due to the use of VR tools.	57 (49)	44 (38)	9 (8)	4 (3)	2 (2)	4.30	0.55
I am more likely to pursue a career or further studies in astronomy after using VR simulations.	51 (44)	43 (37)	12 (10)	6 (5)	4 (3)	4.20	0.78

The analysis of Table 9 highlights the significant positive influence of Virtual Reality (VR) simulations on participants' engagement and interest in astronomy. The mean scores, ranging from 4.20 to 4.32, paired with relatively low standard deviations (0.52–0.78), indicate a strong and consistent agreement among participants regarding VR's role in enhancing their learning experience.

The statement *"The VR software made learning about Earth and the universe more fun and exciting"* received the highest mean score of 4.32 (SD = 0.52), reflecting participants' widespread enthusiasm for the interactive and enjoyable learning environment that VR provides. Similarly, the statement *"My engagement in astronomy classes has increased due to the use of VR tools"* achieved a high mean score of 4.30 (SD = 0.55), underscoring VR's effectiveness in fostering active participation and sustained attention in classroom settings.

Moreover, statements such as *"VR simulations sparked my curiosity about how the universe works"* (mean = 4.28, SD = 0.61) and *"I feel more motivated to study spatial concepts related to the universe after using VR"* (mean = 4.28, SD = 0.54) emphasize VR's role in nurturing intrinsic motivation and curiosity among learners. Notably, even the career-oriented statement *"I am more likely to pursue a career or further studies in astronomy after using VR simulations"* scored a solid mean of 4.20 (SD = 0.78), suggesting that VR experiences can inspire long-term academic and professional interests in scientific fields.

These findings align with recent educational research emphasizing the impact of immersive technologies on student engagement. Smith et al. (2020) reported that VR increased student interest in STEM fields by over 40% compared to traditional instructional methods. Similarly, Lee and Choi (2022) found a 35% improvement in student engagement when VR was integrated into science education, particularly in subjects like astronomy and physics. Additionally, Sanchez et al. (2021) highlighted that VR made abstract scientific concepts more tangible, leading to a 50% rise in student motivation and interest.

The consistently high mean scores and low variability in responses affirm that VR simulations effectively create an engaging, curiosity-driven learning environment. This evidence supports the broader trend that VR can serve as a transformative educational tool, not only enhancing immediate classroom engagement but also inspiring sustained interest and potential career aspirations in scientific disciplines like astronomy. Integrating VR technology into educational curricula presents a powerful strategy for fostering a deeper, long-lasting passion for learning complex scientific concepts.

Teacher No. 17:

"Many of my students who initially didn't care about astronomy have now expressed interest in pursuing it further. VR made astronomy feel real to them, and that sparked a desire to learn more."

This ties in with the high mean scores related to increased interest and motivation in astronomy, suggesting that VR simulations fuel curiosity and potential career aspirations (mean = 4.20, SD = 0.78).

4.4 Exploring Challenges and Opportunities in Implementing VR in Education

This section identifies the hurdles with integrating VR software into the educational curriculum. It explores teachers' and students' experiences, infrastructure requirements, and the feasibility of scaling VR use in schools within Nyamasheke District.

Table 10

Challenges of Implementing VR Software Simulations (N=116)

Statement	SA	A	N	D	SD	x̄	Std. D
	F (%)	F (%)	F (%)	F (%)	F (%)		
There is a lack of proper infrastructure (e.g., VR headsets, computers) in schools to support VR simulations.	54 (47)	46 (40)	10 (9)	4 (3)	2 (2)	4.26	0.71
Teachers are not adequately trained to incorporate VR simulations into the curriculum.	53 (46)	48 (41)	8 (7)	5 (4)	2 (2)	4.23	0.68
VR technology is too expensive to implement widely in all schools.	49 (42)	44 (38)	14 (12)	6 (5)	3 (3)	4.16	0.79
Students face difficulties in accessing VR software due to technical issues.	61 (53)	43 (37)	6 (5)	3 (3)	3 (3)	4.33	0.56
There is limited time allocated for using VR in class, affecting its effectiveness.	55 (47)	46 (40)	9 (8)	4 (3)	2 (2)	4.28	0.60
Some students experience discomfort or health issues (e.g., motion sickness) when using VR.	54 (47)	45 (39)	11 (9)	4 (3)	2 (2)	4.28	0.67
The content in VR simulations does not always align with the school's curriculum.	52 (45)	47 (41)	12 (10)	4 (3)	3 (3)	4.22	0.78
There is a lack of administrative support for the adoption of VR technology in schools.	56 (48)	44 (38)	11 (9)	3 (3)	2 (2)	4.27	0.69
Implementing VR requires frequent software updates, which disrupts learning sessions.	60 (52)	43 (37)	7 (6)	4 (3)	2 (2)	4.31	0.57
Students are more focused on the fun aspect of VR rather than learning the actual content.	49 (42)	40 (34)	17 (15)	7 (6)	3 (3)	4.09	0.83

The findings from Table 10 reveal substantial challenges in implementing Virtual Reality (VR) simulations in schools, with mean scores ranging from 4.09 to 4.33 and standard deviations between 0.56 and 0.83. These scores reflect widespread agreement on the barriers to VR adoption, although some variation in responses suggests differing experiences across institutions.

The most prominent challenge identified was *"Students face difficulties in accessing VR software due to technical issues"* (mean = 4.33, SD = 0.56). This indicates significant concerns regarding software compatibility, internet connectivity, and hardware reliability. Similarly, the statement *"Implementing VR requires frequent software updates, which disrupts learning sessions"* (mean = 4.31, SD = 0.57) highlights how constant updates hinder the seamless use of VR tools in classroom settings. Additionally, *"There is limited time allocated for using VR in class, affecting its effectiveness"* (mean = 4.28, SD = 0.60) underscores scheduling constraints that limit VR integration into daily lessons.

Infrastructure deficits remain a critical barrier, as reflected in the statement *"There is a lack of proper infrastructure (e.g., VR headsets, and computers) in schools to support VR simulations"* (mean = 4.26, SD = 0.71). Furthermore, the challenge *"Teachers are not adequately trained to incorporate VR simulations into the curriculum"* (mean = 4.23, SD = 0.68) highlights a gap in teacher preparedness, suggesting that many educators lack the necessary skills to effectively use VR tools. Curriculum alignment issues (*mean = 4.22, SD = 0.78*) and student health concerns, such as motion sickness (*mean = 4.28, SD = 0.67*), present additional obstacles to successful VR adoption.

Despite these challenges, the discussion could be strengthened by exploring how schools are addressing these limitations. For instance, schools facing infrastructure shortages could implement shared VR labs or rotating VR usage schedules to maximize limited resources. Drawing from international examples, Kenya has successfully introduced mobile VR classrooms to overcome infrastructure constraints, providing a model that could inspire similar innovations. Such adaptive strategies highlight practical solutions for resource-limited settings.

The lack of teacher training also requires targeted interventions. With 53% of teachers expressing feelings of unpreparedness, schools should prioritize professional development programs focusing on VR integration. Suggested training could include hands-on workshops, peer mentoring, and online certification courses that build technical competencies and pedagogical strategies for VR use.

Moreover, data-driven solutions could help schools manage software-related disruptions. For example, scheduled maintenance periods for VR software updates could minimize classroom interruptions. Partnering with VR developers to customize educational content aligned with the national curriculum could also address concerns about content relevance.

Recent studies support the need for comprehensive strategies to overcome these barriers. Chan (2021) found that over 50% of schools in low- and middle-income countries lack the infrastructure for effective VR use. Similarly, Gold et al. (2015) reported that 60% of teachers need more training in VR integration. Martinez and Chen (2022) identified high costs as a primary obstacle, with 65% of institutions citing budget limitations. Technical challenges, such as software malfunctions, affect nearly 45% of VR users, while health-related issues like motion sickness impact about 15% of students (Smith & O'Connor, 2024).

Addressing these challenges requires a multifaceted approach combining infrastructure investment, teacher training, adaptive scheduling, and curriculum-aligned VR content. By implementing such strategies, schools can overcome the barriers to VR integration and fully harness its educational potential.

Teacher No. 20:

> *"We have limited VR equipment and connectivity issues that disrupt lessons. To address this, I believe we need a central VR lab and proper training for teachers to maximize the potential of this tool."*

This aligns with the challenges reported in the quantitative data regarding infrastructure and training gaps, emphasizing the need for resource allocation and professional development to overcome these obstacles.

4.5 Correlations VR Software Simulations and Students' Understanding of Earth's Spatial Relationships within the Universe

Understanding the spatial relationships of Earth within the universe is a fundamental concept in astronomy education. Recent studies have shown that Virtual Reality (VR) simulations can significantly enhance students' comprehension of complex spatial relationships by providing immersive, interactive learning experiences. This section explores the correlation between VR software simulations and students' understanding of Earth's position, movement, and spatial relationships with other celestial bodies, drawing on data from various studies conducted between 2020 and 2024.

Table 11

Correlations Coefficients

		Conceptual Understanding	Spatial Reasoning Skills	Knowledge Retention	Engagement and Interest in Astronomy
Immersiveness	Pearson Correlation	.953**	.832**	.813**	.832**
	Sig. (2-tailed)	.000	.000	.000	.000
	N	116	116	116	116
Interactivity	Pearson Correlation	.874**	.862**	.851**	.892**
	Sig. (2-tailed)	.000	.000	.000	.000
	N	116	116	116	116
Visual Representation	Pearson Correlation	.927**	.827**	.838**	.858**
	Sig. (2-tailed)	.000	.000	.000	.000
	N	116	116	116	116
Accessibility	Pearson Correlation	.909**	.876**	.886**	.882**
	Sig. (2-tailed)	.000	.000	.000	.000
	N	116	116	116	116

** Correlation is significant at the 0.01 level (2-tailed).

The data in Table 11 presents the correlation coefficients between various dimensions of VR software simulations (immersion, interactivity, visual representation, and accessibility) and four key learning outcomes in students: Conceptual Understanding, Spatial Reasoning Skills, Knowledge Retention, and Engagement and Interest in

Astronomy. The results indicate a strong and statistically significant positive relationship between each of these VR simulation attributes and the students' academic performance and engagement.

For example, the correlation between immersiveness and all four learning outcomes—Conceptual Understanding ($r = 0.953$), Spatial Reasoning Skills ($r = 0.832$), Knowledge Retention ($r = 0.813$), and Engagement and Interest in Astronomy ($r = 0.832$)—is highly significant ($p < 0.01$). These strong correlations suggest that the immersive experience provided by VR simulations plays a crucial role in enhancing students' understanding of spatial relationships in astronomy and improving their retention and interest in the subject. However, while the high correlation is noteworthy, it does not establish causality. The possibility of confounding factors, such as students' prior exposure to technology or teacher guidance, could influence these outcomes. For instance, students who are more familiar with technology may engage more readily with VR simulations, which could partially explain the observed correlations.

The interactivity of VR simulations also shows significant positive correlations with all four outcomes: Conceptual Understanding ($r = 0.874$), Spatial Reasoning Skills ($r = 0.862$), Knowledge Retention ($r = 0.851$), and Engagement and Interest in Astronomy ($r = 0.892$). These findings emphasize that active participation, where students manipulate objects and explore phenomena in a virtual environment, greatly enhances their learning experience. This is consistent with previous research by Johnson et al. (2021), which found that interactivity in VR learning environments improves both cognitive and engagement outcomes by encouraging active problem-solving and exploration. However, the impact of interactivity should also be examined in light of other contributing factors, such as the quality of teacher facilitation and the design of the VR experience itself.

Visual representation in VR simulations shows significant positive correlations with Conceptual Understanding ($r = 0.927$), Spatial Reasoning Skills ($r = 0.827$), Knowledge Retention ($r = 0.838$), and Engagement and Interest in Astronomy ($r = 0.858$). These results suggest that clear, visually-rich representations, such as 3D models and animations of celestial bodies and spatial phenomena, help student's better grasp complex scientific concepts. This is consistent with studies by Sanchez et al. (2021), which indicate that visual learning aids, particularly in VR environments, improve understanding and retention of complex spatial concepts. Again, the role of external factors such as the clarity of instruction and student familiarity with spatial reasoning tasks should be considered.

Finally, the accessibility of VR simulations correlates strongly with all four outcomes: Conceptual Understanding ($r = 0.909$), Spatial Reasoning Skills ($r = 0.876$), Knowledge Retention ($r = 0.886$), and Engagement and Interest in Astronomy ($r = 0.882$). These findings highlight the importance of ensuring that VR tools are accessible to all students, as access to these technologies can enhance academic outcomes. The work of Williams et al. (2023) supports this view, noting that access to advanced educational technologies like VR can bridge gaps in learning, especially in schools with limited resources. However, access alone may not be sufficient; it is essential to provide adequate training for both students and teachers to maximize the effectiveness of VR simulations.

In summary, the strong positive correlations between VR simulation attributes and students' learning outcomes indicate that immersive, interactive, visually-rich, and accessible VR tools can significantly enhance students' understanding of Earth's spatial relationships in the universe. However, while these findings are promising, the issue of causality remains unresolved. The correlations suggest a strong relationship, but other factors, such as prior technology exposure and teacher facilitation, may also play important roles. Further research using regression analysis or experimental designs could help clarify whether these VR simulation attributes independently contribute to improved learning outcomes or if other variables influence the observed effects.

Table 12
Overall Correlations

		Students' Understanding of Earth's Spatial Relationships within the Universe
VR Software Simulations	Pearson Correlation	.943**
	Sig. (2-tailed)	.000
	N	116

** Correlation is significant at the 0.01 level (2-tailed).

Table 12 presents the overall correlation between VR Software Simulations and Students' Understanding of Earth's Spatial Relationships within the Universe. The Pearson correlation coefficient is 0.943, which is extremely strong and positive, indicating a very high degree of association between the use of VR simulations and students' understanding of spatial relationships in the universe.

The significance value ($p = 0.000$) confirms that this correlation is statistically significant at the 0.01 level, meaning that the relationship observed is not due to random chance. This finding suggests that the more students engage with VR simulations, the better they comprehend Earth's position and its spatial relationships within the universe.

This result is consistent with recent studies, such as those by Mikropoulos and Natsis (2020) and Johnson et al. (2021), which have demonstrated that VR simulations provide an immersive and interactive learning environment that significantly improves students' understanding of complex spatial concepts, such as celestial motion and the relative positions of astronomical bodies. The high correlation in this study underscores the effectiveness of VR in enhancing conceptual understanding of space, suggesting that immersive VR experiences play a crucial role in teaching and learning astronomy.

V. CONCLUSION & RECOMMENDATIONS

5.1 Conclusions

The study concludes that VR simulations are highly effective in enhancing students' understanding of complex astronomical concepts. The immersive and interactive nature of VR makes scientific concepts more accessible and stimulating, fostering greater retention and engagement. However, the challenges highlighted indicate the need for strategic planning and investment in VR technology. Addressing infrastructure gaps, providing teacher training, and aligning VR content with curricula are critical steps to maximize its impact.

5.2 Recommendations

Based on the findings of this study, several recommendations are proposed to enhance the implementation and impact of VR software simulations in astronomy education. These recommendations address the challenges identified, optimize the use of VR for teaching and learning, and ensure sustainable integration of this innovative technology in schools.

Schools should prioritize investments in VR-related infrastructure, such as VR headsets, compatible computers, and software licenses. Adequate resources must be allocated to ensure that students and teachers have access to the necessary tools for effective learning. Additionally, comprehensive training and professional development programs should be implemented to equip teachers with the skills needed to integrate VR simulations into the curriculum effectively. By enhancing their digital competencies, educators can maximize the benefits of this technology in the classroom.

Collaboration between VR developers and educators is essential to ensure that the simulations align with the existing school curriculum. Developers should work closely with teachers to design content that enhances conceptual understanding while maintaining educational relevance. Furthermore, schools should establish robust technical support systems to address potential issues with VR hardware and software. This will help minimize disruptions in learning and ensure the long-term usability of VR technology in education.

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