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Article

Fostering Creative Thinking Using Immersive Virtual Reality in Education

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Abstract: The integration of Virtual Reality (VR) in education fosters creative thinking by immersing students in interactive, 3D environments that go beyond traditional learning methods. This study aims to explore how immersive VR can enhance creativity, focusing on key aspects such as sensory engagement, interactivity, and experiential learning. By providing rich sensory stimulation (visual, auditory, and haptic feedback) and enabling risk-free experimentation, VR encourages students to think divergently, solve problems creatively, and engage deeply with content. The impact of VR on creativity was confirmed using including pre- and post-assessments of creativity with the Torrance Tests of Creative Thinking (TTCT) and feedback from students and educators. Significant improvements in creativity in art and design, education, gaming, media, healthcare, originality, and flexibility were observed in students exposed to VR. The technological infrastructure is required for VR integration while it is the challenges of accessibility and scalability at the same time. The findings support VR as a transformative tool in education to promote creative exploration and enhance cognitive engagement in learners.

Keywords: Virtual Reality, Creative Thinking, Education

1. Introduction

Creativity has become a core competence for individuals in the modern world. Traditional education systems, with their focus on standardized testing and rigid curriculums, often fail to foster this crucial skill. Virtual Reality (VR), an emerging technology in educational spaces immerses students and stimulates their creative thinking (Bailey 2021) (Table 1). This study aims to examine the effectiveness of a VR environment in enhancing creativity among students and determine how VR can act as a tool for educators to foster divergent thinking, facilitate experiential learning, and promote problem-solving skills in students (Leong 2023a, Leong 2024a).

Table 1. Comparison of traditional learning methods, digital learning, and VR environment in terms of creativity stimulation.

Criteria	Traditional Learning	Digital Learning	VR Environment
Engagement Level	Moderate	High	Very High
Sensory Stimulation	Limited	Moderate (Audio-Visual Content)	Rich (3D Visuals, Audio, Haptic Feedback)
Interactivity	Low (Text and Lecture-Based)	Medium (Click-and-Learn)	High (Interactive Tools)
Immersive Experience	None	None	Full Immersion
Visual and Spatial Understanding	Limited to 2D materials	Moderate (2D and Animated Content)	Advanced 3D Understanding
Risk-Free Experimentation	Limited	Limited	High
Creativity Encouragement	Moderate, heavily structured	High, with structured and semi-open tasks	Very High, with open-ended creative exploration

VR technology is creating a paradigm shift in the educational landscape by introducing an immersive learning environment. Unlike traditional educational tools, VR offers an interactive experience that places students in lifelike settings, enhancing both their engagement and understanding (Brown 2019). Figure 1 shows the key components of the immersive VR environment, which illustrates elements such as sensory stimulation, interactivity, immersive experience, and user engagement. The figure provides a clear understanding of how different components contribute to the overall VR experience, especially in education. From exploring historical sites to simulating chemical reactions in a virtual lab, VR enables experiential learning beyond the limitations of a classroom. In this study, an overview of the role of the immersive VR environment in education was examined in terms of benefits, challenges, applications, and potential future directions.

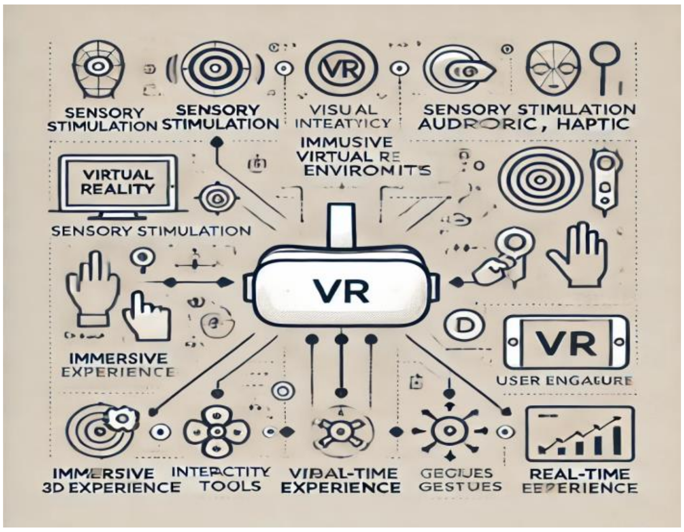

Fig. 1. Key components of immersive VR environment.

VR in education has evolved significantly over the past decade, from experimental pilot programs to a tool being adopted in classrooms worldwide. VR offers a range of benefits for education. VR provides an environment for active learning, where students can interact with content rather than passively consume it. Studies have demonstrated that VR can increase information retention and comprehension (Clark and Mayer, 2016). The immersive VR environment captures students' attention and sustains their interest, making learning enjoyable (Johnson et al., 2020). VR enables students to experience places and phenomena that are otherwise inaccessible. For example, students can travel to ancient Rome or explore the structure of a human cell in 3D. Despite its advantages, challenges are associated with implementing VR in educational settings. High costs, lack of teacher training, and accessibility issues have limited the widespread use of VR in classrooms (Brown & Williams, 2019).

2. Applications of VR in Education

Virtual Reality can be applied across various educational disciplines, offering advantages that traditional methods cannot. VR allows students to conduct experiments in a safe virtual environment. For example, virtual labs enable students to explore complex chemical reactions without the risk of injury or damage. This application not only enhances understanding but also instills a sense of exploration and curiosity.

2.1. History Education: Virtual Historical Tours

VR makes it possible to "travel" to historical landmarks, ancient civilizations, or geographic locations in a matter of minutes. For instance, students can explore the Colosseum using VR headsets (Fig. 2). They can have an immersive learning experience that far exceeds what textbooks can offer. VR allows students to take immersive tours of historical landmarks such as the Roman Colosseum. Students can interact with the environment, explore artifacts, and experience history in a deeply engaging way (Table 2). Figure 3 shows a labeled map showing a VR tour route through the Colosseum, with key historical points such as the Gladiator Arena, Emperor's Box, Entry Gate, and Audience Seats. The route is marked with a blue dashed line, highlighting the stops for deeper learning within the virtual environment.

Fig. 2. A virtual tour of the Roman Colosseum, with students using VR headsets to explore the ancient structure and experience life in ancient Rome.

Table 2. Comparison of textbook learning vs. VR historical tours.

Aspect	Textbook Learning	VR Historical Tours
Visual Understanding	Limited to 2D images	3D interactive environments
Engagement Level	Low	Very high
Cultural Context	Limited to text explanations	Immersive, realistic context
Interaction	None	Full interaction

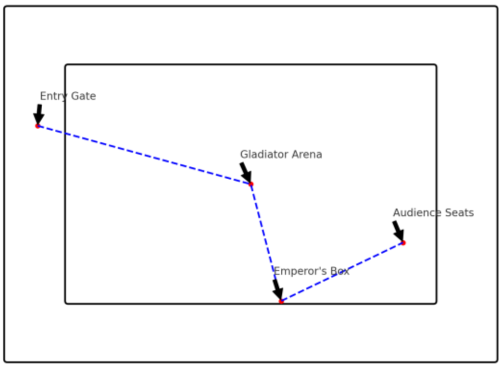

Fig. 3. A labeled map showing a VR tour route through the Colosseum, with stops at key historical points for deeper learning.

2.2. Medical Education: Virtual Surgery

In medical education, VR provides students with an opportunity to practice surgeries or understand anatomy without a cadaver. Tools such as VR simulations for medical procedures help students gain practical skills in a risk-free environment (Bailenson, 2018) (Fig. 4). VR provides medical students with realistic surgery simulations. They can practice surgical techniques, explore anatomy, and receive real-time feedback, which reduces the risk of errors in real-life surgeries. Figure 4 shows the image of a virtual surgery setup and medical students performing complex operations using virtual instruments on a detailed, 3D-rendered human body. This immersive environment provides real-time feedback for students to learn surgical techniques in a safe and controlled virtual setting (Table 3). Figure 5 guides medical students to perform complex operations using virtual instruments on a 3D-rendered human body. It highlights key components such as VR headsets, virtual tools, and real-time feedback displays. This layout provides a clear and informative look at the educational aspects of virtual surgery.

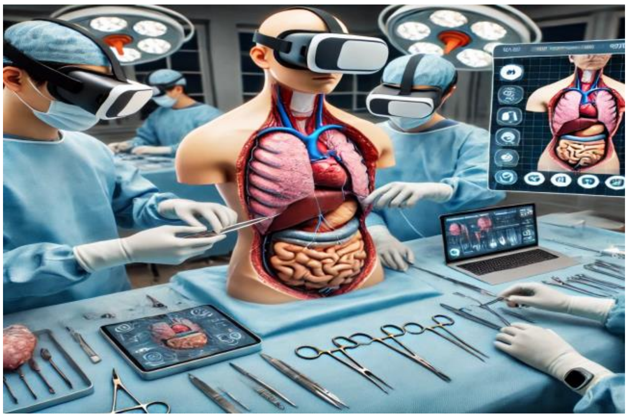

Fig. 4. A virtual surgery setup where medical students perform complex operations using virtual instruments on a detailed, 3D-rendered human body.

Table 3. Traditional Surgery Training vs. VR Surgery Training

Aspect	**Textbook Learning**	**VR Historical Tours**
Hands-On Practice	Limited to cadavers or models	Unlimited, virtual patients
Risk to Patients	Potentially risky	Completely risk-free
Feedback	Instructor feedback only	Real-time, AI-driven feedback
Anatomy Understanding	Limited visualization	Detailed 3D anatomy

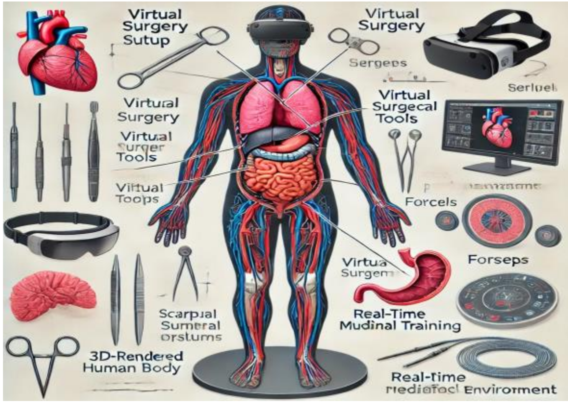

Fig. 5. A virtual surgery setup where medical students perform complex operations using virtual instruments on a detailed, 3D-rendered human body.

2.3. Language Learning: Virtual Language Immersion

VR is also used in language learning to engage students in real-life conversations with virtual characters in an immersive environment. This method enhances language acquisition by offering an immersive, context-rich experience. Students practice real-world conversations in virtual environments, such as ordering food at a restaurant or asking for directions in a virtual foreign city. Figure 6 shows the image of a student in a VR language environment, where the student practices conversation skills by interacting with a virtual vendor in a marketplace. The scene emphasizes immersive learning with cultural elements, creating a vibrant, realistic setting presented in Table 4. Figure 7 shows a student in a VR language learning environment, interacting with a virtual vendor in a marketplace. It highlights key components including the VR headset, virtual vendor, marketplace stalls, and conversation prompts, illustrating the immersive and interactive learning process.

Fig. 6. A student in a VR language environment, practicing conversation skills by interacting with a virtual vendor in a marketplace.

Table 4. Traditional language learning vs. VR language learning.

Aspect	Traditional Learning	VR Language Immersion
Speaking Practice	Limited to class time	Available anytime in VR
Confidence Building	Slower due to limited interaction	Rapid, immersive practice

Cultural Understanding	Limited to reading	Full immersion in virtual cultural environments
Interaction	Classroom-based	Full interaction with virtual characters

Fig. 7. A student in a VR language environment, practicing conversation skills by interacting with a virtual vendor in a marketplace.

2.4 Engineering: Virtual Prototyping and Simulation

In engineering, VR allows students to design and test prototypes virtually (Leong 2024b, Leong 2012). They can build models of bridges, cars, or buildings and subject them to virtual stress tests and environmental conditions (Lee 2009). Figure 8 presents the image of a student in a VR engineering environment, testing a bridge prototype for structural integrity using virtual forces and seeing real-time data on stress and strain (Leong 2023b). The scene emphasizes the immersive nature of structural analysis in a high-tech engineering lab (Table 5). Figure 9 shows the step-by-step diagram of the engineering process in VR, showing the stages of designing a model, applying stress tests, analyzing the results, and refining the prototype. The diagram emphasizes the iterative nature of the process, with clear and informative visuals.

Fig. 8. A student in a VR engineering environment, testing a bridge prototype for structural integrity using virtual forces and seeing real-time data on stress and strain.

Table 5. Physical prototyping vs. virtual prototyping.

Aspect	Physical Prototyping	VR Prototyping
Material Cost	High	Low
Testing Flexibility	Limited to available materials	Full flexibility, various environments
Time Efficiency	Time-consuming	Rapid testing and iteration
Environmental Impact	Generates waste	No waste produced

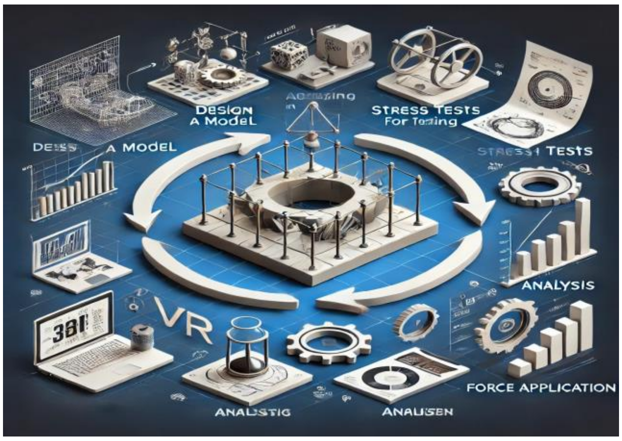

Fig. 9. A step-by-step diagram of the engineering process in VR: designing a model, applying stress tests, analyzing the results, and refining the prototype.

2.5. Art and Design: 3D VR Art Creation

Artists and designers use VR tools such as Google Tilt Brush to create 3D artwork in an immersive, limitless environment. They can sculpt, paint, and create with tools that go beyond the limitations of traditional mediums (Table 6). Students can use VR art tools to paint in 3D space, with vivid colors and creative designs and have the immersive experience of creating art in virtual reality such as 3D painting (Fig. 10). Figure 11 shows the flow diagram illustrating the creative process in VR for artists, from selecting tools to manipulating 3D objects and creating digital sculptures. Figure 11 emphasizes the step-by-step workflow in a virtual reality environment.

Table 6. Traditional art vs. VR art creation.

Aspect	**Traditional Art**	**VR Art Creation**
Material Cost	High	Minimal after setup
Canvas Size	Limited to physical size	Infinite in 3D space
Collaboration	Physical space constraints	Multi-user collaboration
Editing and Undoing	Difficult to correct	Easy with undo features

Fig. 10. A student using VR art tools to paint in 3D space, with vivid colors and creative designs forming around them.

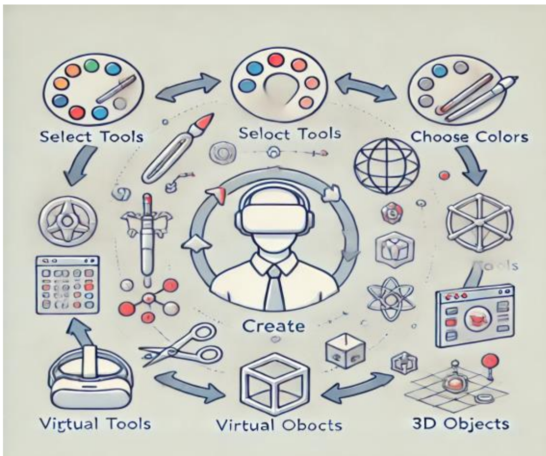

Fig. 11. A flow diagram showing how artists create in VR, starting with selecting tools, then choosing colors, and manipulating 3D objects to create digital sculptures.

3. Literature Review

The concept of immersive VR has its roots in the 1960s when early VR prototypes such as Morton Heilig's "Sensorama" and Ivan Sutherland's "Ultimate Display" laid the foundation for virtual experiences. However, VR remained largely theoretical until technological advancements in the 1990s made early VR systems more practical, albeit expensive. By the early 2000s, VR had limited applications in medical training and flight simulations. As technology advanced, VR headsets such as Oculus Rift (2012) enabled affordable, high-quality immersive experiences to a broader audience. These advancements increased interest in educational applications, and by the mid-2010s, VR was being integrated into classrooms worldwide. Initially, VR was used in education to enhance engagement and deliver complex visual information in anatomy and engineering. However, as more applications emerged, educators started exploring its potential for creative thinking. The immersive quality of VR places students in new worlds and scenarios and makes it an ideal tool for stimulating divergent thinking and ideation.

Creativity in education encourages divergent thinking, problem-solving, and the ability to generate new and innovative ideas (Leong 2024c). Guilford (1950) introduced the concept of divergent thinking as a core element of creativity. Csikszentmihalyi (1996) discussed the importance of creating an environment to stimulate flow—a state where students are fully immersed and engaged in the learning process. VR with its capacity to create an immersive environment, aligns well with these theories, making it an effective tool for fostering creativity (Leong 2005).

Research indicates that VR has the potential to create an engaging learning environment, which is critical in creativity. Johnson *et al*. (2020) found that VR fosters a high level of engagement due to its immersive nature, allowing students to explore concepts and ideas more freely than in traditional classroom settings. Experiential learning, a theory popularized by Kolb (1984), emphasizes the importance of learning through experience. VR provides an ideal platform for experiential learning, where students can engage in simulations, conduct virtual experiments, or explore different scenarios. This type of learning fosters curiosity and problem-solving—key ingredients for creativity (Mayer & Moreno, 2017). Storytelling is a method used to foster creativity, and VR's ability to immerse students in stories and scenarios has proven effective in storytelling. Rizzo et al. (2018) demonstrated that students using VR showed significant improvements in creative writing compared to those using traditional methods. The immersive nature of VR allows students to be narrative, think creatively, and make unique contributions to the storyline.

Several tools have demonstrated the impact of VR on creative thinking in education. Google Tilt Brush allows students to "paint" in a 3D virtual space, giving them the freedom to create without the constraints of a physical canvas. Smith and Lee (2019) showed that students using Tilt Brush exhibited enhanced levels of creative expression, exploring colors, textures, and designs that would be challenging in a traditional art setting. Bailey et al. (2021) explored the use of VR virtual labs in science education. When participating in virtual lab experiments, students were more likely to engage in creative problem-solving than in traditional labs, as VR enabled them to test hypotheses without fear of failure. Brown and Thompson (2019) compared traditional classroom methods with VR-enhanced learning methods. Their findings suggested that students in a VR environment improved creative problem-solving, divergent thinking, and ideation. The visual and immersive nature of VR made abstract concepts accessible and facilitated creative exploration.

4. Methodology

Creativity is a critical skill for students to succeed in the modern world. Unfortunately, traditional educational methods often do not foster creativity effectively. VR technology offers possibilities for experiential and creative learning by providing an immersive and interactive environment. In this study, the impact of immersive VR on fostering creativity among high school students was investigated for six weeks. Figure 12 illustrates the research process, starting with the pre-assessment, moving to the VR intervention, and ending with the post-assessment and data collection phases.

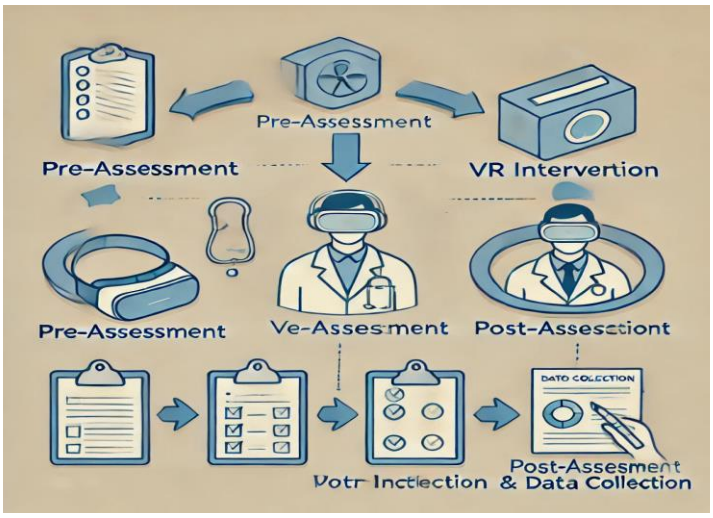

Fig. 12. Research flow in this study.

The participants were 60 high school students (aged from 14 to 17 years old) and five teachers educating science, history, and art. A mixed-method approach was used to determine qualitative and quantitative measures. The students were divided into two groups: a control and an experimental group. The students were assigned into a group randomly. The experimental group was exposed to a VR environment for various educational activities, including immersive storytelling, virtual lab simulations, and creative problem-solving exercises. The control group used traditional tools with textbooks and online media. Pre- and post-assessments were conducted to evaluate creativity levels using the Torrance Tests of Creative Thinking (TTCT). Observations, surveys, and focus group discussions were used to gather qualitative data. Oculus Rift headsets and VR tools such as Google Tilt Brush, CoSpaces Edu, and virtual lab simulation software were used for six weeks.

In chemistry, students used a VR lab simulation to create hypotheses and explore the results of experiments. The students engaged in creative problem-solving without limitations. Figure 13 shows the interaction with virtual equipment and the detailed elements in the VR science lab simulation.

Fig. 13. VR in the science lab, showing interaction with virtual elements.

In history, students used VR to experience interactive virtual tours of ancient civilizations, integrating narrative elements. Figure 14 shows a student using VR to explore a historical landmark virtually and highlights the educational potential of VR in visualizing to understand historical events.

Fig. 14. VR to explore a historical landmark virtually.

In art and design, students used Tilt Brush to create 3D artworks based on the themes of "Nature" and "The Future". VR allowed them to paint in a limitless virtual environment, encouraging creativity. Figure 15 shows virtual artworks created by students. Diverse 3D paintings were created by students using VR tools. The artworks reflect nature and futuristic worlds with the imagination and creative expression fostered in the immersive virtual environment.

Fig. 15. Showcase student-created virtual artwork that reflects imaginative thinking.

5. Results and Analysis

TTCT was developed by Paul Torrance and is widely used to assess creativity in individuals. TTCT is used to evaluate creative thinking, such as fluency, flexibility, originality, and elaboration. There are two main types of TTCT assessments: verbal and figural. Each is designed to capture different dimensions of creative thinking. The verbal part consists of tasks that require participants to engage in creative thinking through written or verbal responses. Participants are shown a scenario or a picture and asked to generate as many relevant questions as possible. Participants are asked to suggest ways to improve or modify a particular product. This task involves identifying unusual or alternative uses for common objects. The verbal test focuses on fluency (number of ideas), flexibility (variety of ideas), originality (novelty of ideas), and elaboration (detailed explanation).

The quantitative and qualitative measures of TTCT include the following measures.

- Fluency: Number of relevant responses or ideas.
- Flexibility: The diversity of responses or shifts in perspective.
- Originality: Uncommon or unique responses that stand out from the norm.
- Elaboration: The level of detail in the responses or ideas.
- Resistance to Premature Closure: The ability to keep an open mind and not settle on the first or simplest solution.

TTCT provides a creativity Index based on a combination of these measures. TTCT is comprehensive and flexible, including both verbal and figural aspects of creativity. It is widely accepted across many disciplines. Creativity is a complex, multifaceted trait so TTCT might not fully capture all aspects of creativity. Cultural differences in responses and interpretation of creative tasks also affect the test's results. The creativity score is a quantitative measure to assess a person's creative thinking abilities. It is often derived from standardized creativity tests from specific tasks designed to evaluate different aspects of creativity. The score reflects various dimensions of creative thinking, including fluency, originality, flexibility, and elaboration.

The pre- and post-intervention TTCT scores were analyzed to determine the effect of VR on creative thinking in this study. Table 7 compares pre- and post-intervention creativity scores in fluency, originality, and flexibility. Iimprovements were observed in each creative aspect.

Table 7. Pre- and post-intervention creativity scores.

Creativity Component	Pre-Intervention Average	Post-Intervention Average	Percentage Increase
Fluency	22	30	36%
Originality	18	24	33%
Flexibility	15	19	27%

The results of the focus group discussions and interviews were analyzed to understand students' experiences (Table 8). The students expressed enthusiasm for VR indicating that it made learning more enjoyable and interactive. The students also felt comfortable experimenting without fear of failure. The students exhibited greater curiosity and asked more questions during VR activities. To understand the effectiveness of VR compared with traditional classroom settings, the results of the VR and control groups were compared as shown in Table 9.

Table 8. Student feedback.

Theme	Representative Quote
Engagement	"It felt like I was actually there, and I wanted to learn more."
Risk-Taking and Experimentation	"I wasn't afraid to make mistakes because it was just virtual."
Immersive Learning	"It was much easier to imagine how things worked when I could see them in 3D."

Table 9. Comparison of VR vs. control group.

Parameter	VR Group (Average Score)	Control Group (Average Score)
Creativity Score	24	18
Engagement Level	4.8/5	3.2/5
Willingness to Experiment	4.5/5	3.1/5

Figure 16 illustrates the changes in fluency, originality, and flexibility before and after the VR intervention. The results highlight the improvement in creativity scores with the VR experience. The experimental group demonstrated a significant improvement in creativity scores compared with the control group. The post-test scores of the experimental group showed a 25% increase in fluency and flexibility of thought, compared with an 8% increase in the control group. The students expressed heightened engagement and excitement when using VR tools. The focus group indicated that VR-using students visualized complex ideas more clearly, thereby enhancing their creative confidence.

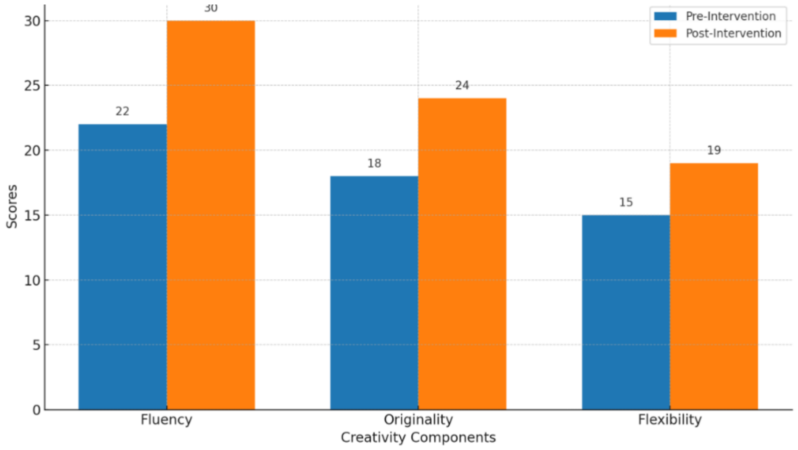

Fig. 16. Comparion of creativity scores in pre- and post-intervention.

Figure 17 represents the differences between the VR group and the control group in creativity score, engagement level, and willingness to experiment. The results show the advantages of VR for enhancing creativity and student engagement.

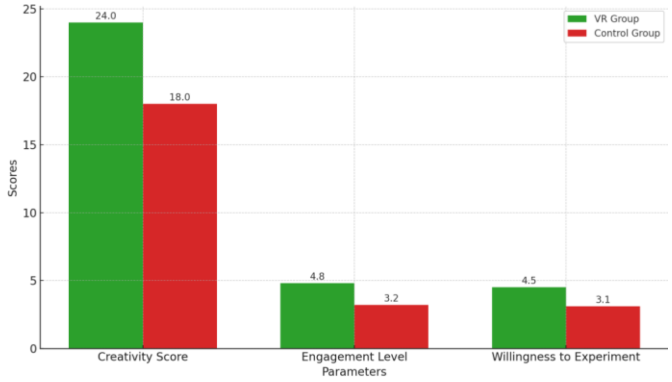

Fig. 17. Creativity scores of VR and control groups.

The advantages of VR and traditional learning methods were compared focusing on engagement, visualization, and risk-free experimentation (Fig. 18). The figure illustrates the benefits of VR and traditional learning methods and differences in immersion, interactive learning, accessibility, cost-effectiveness of traditional methods, collaboration potential, and knowledge acquisition.

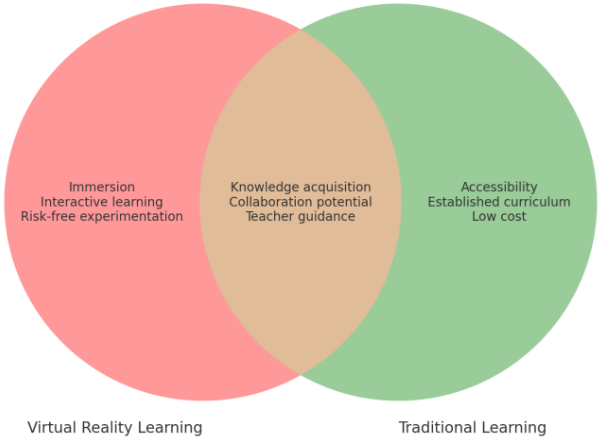

Fig. 18. Venn diagram showing the advantages of VR and traditional learning methods.

VR creates an immersive environment that motivates students to learn by making lessons more interactive and entertaining. The novelty of VR increases student enthusiasm and sustained attention. VR environments are beneficial for understanding complex spatial relationships. For instance, in engineering, architecture, or anatomy, VR enables students to view objects in three dimensions, leading to better comprehension. VR can personalize learning for each student. Virtual environments adapt to the needs of students, offering a flexible approach that is difficult to achieve in traditional classrooms. Experiential learning is the process of learning through experience facilitated by VR's immersive qualities. Students can "learn by doing," which enhances memory retention and understanding.

6. Challenges and Limitations

The results of the case study demonstrated that the immersive VR environment significantly fostered the creative thinking of high school students. The results of this study indicate that VR can serve as an effective tool for stimulating divergent thinking and problem-solving skills. Their feedback highlighted the increased engagement and willingness to experiment as key factors contributing to enhanced creativity. However, there are challenges and limitations of fostering creative thinking through an immersive VR environment in education.

VR technology, including headsets and software, is expensive, which makes it challenging for schools, especially those with limited budgets, to adopt and integrate VR into their curriculums. The maintenance and update costs are also needed. Not all students have access to VR at home or in schools, contributing to an inequity in educational opportunities. This digital divide can exacerbate existing gaps between well-funded and underfunded institutions. Effective implementation of VR in education requires teachers to be adequately trained. Many teachers lack the technical skills or confidence needed to incorporate VR meaningfully into their lessons. This lack of preparedness limits the technology's effectiveness in fostering creativity. Teachers accustomed to traditional teaching methods can be resistant to incorporating VR due to the perceived complexity or skepticism about its educational benefits. VR setups are complex and cause technical issues such as hardware malfunctions, software glitches, or connectivity problems. These issues can disrupt the learning experience, reduce engagement, and create frustrations for both students and teachers. VR requires adequate infrastructure, such as powerful computers, sufficient physical space, and stable internet connections, which many schools do not have.

Extended use of VR can cause motion sickness, eye strain, and fatigue in some students. These health concerns can limit the duration and frequency of VR sessions, affecting the continuity of learning. Students can feel uncomfortable or disoriented when using VR headsets, which affects their learning experience and reduces the effectiveness of the immersive environment. Integrating VR into an existing curriculum supports educational objectives while fostering creativity. However, available VR content and the learning goals or standards of specific subjects are still limited. In many cases, VR is used as a supplementary tool rather than being integrated into the curriculum. This limits its impact, as students may only occasionally engage with VR, reducing its effectiveness in consistently fostering creativity. Most research on VR in education focuses on short-term outcomes, such as immediate engagement or creativity improvement during or shortly after VR exposure. There is a lack of longitudinal studies exploring the long-term impact of VR on creative development and overall academic performance.

High-quality curriculum-aligned VR content remains limited. VR experiences are complex and time-consuming, often requiring collaboration between educators and developers. All VR applications are not specifically designed for educational purposes and do not adequately support the desired learning outcomes, such as encouraging creativity through meaningful engagement. Unlike traditional classroom activities that involve group work and direct interaction, VR experiences are solitary. Although multi-user VR environments exist, effective collaboration in VR is a technical and pedagogical challenge. In a VR environment, social cues, such as facial expressions and gestures, are limited. This lack of social presence can limit the effectiveness of collaborative learning and reduce opportunities for creative group problem-solving. VR systems often collect data on users, such as movement and behavioral patterns. Schools need to be mindful of data privacy and ethical considerations, ensuring compliance with regulations and protecting student data. Teachers need to be vigilant about the appropriateness of VR content as content might not be appropriate for students. Content moderation is necessary to ensure a safe and supportive learning environment.

Addressing these challenges requires training teachers, investing in infrastructure, ensuring equitable access, and developing quality content tailored to the educational curriculum. By overcoming these barriers, VR can be effectively used to foster creative thinking in education. In general, VR fosters creativity and contributes to creative learning in immersion, interactivity, and novelty. The feeling of being 'inside' the learning environment helps students focus and engage deeply with the material. The ability to interact with virtual objects and scenarios promotes active learning and experimentation, crucial for creative thinking, and VR provides experiences that overcome the monotony of traditional classrooms, thereby stimulating curiosity and innovative thought. Future research is necessary to explore the long-term impact of VR on creativity and its applications in different educational contexts such as vocational training or special education. Additionally, the effectiveness of combining VR with other technologies such as artificial intelligence needs to be explored to create more adaptive, personalized learning experiences.

7. Conclusion

The integration of VR into education is effective in fostering the creative thinking of students. In an immersive, interactive, and experiential environment, VR engages learners in ways that traditional education methods cannot achieve. Through the quantitative and qualitative assessments of creativity, particularly in fluency, originality, flexibility, and elaboration using TTCT, VR was proven to increase student engagement by offering interactive and dynamic experiences. VR increased engagement and promoted connection to learning materials, allowing students to explore creative solutions freely. The sensory-rich experiences provided by VR stimulated multiple cognitive pathways, enhancing students' capacity for divergent thinking. VR's capacity to simulate real-world scenarios, abstract environments, and problem-solving encouraged students to think divergently. Students performed open-ended tasks in complex situations where they experimented without real-world limitations and developed unique and novel solutions. This fostered creative thinking by allowing them to approach problems from different perspectives, thereby enhancing flexibility and originality.

One of the benefits of VR is the opportunity for risk-free experimentation. Unlike physical environments, where failure may result in tangible consequences, VR allows students to take creative risks without fear. This environment encourages trial-and-error learning, stimulating curiosity and exploration, which are foundational to the creative process. By offering multisensory inputs (visual, auditory, and haptic feedback), VR enhances students' ability to visualize complex concepts, objects, and scenarios. This multimodal stimulation helps students better abstract ideas and fosters detailed and imaginative creative outputs. The ability to visualize 3D models and manipulate objects using VR enhances elaboration and creative responses. While previous VR research focused on individual creativity, collaborative creativity through multi-user VR platforms needs to be researched. Such a platform allows students to cooperate in the virtual space, offering collaborative problem-solving and creative ideation. Future research is needed to explore how VR can facilitate group creativity, expanding the scope of its educational applications.

Despite the promising results, challenges remain. The high cost of VR equipment, lack of access in underfunded schools, and the need for teacher training to implement VR effectively are barriers to widespread adoption. Furthermore, not all students respond equally to VR-based interventions, indicating the need for personalized approaches. To fully harness the potential of VR in fostering creativity, further research is necessary to assess the impact of VR on creative development in the long term. Additionally, it is necessary to explore how VR can be integrated into curriculum design, teacher training programs, and group-based learning environments to expand its applicability in education.

VR significantly fosters creative thinking in education. Its ability to engage learners, support divergent thinking, and provide multisensory experiences makes it a powerful tool for cultivating creativity. However, to maximize its impact, challenges related to accessibility, teacher training, and scalability must be solved. With further research and development, VR can have more potential

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