The Influence of Virtual and Augmented Reality on the Spatial Performance and Academic Achievement of Learners: A Review

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ABSTRACT

The vast development in Virtual Reality (VR) and Augmented Reality (AR) showed a magnificent impact of these technologies on the spatial performance of learners as well as their academic achievement. While the literature reported lots of empirical evidence on the substantial impact of AR and VR in the educational context, this paper addressed that the past academic works did not report which technology showed the higher degree of improvement on the spatial performance of learners and academic achievement. Hence, this study analyzes this relationship and present a new perspective on the influence of these technologies on developing the learning process in various fields of education. The outcome shows that despite VR is an efficient technology and provide good tools for spatial memory rehabilitation programs, e.g., patients and students, but it does not give the same improvement on spatial performance of learners as AR do. Therefore, spatial performance of learners can be described as VR less effective than AR. Given AR established more advantages compared to VR, this study claims that AR/VR-based experimental model may be able to reduce this gap and give developers of virtual classrooms a better perspective on the realism of VR and AR in education.

Keywords: Virtual Reality, Augmented Reality, Spatial Performance, Academic Achievement

INTRODUCTION

Augmented Reality (AR) and Virtual Reality (VR) made learning immersive and engaging. Both technologies allow learners to explore virtual environments or overlay digital information on the real world, improving spatial cognition and making learning more engaging. AR allows students engage with virtual objects in real life, boosting difficult topic comprehension [1]. VR lets students actively participate in realistic scenarios to rehearse and apply their knowledge safely [2]. AR and VR have made education more accessible, interactive, and immersive, providing a unique and engaging experience for varied learners [3]. AR and VR boost presence and engagement, improving information retention and comprehension [4]. Interactive technologies encourage critical thinking and creativity via active problem-solving. It's important to understand how this technology affects kids' spatial and navigation abilities as it becomes more integrated into our everyday lives and classrooms. Studying AR and VR will show how students use the technology and how they may enhance their spatial skills. Understanding architecture, engineering, design, and medicine requires spatial performance [5]. Studying spatial performance can reveal how AR and VR can enhance curriculum and learnability. This study should disclose factors that impact spatial perception and cognitive constraints in spatial cognitive representation courses. Studying AR and VR's influence on academic achievement can assist build virtual classrooms and improve simulation-based learning [6]. Virtual classes assist architects and engineers learn spatial skills and problem-solving [7]. This may improve design efficiency and creativity. It's unknown how AR and VR influence students' spatial skills and academic achievement [3]. Despite AR and VR have been reported to helps the minds of learners to easy remember locations in space, there is limited empirical evidence on how these technologies specifically impact students' spatial skills and academic achievement. The lack of concrete data on their effectiveness raises concerns about the potential mismatch between the perceived benefits of AR and VR and their actual influence on learning outcomes. However, the issues for effective virtual learning needs robust and critical review of which technology AR or VR im-prove spatial performance and academic achievement.

The Purpose of the Review

Today, modern educational institutions use virtual classrooms increasingly. Hence, distinction between AR and VR is important, as well as their impact on student aca-demic achievement and their spatial performance is critical which help to determine the cost and effectiveness of learning. Accordingly, the purpose of this review paper is to review how previous findings report on these relationships, and identify the difference of effect between AR, VR in spatial performance, and academic achievement.

LITERATURE REVIEW

Virtual Reality

VR uses headsets to immerse users in simulated environments. It lets people explore a computer-generated world, giving it presence and reality [8]. VR is popular in entertainment, education, and healthcare. VR has transformed gaming, offering unprecedented immersion and involvement [9]. VR lets students visit historical locations, explore faraway worlds, and study hands-on [10]. VR also helps doctors perform complicated surgery and therapists address phobias and anxieties [11]. VR could improve our daily lives and change how we use technology. Thus, few studies compare VR's and AR's effects on spatial performance. Further research will assist construct virtual classes and let students choose technology that matches learning materials which help learners to improve their academic achievement and boost their spatial performance.

Augmented Realiy

AR adds digital information or virtual objects to reality. Blending computer-generated features with the real world improves our impression of realism. This cutting-edge technology lets users engage with virtual content in real time, offering an immersive experience [12]. AR is available on smartphones, tablets, smart glasses, and headsets. These gadgets show digital content based on the user's surroundings using cameras and sensors. As educators and academics see AR's potential to revolutionize teaching, its use in education is growing [13]. AR helps pupils understand abstract concepts by making them more tangible. AR lets pupils visualize difficult ideas, explore three-dimensional models, and interact with virtual things [14]. This engaging and interactive method boosts student engagement, retention, and comprehension. AR systems benefit engineering most [15]. AR interfaces create a novel learning environment that may help overcome this cognitive filter by providing various learning experiences tailored to each student's needs and learning style representation methods to improve kids' spatial skills [16]. However, understanding how AR influence spatial performance and academic achievement of learners is critical for educational institutions to boost education.

Spatial Performance

Human spatial performance is the ability to perceive, analyze, and manipulate spatial information. The cognitive talents include spatial thinking, mental rotation, visualization, and remembering. Spatial performance involves visualizing things in three dimensions. Gardner [17] proposes that everyone has several forms of intelligence and spatial intelligence. Maier [18] added that spatial intelligence has five components: perception, visualization, mental rotation, spatial relations, and spatial rotations. This element of human cognition is vital for everyday tasks including navigating space, interpreting maps, understanding directions, and even playing sports or solving puzzles [19]. Reversely, the ability-as-enhancer theory states that high spatial abilities leave adequate cognitive load to analyze models [20]. Spatial skills have been linked to creativity, critical thinking, problem solving, and higher academic performance in educational settings [21], so studying their effects on students is important in engineering, geometry, mathematics, biology, chemistry, and physical education [22]. Learners and developers of AR and VR education apps must understand spatial performance. New evidence on this scenario will help them design problem-solving applications and improve AR or VR cognitive capability.

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Understanding how AR and VR enhance the brain processes and manipulates spatial information helps educators create successful teaching strategies for diverse learning styles as well as students to understand complicated subjects. Researchers have proven that spatial abilities may be increased through AR and VR, making it a significant area of attention for educators seeking academic achievement [23]. To that end, the difference of effect between AR and VR is critical and decisive.

Academic Achievement

A student's success or accomplishment is called academic achievement. Grades, test scores, class ranks, and academic achievement are included. Spatial performance improves critical thinking and problem-solving, in some studies, spatial performance affects student academic success, e.g., MIX [24] reported that spatial abilities are needed to visualize and manipulate complex notions in math and science. In other words, mental rotation and mathematics are linked to each other. Students can over-come 3D object movement and technical drawing class hurdles by using AR or VR to improve their spatial abilities [25]. Students can utilize AR or VR to interact with virtual representations of molecules or organisms to better comprehend their structure and function [26]. To that end, AR and VR could be utilized to create safe and regulated virtual simulations and settings for learners to practice and apply their skills.

DISCUSSIONS OF RESULTS

Changes in major brain networks affect how people absorb sensory information, develop spatial representations, and plan and manage navigational actions, according to several studies. Spatial performance is growing increasingly essential as more jobs require it. It explains item-space relationships. To improve spatial intelligence, many paper-based tests on AR and VR's role in spatial performance have been created. Medical students can practice surgery in VR before doing it on patients. Improves skills and reduces patient risk. Akkuş [14] reported that AR affects engineering students' spatial performance. AR apps can enhance technical drawing students' spatial skills, they suggested. AR can transport pupils to other times and places in history and geography classes. AR and VR may change education by engaging all senses and increasing participation. Lee et al. (2023) [27] found that AVR-based technique for 360-degree spatial visualization, allowing users to comprehend contextual information. In the same context, Stammler et al. 2023 [28] developed an AR-based app for treating spatial deficit, including visual exploratory training. Their findings show that natural connection with the physical environment during fun activities reduces spatial neglect side effects.

In brief, AR provides remarkable visual realism and enhances environmental awareness, sophisticated idea absorption, and enhanced learning in real-life and unreal circumstances. VR promotes abstract thinking, high-level learning, and complicated subject generalization despite its reduced visual real-ism. Visual realism depends on the course's objective and application. Learning is enhanced by visual reality [29]. Thus. AR enhances spatial performance better than VR. VR surgery in medicine courses involves extremely accurate human body representations and demands the most authentic surroundings, although AR would be more useful. Historic building representations may benefit more from AR's high real-ism and object immersion than VR [30]. Even with low visual realism, VR may im-prove gaming, scientific visualizations, and visual arts since these settings are based on symbolization and abstraction. In conclusion, few empirical studies have examined the effects of AR and VR on learner spatial performance and academic achievement, and it is unclear which technology is better at preserving knowledge in learners' minds, how much AR outperforms VR, and how much AR and VR develop human brain special memory [31]. The literature should illustrate how AR or VR affects spatial memory performance or whether AR cue changes distract users and VR is better. These challenges needed proof to show how AR and VR affect learners' spatial memory. AR lessons may seem more like real-world navigation than VR classes, therefore employing AR for exploration might improve learner experience and spatial memory performance. Table 1 summarize the recent findings from studies that examined the influence of AR and VR on spatial performance of learners and their academic achievement.

Table I The Impact Of Vr And Vr On Academic Achievement, Considering Spatially Related Problems

Authors	**Objective**	**Findings**
Lee et al, 2023 [27]	Discusses an approach to augmented VR (AVR) and 360-degree spatial visualization	AVR-based approach enables users to easily understand the surrounding contextual information
Zhao et al, 2023 [3]	Evaluating AR landmark cues and frame of reference displays with VR	The world-fixed frame of reference resulted in better spatial learning when there were no landmarks cued; adding AR landmark cues marginally improved spatial learning in the screen-fixed condition
Stammler et al, 2023 [28]	Develop an AR-based app for the treatment of spatial neglect that combines visual exploration training	Through participants' natural interaction with the physical surrounding environment during playful tasks, side effects as symptoms of spatial neglect are minimized
Partala et al, 2023 [32]	Examine walk-in AR model to present an attraction to tourist near the original attraction	The participants also gave relatively high ratings for spatial presence while viewing the 3D model using tablet-based AR
Stübl et al, 2023 [29]	Develop a spatial AR system, where a projector directly displays information on the product to assist the worker	The usage of human pose estimation would enable the workers to interact with the AR system in a natural way
Majeed and AlRikabi, 2022 [30]	Examine the effect of AT technology on spatial intelligence among high school students	AR technology has a positive on spatial intelligence in mathematics
Volmer et al, 2022 [4]	Investigate predictive cues under a sub-optimal scenario by depriving users of sleep through spatial AR tool	Providing spatial AR predictive cues was beneficial throughout sleep deprivation
Azarby and Rice, 2022 [31]	Explores the differences in spatial perception between an immersive AR and traditional VR	The results showed significant space size variations produced by participants between and within the two different VR systems

A review of above findings reveals that AR provides high visual realism and facilitates significant perception of details in the surrounding environment, incorporation of abstract concepts, and advanced learning in scenarios connecting learners to real life and immersion with unreal objects [33]. VR, on the other hand, exhibits less effective visual realism while nevertheless encouraging abstract thinking such as in mathematics [34], high-level understanding, and generalization of complicated concepts. The demand for low and high visual realism is frequently determined by the application and goal of the learning course. High visual realism can often significantly assist information acquisition and transfer in education and training. As a result, we conclude that AR is more effective than VR in terms of improving the spatial performance. Virtual surgery in medicine courses, for example, frequently uses highly de-tailed representations of the human body and requires the highest degree of natural environments which is more effective if AR was deployed to provide a simulation for human body, as well as people involved in historic architecture visualizations may benefit more from AR in demonstrating high realism with high-level immersion with objects in realism comparing to VR. In summary, the recent findings in AR and VR applications for academic purposes shows some gaps, such as the lack of standardized platforms and tools for educators to easily integrate these technologies into their curriculum. Additionally, there is a need for more research on the effectiveness of AR and VR in enhancing student learning outcomes and engagement in various academic subjects. Furthermore, there is a lack of training and professional development opportunities for educators to effectively utilize AR and VR technology in the class-room. Also, the gaps in the effect of AR and VR on the spatial performance of learners must be explored further in order to fully understand the impact of these technologies on student learning. In addition, more studies are needed to determine the long-term effects of incorporating AR and VR into educational practices. Addressing these gaps will be crucial in harnessing the full potential of AR and VR in academic settings.

While the findings of this study and prior literature indicate that AR often demonstrates stronger effects on spatial performance due to its high visual realism and environmental integration, it is important to acknowledge situations in which VR may be more advantageous. VR appears particularly effective in learning contexts that emphasize abstract reasoning, symbolic representation, and conceptual generalization, such as advanced mathematics, scientific visualization, and theoretical modeling. In addition, VR offers clear advantages for simulating dangerous, costly, or inaccessible environments, including surgical training, hazardous industrial operations, disaster response scenarios, and space or deep-sea exploration. In such cases, full immersion within a controlled virtual environment allows learners to repeatedly practice complex spatial tasks without real-world risk, which may not be feasible through AR alone.

From a practical perspective, the results suggest several actionable recommendations for educators and developers. First, the selection of AR or VR platforms should be aligned with learning objectives rather than technological novelty. AR is better suited for courses requiring strong connections between physical environments and digital overlays, such as engineering drawing, architecture, geography, and anatomy. VR, on the other hand, may be more appropriate for abstract spatial reasoning, procedural training, and simulations where real-world access is limited. Second, effective integration of AR and VR requires structured instructional design, including guided tasks, clear spatial cues, and reflection activities, rather than unguided exploration. Third, educators should receive targeted training that focuses not only on technical operation, but also on pedagogical strategies for embedding VR and AR into assessment, feedback, and collaborative learning activities.

Despite promising results, several gaps remain that warrant further investigation. One major limitation in the current body of research is the lack of evidence on long-term learning retention and spatial memory durability following AR and VR interventions. Most studies focus on short-term performance gains, making it unclear whether these technologies support sustained cognitive development over time. Accessibility also remains a concern, as learners with visual impairments, motion sensitivity, or limited technological resources may experience barriers when using VR or AR systems. In addition, the cost-effectiveness of large-scale implementation is still underexplored, particularly in public education settings where hardware, software maintenance, and training expenses may limit adoption.

Future research should therefore move beyond comparative performance outcomes and examine longitudinal learning effects, inclusive design approaches, and economic feasibility models. Studies that combine behavioral data with cognitive and neuroscientific measures may also provide deeper insight into how AR and VR influence spatial memory and brain-based learning processes. Addressing these issues will support more informed decisions regarding real-world implementation and help ensure that VR and AR technologies are deployed in ways that are pedagogically meaningful, equitable, and sustainable.

CONCLUSIONS

The review of literature shows that both AR and VR have benefits in educational settings. In this regard, AR's ability is significant for improving spatial skills, reduce cognitive load, support collaborative learning, and provide practical, accessible applications gives it a clear advantage over VR in terms of fostering and improving learners' spatial performance. Moreover, AR's contextual integration of digital aspects with the actual world is well-suited to educational purposes, making it a more effective tool for improving learning experiences and results. In addition, AR's interactive nature allows for a more engaging and immersive learning experience, helping to keep students focused and motivated. Hence, the practical applications of AR in fields such as science, engineering, and medicine also make it a valuable tool for enhancing learner's understanding and retention of complex concepts. Overall, the potential impact of AR on academic achievement is significant, making it a crucial technology to incorporate into educational settings for the benefit of learners' spatial skills and overall learning outcomes. By providing learners with hands-on experiences and real-world simulations, AR can bridge the gap between theoretical knowledge and practical application. This not only helps students grasp difficult concepts more easily but also prepares them for success in their future careers. In sum, AR is better than VR for customizing learning experiences in spatial scenario based which give an added ad-vantage for learners to boost their academic achievement and improve their spatial performance.

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