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ORIGINAL

Virtual reality for enhancing spatial ability in interior design Education

Realidad virtual para mejorar la habilidad espacial en la educación de diseño de interiores

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ABSTRACT

Introduction: this study investigated the effectiveness of virtual reality (VR) technology in enhancing spatial ability among interior design students.
Method: a mixed-methods approach was employed, involving a quasi-experimental design with pre- and post-tests. Sixty-two second-year interior design students were divided into an experimental group (n=28), which received VR-based instruction, and a control group (n=34), which underwent traditional teaching. The intervention utilized a head-mounted display (HMD) VR system in a dedicated immersive classroom. Standardized instruments, including the Spatial Reasoning Instrument (SRI) and the Architecture and Interior Design Spatial Ability Test (AISAT), were used to measure spatial ability. Semi-structured interviews provided qualitative insights.
Results: the experimental group showed significant improvements in mental rotation ($F=16,07$, $p<0,001$, $\eta^2=0,25$) and spatial visualization ($F=20,83$, $p<0,001$, $\eta^2=0,16$), as well as overall spatial ability ($F=23,56$, $p<0,001$, $\eta^2=0,12$). No significant change was observed in spatial orientation. Qualitative data indicated that students found VR immersive, intuitive, and beneficial for understanding spatial relationships.
Conclusions: the study demonstrated that VR-based instruction significantly enhances specific spatial abilities in interior design education. However, spatial orientation requires further targeted intervention. These findings support the integration of VR into design curricula, guided by experiential and cognitive learning theories.

Keywords: Virtual Reality; Spatial Ability; Interior Design Education; Immersive Learning; Mixed Methods.

RESUMEN

Introducción: este estudio investigó la efectividad de la tecnología de realidad virtual (RV) para mejorar la habilidad espacial en estudiantes de diseño de interiores.
Método: se empleó un enfoque de métodos mixtos que incluyó un diseño cuasiexperimental con pruebas previas y posteriores. Sesenta y dos estudiantes de segundo año de diseño de interiores fueron divididos en un grupo experimental (n=28), que recibió instrucción basada en realidad virtual (RV), y un grupo de control (n=34), que siguió un método de enseñanza tradicional. La intervención utilizó un sistema de RV con visor (HMD) en un aula inmersiva dedicada. Se utilizaron instrumentos estandarizados, como el Spatial Reasoning Instrument (SRI) y el Architecture and Interior Design Spatial Ability Test (AISAT), para medir la habilidad espacial. Entrevistas semiestructuradas proporcionaron insights cualitativos.
Resultados: el grupo experimental mostró mejoras significativas en rotación mental ($F=16,07$, $p<0,001$, $\eta^2=0,25$) y visualización espacial ($F=20,83$, $p<0,001$, $\eta^2=0,16$), así como en la habilidad espacial general ($F=23,56$, $p<0,001$, $\eta^2=0,12$). No se observaron cambios significativos en orientación espacial. Los datos

cualitativos indicaron que los estudiantes consideraron la RV inmersiva, intuitiva y beneficiosa para comprender relaciones espaciales.
Conclusiones: el estudio demostró que la instrucción con RV mejora significativamente habilidades espaciales específicas en la educación de diseño de interiores. Sin embargo, la orientación espacial requiere intervenciones dirigidas. Estos hallazgos respaldan la integración de la RV en los currículos de diseño, guiados por teorías de aprendizaje experiencial y cognitivo.

Palabras clave: Realidad Virtual; habilidad Espacial; Educación en Diseño de Interiores; Aprendizaje Inmersivo; Métodos Mixtos.

INTRODUCTION

With the rapid advancement of digital technology, Virtual Reality (VR) has emerged as a transformative tool in higher education, particularly within design-related disciplines such as interior design. Spatial ability—comprising mental rotation, spatial visualization, and spatial orientation—is a critical cognitive skill for success in this field, enabling students to perceive, manipulate, and reason about three-dimensional spaces.[1,2] Traditional pedagogical methods, including two-dimensional drawings and physical models, often fall short in fostering these skills, especially in translating abstract concepts into tangible spatial understanding.[3]

VR technology, with its immersive and interactive capabilities, offers a promising alternative. It allows learners to engage in real-time manipulation of virtual environments, thereby enhancing their comprehension of spatial relationships, scale, and materiality.[4] Research across STEM and design education has demonstrated VR's efficacy in improving spatial reasoning through multi-perspective exploration and dynamic interaction.[5] Moreover, VR's ability to reduce cognitive load and provide experiential learning opportunities aligns with established theories such as Cognitive Load Theory,[6] Experiential Learning Theory,[7] and Constructivism,[8] which collectively support its educational value.

However, despite these advantages, a significant gap remains in the integration of VR within theoretically grounded instructional models. As noted by Serrano-Ausejo et al.[9] and Dawson et al.[10] while VR shows great potential in spatial ability training, there is a pressing need to bridge the gap between technological application and pedagogical theory. Many existing studies focus on the technological aspects of VR without sufficiently embedding them within a coherent learning framework that guides instructional design and task development.

This study aims to address this gap by proposing and evaluating a VR-based teaching model rooted in experiential learning, cognitive load, and constructivist theories. Through a mixed-methods approach involving quasi-experimental design and qualitative interviews, we investigate the effectiveness of VR in enhancing specific spatial abilities among interior design students. Our research seeks to not only validate the use of VR in design education but also to contribute to a more theory-driven approach to immersive learning design.

METHOD

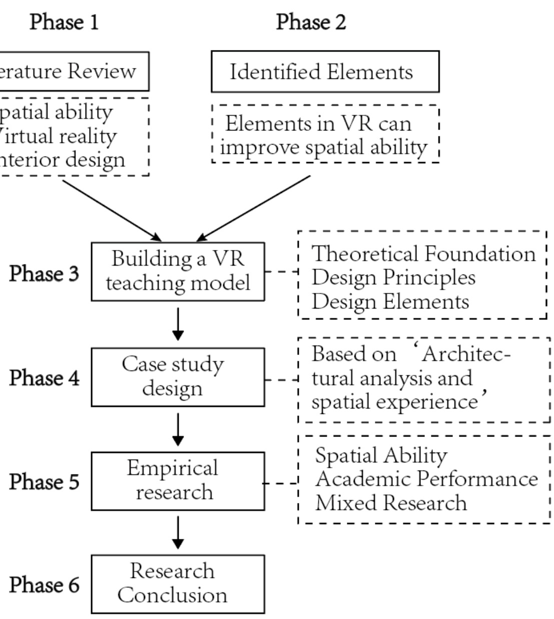


Figure 1. Research design

This study first conducts an in-depth analysis of relevant literature on spatial ability, virtual reality technology, and interior design to identify the key elements required for cultivating spatial ability in interior education. It then analyses the advantages of virtual reality technology in promoting the development of spatial ability. Based on experiential learning theory, constructivism theory, and flow theory, a virtual reality teaching model targeting the development of spatial ability is designed. This virtual reality teaching model is applied to design a teaching case study. This study conducted a quasi-experiment using a mixed-methods research approach to validate the teaching case study, thereby testing the effectiveness of the designed virtual reality teaching model in fostering spatial ability development. Finally, the research conclusions are drawn, and the research design is summarized in figure 1.

VR Teaching Model Design

The design of VR teaching models revolves around six core elements: first, clearly defining 'learning content' (What to learn), selecting course materials suitable for VR conversion to ensure they effectively cultivate spatial ability (SA); second, planning 'learning methods' (How to learn), constructing a teaching framework based on Kolb's experiential learning theory; third, establishing 'design principles' (Design Principle), ensuring the systematic nature of teaching from five dimensions: context, content, learners, activities, and environment; fourth, establish the 'learning environment' (Where to learn), configure hardware devices such as HMDs and plan teaching environments such as classrooms or homes; fifth, design the 'learning process' (Process), corresponding to the four stages of Kolb's theory: concrete experience, reflection and observation, abstract concept, and active experimentation. Finally, conduct 'learner analysis' (Who is learning) to precisely identify the characteristics of the target audience. This model aligns deeply with Kolb's experiential learning theory: in the experiential stage, students directly perceive three-dimensional space through immersive VR environments; in the reflective observation stage, they analyze spatial relationships by manipulating virtual models from multiple angles; in the abstract concept stage, they elevate practical experience into theoretical knowledge; and in the active experimentation stage, they validate learning outcomes by modifying design parameters. Taking an architectural appreciation course as an example, students can use VR devices to 'enter' the interior of a building and adjust structural components in real time. This 'learning by doing' model not only enhances spatial visualization skills but also perfectly embodies the complete cycle of Kolb's experiential learning theory 'experience-reflection-theory-practice' providing an innovative teaching solution for cultivating spatial abilities, the VR teaching model was designed in figure 2 below.

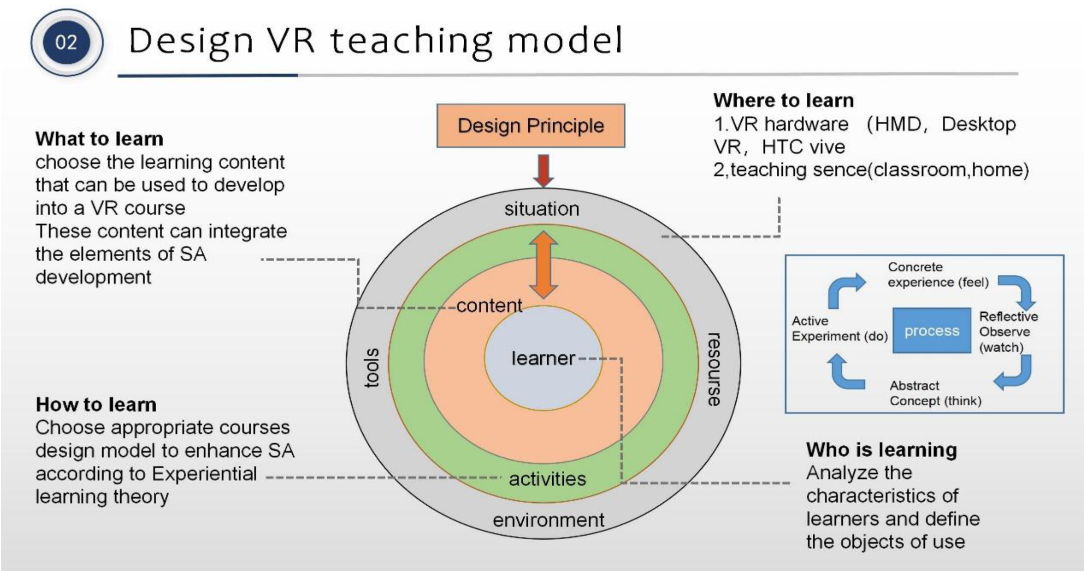


Figure 2. The VR teaching model

Quasi-experimental design

The non-equivalent group design is the most used quasi-experimental design[10] and is like the pretest-posttest comparison group design. The difference between the two is the non-randomization to the treatment and comparison group in the quasi-experimental design. This type of design has been found to be more trustworthy and excellent at reducing threats to internal validity.[11] The nonequivalent comparison design is illustrated in figure 3. Although this type of design is associated with comparing the experimental and comparison group, it could also be used to compare two or more intervention groups. Figure 3 illustrates the non-equivalent comparison group design from Johnson et al.[12]

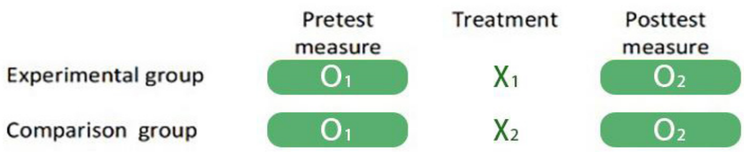


Figure 3. Non-equivalent comparison group design

Participants

This study targeted second-year students majoring in Interior design at the School of Art and Design, H University. A sample of 62 students was randomly selected from six parallel classes based on student ID numbers. These classes were grouped according to average Gaokao scores, ensuring comparable foundational abilities and favorable comparability. All 62 sample students participated in the core course 'Architectural Analysis and Spatial Experience'. Within this framework, one class of 34 students underwent traditional teaching methods, while another class of 28 students received VR-based immersive instruction, constituting a cross-over experimental design for the two pedagogical approaches.

To minimize interference from extraneous variables, instruction was delivered by a single teacher with over three years' teaching experience, who received guidance from specialists in educational technology and immersive technologies to ensure teaching compliance with experimental protocols. Both the experimental and control groups maintained identical teaching objectives, plans, content, and difficulty levels, with the sole distinction being the introduction of virtual reality technology as the instructional intervention factor in the experimental group to guarantee the scientific validity and efficacy of the experiment.

Intervention Details

The experiment was conducted in an immersive classroom jointly built by H University and an internet company. The 100-square-meter classroom is equipped with an interactive whiteboard and six sets of VR devices (including high-performance computers, head-mounted displays, and motion controllers). PICO 4/Neo3 headsets (resolution 3664×1920, refresh rate 72Hz) and Wi-Fi 6 technology are used to support free movement and interaction within a 10×10-meter area. Through laser scanning, WebGL, and 3D modeling technologies, indoor construction scenarios and processes are highly simulated, significantly enhancing students' immersive learning experience.

The entire duration of the experiment was about six weeks. During the first week, all learners took course-related pre-tests, including the General Spatial Aptitude Test, the AISAT test, and an academic quiz. Before the test began, the researchers verbally provided learners with test instructions and instructed them to pay attention to accuracy. From the second week to the fifth week, the experimental group used HMD-based VR technology to study EADE courses in classrooms equipped with VR equipment, while the control group learned the same content in the traditional classroom teaching environment with the help of PPT, videos, and other forms. The experimental group and the control group differed only in the use of VR technology as a teaching and learning tool. In the sixth week, all learners underwent post-testing related to the course.

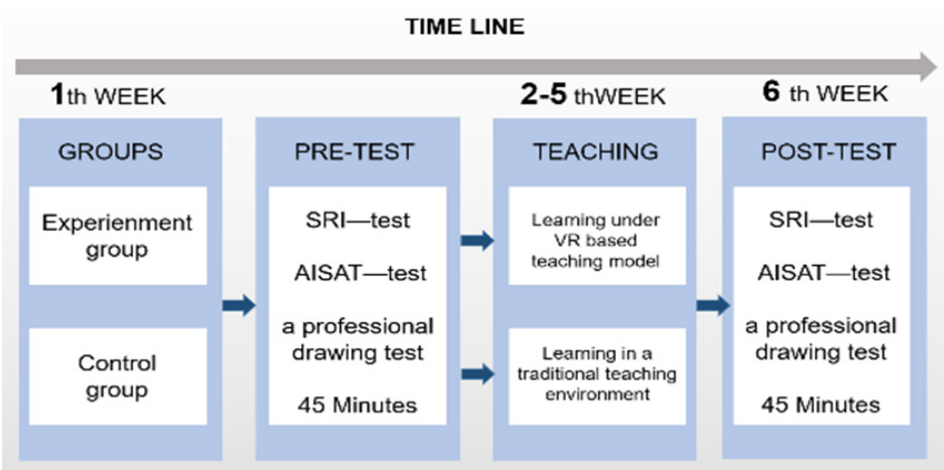


Figure 4. The experimental design of the study

Experimental Procedure

This study employed a quasi-experimental design to compare the effects of VR-based instruction and traditional instruction on students' spatial abilities through a three-stage process. In the first stage (pre-test), baseline data was collected using standardized spatial ability tests and self-report questionnaires assessing spatial abilities. In the second stage (main experiment), participants were divided into a control group (traditional instruction) and an experimental group (VR-based instruction model), with instructional interventions conducted under conditions where instructional content and duration were kept consistent. In the third phase (post-test), standardized tests and questionnaires were administered again, and semi-structured interviews were conducted with the experimental group to collect their subjective experiences of VR-based instruction. The semi-structured interviews are usually constructed on a flexible procedure that offers a loose arrangement of open-ended questions to examine experiences and viewpoints of the participants. The study quantifies teaching effectiveness by comparing post-test score differences between the two groups (t-test/ ANCOVA) and explores the advantages and limitations of VR teaching through thematic analysis of interview transcripts. The experimental design strictly controls variables such as teaching environment and teacher factors, employs stratified random grouping to reduce bias, ensuring internal validity while comprehensively evaluating intervention effects through a mixed-methods approach (quantitative + qualitative). The experimental design is illustrated in figure 5.

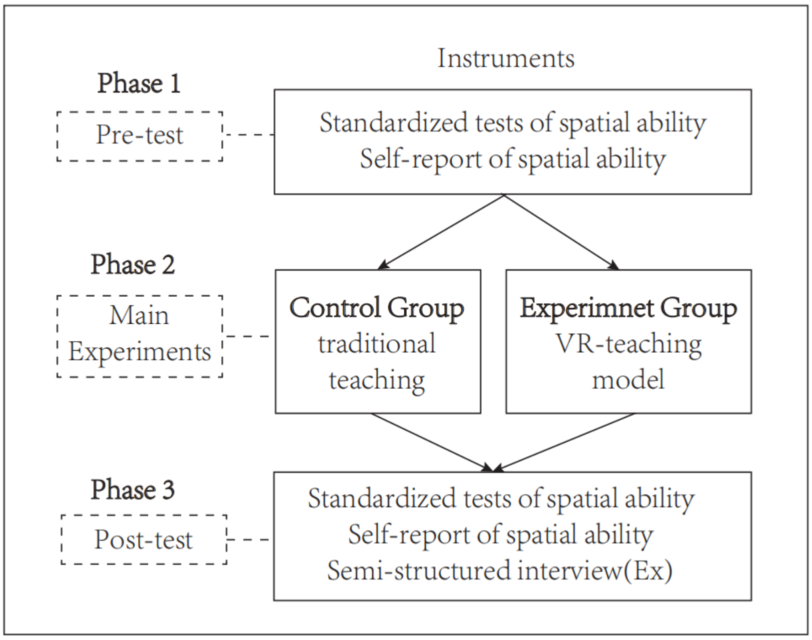


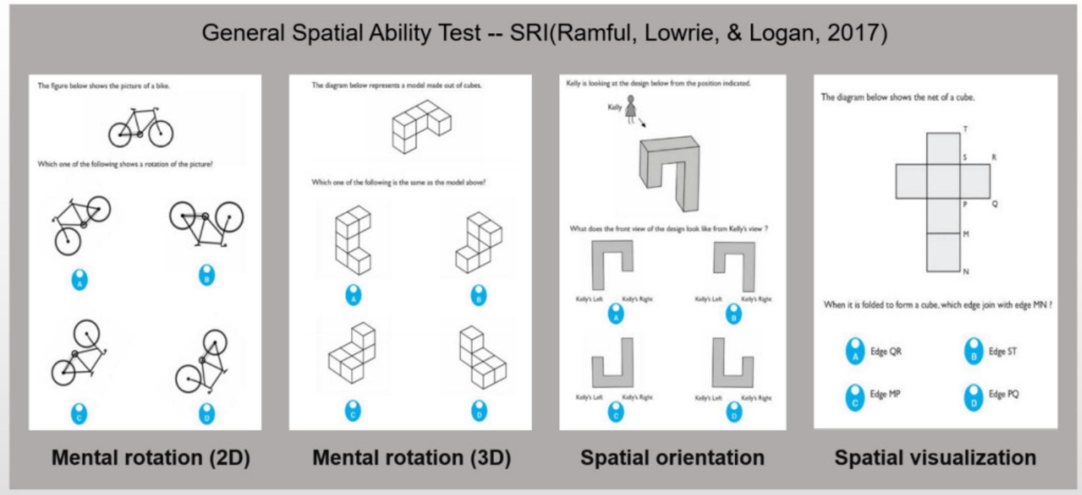
Figure 5. The experimental design of the study

Instruments

To accurately and validly measure spatial ability, it is necessary to select a comprehensive spatial ability test instrument with satisfactory reliability and validity that covers the three dimensions of mental rotation, spatial visualization, and spatial orientation.(13,14) Considering that this study focuses in the field of higher education and the target population is college students majoring in EAD, the SRI, a spatial ability test developed by Ramful et al.(15) and the AISAT, a standardized test for EAD majors developed by Cho et a.(16) were used in this study, which includes three dimensions of mental rotation, spatial orientation, and spatial visualization, and are not only designed and developed for college students but also for EAD majors. It was designed and developed not only for university students, but also for related disciplines that focus on the educational purposes of the EAD profession.

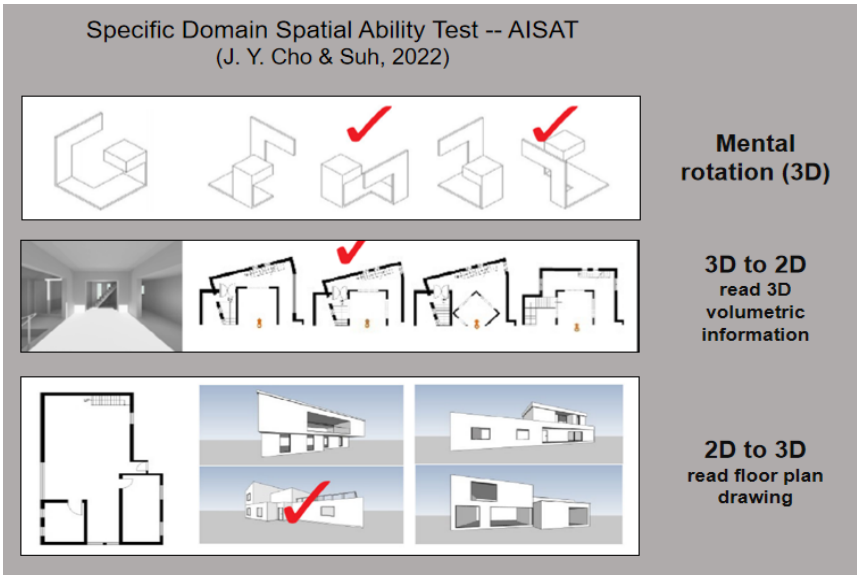
The sub-test assesses the General Spatial Ability dimension by adopting the SRI test tool developed by Ramful et al.(15) This test tool includes four dimensions: mental rotation(2D), mental rotation(3D), spatial orientation and spatial visualization, as shown in figure 4. Whilst the second sub-test was adopted to assess the Architecture and Interior design domain-specific Spatial Ability Test (AISAT).(14) Figure 6 shows samples from the test tool.

A common method to measure the reliability of questionnaires is the A-coefficient, which can show the degree of correlation between a group of test items. If the A-coefficient is greater than or equal to 0,70, it indicates that the internal consistency of the test is satisfactory. According to the research of Ramful et al.(15), it has been confirmed that the A-coefficient of SRI standardized test ranges from 0,79 to 0,85, which is in line with the standard. Ramful's standardized test of spatial ability has been widely used in education. For example, Legault et al.(17) used a standardized spatial aptitude test tool developed by Ramful to measure spatial ability in learning vocabulary in a second language using an immersive VR tool.(15)



Source: the SRI test tool developed by Ramful et al.[15]
Figure 6. Sampling Model

J. Y. Cho et al.[16] have demonstrated the validity of AISAT in terms of space capability. The results from content, concurrent, and convergent validity show that the current version of the AISAT is valid for use in the field of spatial design. The correlation analysis showed performance in DSA has a high correlation with that in GSA. Such results support convergent validity.



Source: Spatial Ability Test (AISAT) test tool[14]
Figure 7. Sampling Model

Main experiments

Case background

This study was conducted at the Art and Design College of H University, focusing on first-year interior design students. A total of 62 participants were randomly selected from four EAD courses and divided into two groups: an experimental group (28 students) using VR technology for architectural analysis and spatial experience, and a control group (34 students) receiving traditional teaching. Based on Cohen's d effect size (preset d = 0,8) and α = 0,05, a G Power analysis indicated that a minimum of 52 participants (26 per group) were required to achieve 80 % statistical power. The current sample size (N = 62) meets this requirement. Both groups followed the same syllabus, instructor, and class hours, with VR as the only independent variable. Pre-test ANOVA confirmed no significant baseline differences (p>0,05).

The study chose "Architectural Design Appreciation" due to its importance in design education and the challenges of real-world building analysis (e.g., immobility, large scale, and geographic dispersion). VR enables multi-perspective exploration (form, space, structure, materials, and details), helping students analyze architectural concepts, understand design principles, and gain inspiration for future practice.

Teaching content

Based on the teaching objectives of the course " Architectural Design Appreciation " and the objectives of this study, an operational learning activity based on HMD immersive learning environment oriented to the development of spatial ability is designed. The description of the learning activity and the corresponding elements of students' spatial ability are shown in table 1.

Table 1. Experimental teaching content

VR course	Component dimension	Development elements	Corresponding skills and learning activities
Architectural Design Appreciation	Spatial visualization	1.Visual presentation 2.Identification, composition and decomposition	Visual presentation: View the structure and appearance of buildings from different angles, use virtual reality devices to select tools and grab tools in a virtual environment, and complete related architectural appreciation activities.
	Mental rotation	Mental rotation and transformation	Mental rotation and transformation: Use VR devices to move tools, rotate building objects from different angles, and switch sites and interfaces;
	Spatial orientation	navigation	Navigation: Walk around and navigate the construction site, use VR gear to figure out where people are and the angle of the building, and take students to different spots to check out the building.

Implementation process

As shown in figure 8 below, students used VR motion controllers to freely interact with the internal components of the virtual environment throughout the building analysis and spatial experience. For example, students can use the VR motion controllers to 'roam', move, recognize, shoot, etc. inside the building. 'And filming.' With attachments. In addition, students can observe the building's appearance, features, and structure from different perspectives. All these interactive behaviors move the student through the virtual building space.

Figure 8. Spatial experience photography

Main Experiment: Analysis and Result

All statistical data and analyses were performed using IBM SPSS 27 software. For standardized tests of spatial ability, one-way ANOVA has been conducted to compare the pre-test score differences between the experimental and control groups, and ANOCOVA was used to compare post-test score differences between the two groups.

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Pre-test analysis between experimental group and control group

To examine whether there was a difference in learners' spatial abilities before the experiment was carried out, a one-way ANOVA was conducted on the changes in spatial ability and its three sub-dimensions between the experimental and control groups before the experiment was carried out. To ensure the soundness of the ANOVA, the data were tested for homogeneity of variance. The results showed that the variance homogeneity condition was satisfied for mental rotation (p=0,53>0,05), spatial visualization (p=0,72>0,05), spatial orientation (p=0,69>0,05), and spatial ability (p=0,68>0,05).

The statistical results after carrying out one-way ANOVA are shown in table 2 below; there were no significant differences between the experimental and control groups in mental rotation (F=2,12, p=0,53>0,05), spatial visualization (F=0,18, p=0,72>0,05), spatial orientation (F=0,27, p=0,69>0,05), and spatial ability (F=0,73, p=0,68>0,05) were not significantly different. This indicates that before the experiment was conducted, the experimental control group had similar base levels of spatial abilities as well as the three sub-dimensions of mental rotation, spatial orientation, and spatial visualization.

Table 2. Pre-test analysis between experimental group and control group

Dimention	Class	N	Mean	Std. Deviation	Std. Error	F	P
MR	EX	28	5,46	1,858	0,315	2,12	0,53
	CO	34	5,79	1,452	0,289		
SV	EX	28	5,18	1,842	0,344	0,18	0,72
	CO	34	5,65	1,787	0,309		
SO	EX	28	4,96	1,543	0,342	0,27	0,69
	CO	34	5,50	1,691	0,332		
Total	EX	28	15,61	4,476	0,760	0,73	0,68
	CO	34	16,94	4,750	0,820		

The mean distributions of spatial ability and their three sub-dimensions are shown in figure 9 below. For the mental rotation sub-dimension, the levels of mental rotation in the experimental group (M=5,46) and the control group (M=5,79) were basically the same (mean difference of 0,33. For the spatial visibility sub-dimension, the levels of spatial visibility in the experimental group (M=5,18) and the control group (M=5,65) were basically the same (mean difference of 0,47). For the spatial orientation sub-dimension, the experimental group (M=4,96) and the control group (M=5,50) had essentially the same level of spatial visualization (meaning difference of 0,54). For spatial ability, the level of spatial ability of the experimental group (M=15,61) and the control group (M=16,94) remained basically the same (mean difference of 1,33). It can be learnt that there is no significant difference in the levels of mental rotation, spatial visualization, spatial orientation and spatial ability between the experimental and control groups.

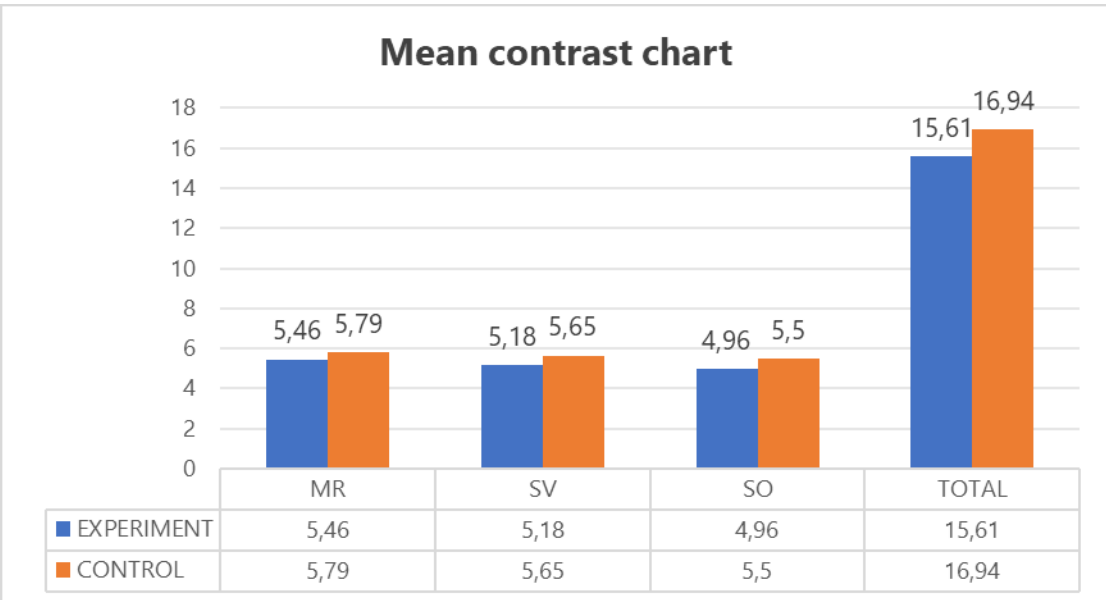

Figure 9. Pre-test means contrast between experimental group and control group Title of figure

Post-test analysis between experimental group and control group

Based on the ANCOVA results presented in table 3, the following conclusions can be drawn regarding the impact of the HMD-based immersive learning environment on spatial ability dimensions: The analysis revealed statistically significant differences between the experimental and control groups in mental rotation (F=16,07, p<0,001, η^2=0,25) and spatial visualization (F=20,83, p<0,001, η^2=0,16), with the experimental group achieving substantially higher mean scores (MR: 8,11 vs. 6,29; SV: 7,18 vs. 5,85) in both dimensions. Furthermore, a significant difference was found in overall spatial ability (F=23,56, p<0,001, η^2=0,12), with the experimental group demonstrating a notably higher total score (22,43 vs. 18,42), indicating a positive general effect of the immersive learning intervention. However, no significant difference was observed in spatial orientation (F=1,28, p=0,238, η^2=0,02) between the two groups, with mean scores being relatively similar (6,89 vs. 6,53), suggesting that while the HMD-based environment may have a slight positive influence, its effect on this particular subskill is not statistically meaningful. In summary, the HMD-based immersive learning environment demonstrates a strong and significant positive impact on learners' overall spatial ability, particularly in enhancing mental rotation and spatial visualization skills. The lack of significant improvement in spatial orientation, despite a slight positive trend, may be attributed to factors such as instructional focus, task design, or measurement sensitivity. Future studies could explore strategies to specifically enhance spatial orientation within immersive learning contexts.

Table 3. Post-test analysis between experimental group and control group

Dimention	Class	N	Mean	Std. Deviation	Std. Error	F	P	H^2
MR	EX	28	8,11	0,763	0,174	16,07	<0,001	0,25
	CO	34	6,29	1,421	0,163			
SV	EX	28	7,18	1,253	0,284	20,83	<0,001	0,16
	CO	34	5,85	1,83	0,269			
SO	EX	28	6,89	1,52	0,261	1,28	0,238	0,02
	CO	34	6,53	1,863	0,372			
Total	EX	28	22,43	1,942	0,355	23,56	<0,001	0,12
	CO	34	18,42	3,703	0,601			

The mean distributions of spatial ability and its three sub-dimensions are shown in figure 10 below. For the mental rotation sub-dimension, the levels of mental rotation in the experimental group (M=8,11) and the control group (M=6,29) were basically the same (mean difference of 1,82). For the spatial visibility sub-dimension, the levels of spatial orientation in the experimental group (M=7,18) and the control group (M=5,85) were basically the same (mean difference of 1,33). For the spatial orientation sub-dimension, the experimental group (M=6,89) and the control group (M=6,53) had essentially the same level of spatial visualization (mean difference of 0,36).

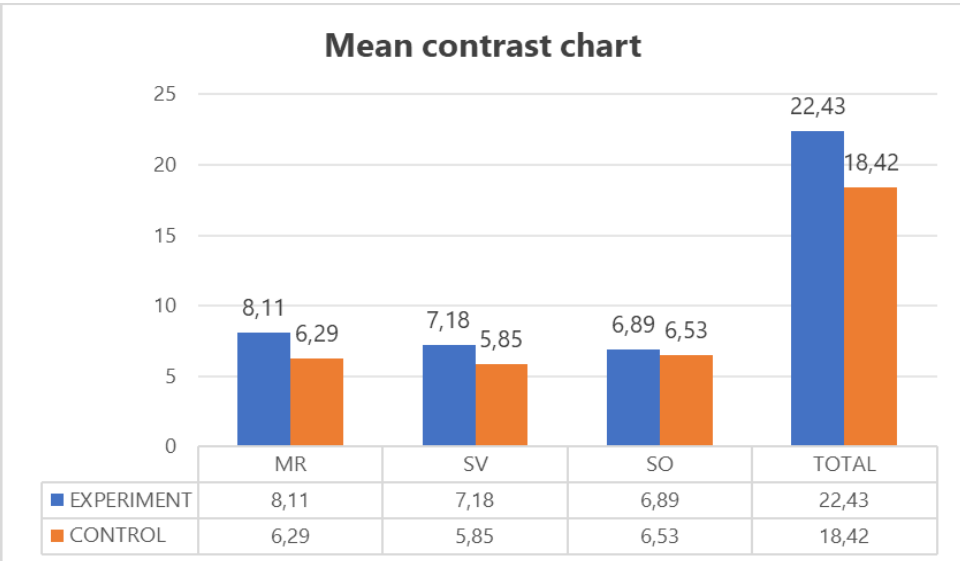

Figure 10. Mean contrast between experimental group and control group

For spatial ability, the level of spatial ability of the experimental group (M=22,43) and the control group (M=18,42) remained basically the same (mean difference of 4,01). It can be learnt that there is no significant difference in the levels of mental rotation, spatial visualization, spatial orientation and spatial ability between the experimental and control groups.

The Analysis of accuracy between Ex and Post Pre-test and Post-test (n=62)

Before and after the experiment, the accuracy rates of specific test questions (each sub-dimension consists of 10 questions) on spatial ability and its sub-dimensions were analyzed for the experimental control group, and the results are shown in table 4 below.

Table 4. The Analysis of accuracy of SA between Ex and Post Pre-test and Post-test

	MR		SV		SO		Total	
	pre	post	pre	post	pre	post	pre	post
Experimental	55 %	81 %	52 %	72 %	50 %	69 %	52 %	74 %
Control	58 %	63 %	57 %	59 %	55 %	65 %	56 %	62 %

For the experimental group, the accuracy of the mental rotation posttest (81 %) was higher than the pre-test (55 %); the accuracy of the spatial visualization posttest (72 %) was higher than the pre-test (52 %); the accuracy of the spatial orientation posttest (69 %) was higher than the pre-test (50 %); and the accuracy of the spatial ability posttest (74 %) was higher than the pre-test (56 %). At the end of the experiment, the accuracy of the spatial ability, mental rotation, spatial visualization, and spatial orientation sub-dimensions were higher in the experimental group than before the experiment was conducted.

For the control group, As shown in figure 10 below, After conducting the chi-square test, the accuracy of the mental rotation posttest (63 %) was higher than the pre-test (58 %); the accuracy of the spatial visualization posttest (59 %) was higher than the pre-test (57 %); the accuracy of the spatial orientation posttest (65 %) was higher than the pre-test (55 %); and the accuracy of the spatial ability posttest (62 %) was higher than the pre-test (50 %). At the end of the experiment, the control group's accuracy in the spatial ability, mental rotation, spatial visualization, and spatial orientation sub-dimensions were higher than before the experiment was conducted.

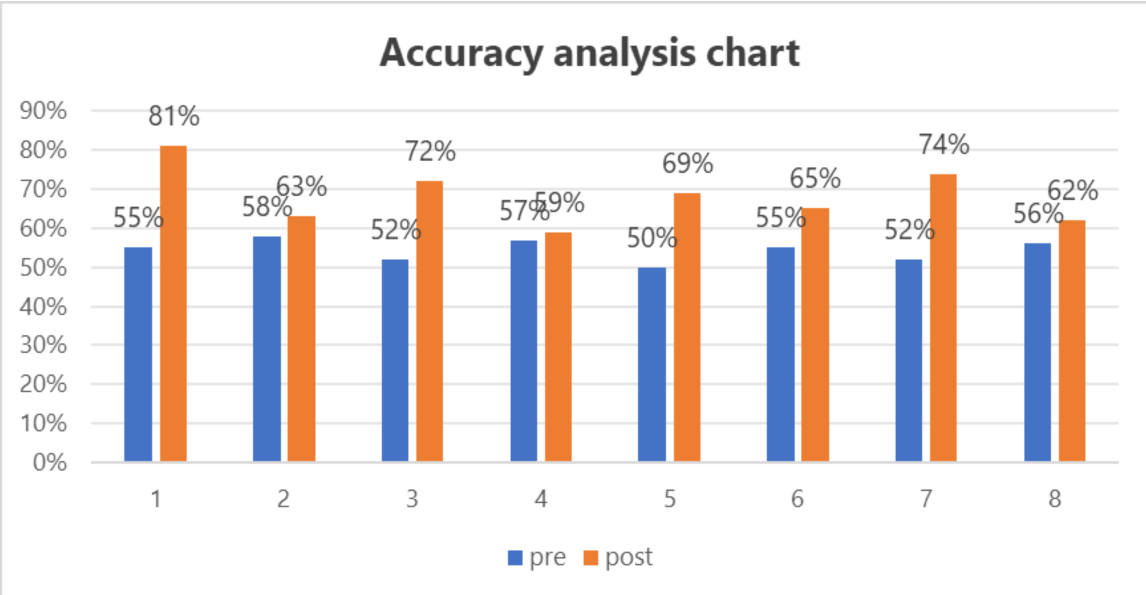

Figure 10. Accuracy contrast between experimental group and control group

The accuracy distribution of spatial ability and its sub-dimensions in the experimental control group is shown, where the experimental group had higher accuracy gains in mental rotation (M experiment = 26 %>M control = 5 %), spatial visualization (M real = 20 %>M control = 2 %), spatial orientation (M real = 19 %>M control = 10 %), and overall spatial ability (M real = 22 %>M control = 6 %) than the control group. This suggests that at the end of the experimental group, they had higher accuracy gains in spatial ability, mental rotation, spatial orientation, and spatial visualization sub-dimensions than the control group.

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Qualitative study of spatial ability (Semi-structured interview)

To support the quantitative findings, this study conducted one-by-one semi-structured interviews with 30 students in the experimental group. In response to the interview question: What are your thoughts on using VR technology for Architectural analysis and spatial experience course?'. From the results of the interviews, most of the students thought that the VR courses program had a positive effect on their learning. Table 5 below presents the results of the qualitative analysis of the students' perceptions of using VR for Decorative Materials and Construction Process courses.

Table 5. Students' thoughts and feelings about using VR technology courses

Keywords	Subject	Percentage
knowledge	VR courses are a great way to learn.	37,8
interest	VR courses very interesting	31,86
immersion	VR courses are immersive	18,35
realistically.	VR courses are more real	15,30
collaboration	VR courses can do hands-on work	10,42
3D presentation	VR courses can present 3D objects	9,8
interaction	VR courses can interact	8,5
usability	VR courses are more convenient, compared with traditional courses.	5,2

As can be seen from table above, 37,80 % of the students thought that the VR decorative architecture class had a positive effect on their academic performance, and they felt that the course could give them knowledge about decorating and building; in addition, 31,86 % of the students thought that the VR decorative architecture class was very interesting, and they felt that the course had a great deal of fun and that the content of the study was very interesting to them: 18,35 % of the students thought that the VR Decorative Architecture class makes spatial analysis more intuitive and immersive. 15,30 % of the students think that VR Decorative Architecture class are better for testing scale and proportions realistically.

The following are some examples taken from the students' interviews:

- "Make abstract concepts easier to understand and acquire more knowledge" (PVr01) (The code PVr01 represent the participants, as to keep the participant anonymity)
- " Interesting and engaging way to study architecture." (PVr02)
- "VR makes spatial analysis more intuitive and immersive." (PVr03)
- "Great for testing scale and proportions realistically." (PVr04)

In addition, some students also described the advantages of VR technology from the perspective of its own characteristics they (10,42 %) pointed out that the VR decorative architecture course can enhances collaboration in group projects, which is 3D presentation (9,8 %), interactive (8,5 %), and that the course is more convenient than the traditional course, which saves a lot of materials and time (5,2 %).

Here are some examples taken from their interviews:

- "Enhances collaboration in group projects." (PVr05)
- 'VR presents buildings in a very three-dimensional and good-looking way.' (PVr06)
- "More interactive than traditional methods." (PVr07)
- "Useful for experiencing lighting and materials realistically." (PVr08)
- 'The VR classroom atmosphere made me feel relaxed and interesting' (PVr09)
- 'VR presents buildings in a very three-dimensional and good-looking way.' (PVr10)
- 'More interactive sessions were added, livelier and more interesting.' (PVr11)
- 'The VR course is more convenient than the regular one and can save a lot of materials and time.' (PVr12)

DISCUSSION

This study employed a mixed-methods approach to evaluate the effectiveness of an HMD-based VR learning environment in enhancing spatial ability among interior design students. The quantitative results demonstrated statistically significant improvements in mental rotation ($F=16,07$, $p<0,001$, $\eta^2=0,25$) and spatial visualization ($F=20,83$, $p<0,001$, $\eta^2=0,16$), along with overall spatial ability ($F=23,56$, $p<0,001$, $\eta^2=0,12$). These findings can be meaningfully interpreted through the theoretical frameworks guiding this study—Experiential Learning Theory,[7] Cognitive Load Theory,[6] and Constructivism.[8]

The significant gains in mental rotation and spatial visualization align closely with the principles of experiential learning. The VR environment provided students with concrete 3D experiences—such as rotating building components and navigating virtual spaces—which facilitated reflective observation and abstract conceptualization. This direct manipulation of objects likely reduced cognitive load by overworking mental imagery into the interactive environment, allowing learners to focus on spatial reasoning rather than representation.[17] These results corroborate the findings of Assali[18] and Darwish et al.[19], who also reported that immersive technologies enhance spatial understanding through embodied interaction.

However, no significant improvement was found in spatial orientation ($F=1,28$, $p=0,238$, $\eta^2=0,02$). This discrepancy may be attributed to the instructional design and task structure. While the VR experience emphasized object manipulation (benefiting mental rotation and visualization), it may not have sufficiently required learners to adopt alternative viewpoints or navigate complex paths—key components of spatial orientation.[20,21] Additionally, the AISAT and SRI instruments may prioritize static spatial reasoning over dynamic navigation skills, which could explain the lack of measurable improvement. This finding partially contrasts with Guevara et al.[3] who reported broader spatial gains but aligns with Serrano-Ausejo et al.[9], who noted that not all spatial subskills are equally supported by all VR designs.

Qualitative data further support these interpretations. Students reported that VR made spatial relationships "more intuitive" (PVr03) and helped in "testing scale and proportions realistically" (PVr04), which aligns with the reduced cognitive load and enhanced immersion predicted by flow theory.[21,22,23] The high percentage of students emphasizing knowledge acquisition (37,8 %) and interest (31,86 %) also reflect the motivational benefits of immersive learning.

CONCLUSIONS

This study provides evidence that a theory-driven VR learning model—grounded in experiential learning, cognitive load theory, and constructivism—can significantly enhance specific spatial abilities, namely mental rotation and spatial visualization, among interior design students. The immersive, interactive nature of VR facilitates hands-on experience and reduces extraneous cognitive load, thereby supporting deeper spatial understanding.

However, the lack of significant improvement in spatial orientation suggests that not all spatial subskills are equally addressed through current VR instructional designs. This highlights the need for more targeted spatial orientation tasks, such as wayfinding exercises, perspective-taking, and dynamic navigation scenarios.

Several limitations should be acknowledged. The sample was limited to 62 first-year students from a single university, which may affect the generalizability of the findings. The short intervention period (one semester) may not have been sufficient to foster all spatial subskills, particularly those requiring long-term integration. The experimental group utilized VR equipment within an immersive classroom setting, whilst the control group employed PowerPoint presentations and videos in a conventional classroom. Although instructors, teaching content, and duration remained consistent, the learning environments differed significantly in terms of immersion and interactivity. This disparity may have introduced the Hawthorne effect or novelty effect, whereby students performed better due to the novelty of the experience. Future research should endeavor to control environmental variables (e.g., employing VR without activating immersive mode as the control group). Alternatively, conducting 'adaptive training' prior to the experiment may mitigate the novelty effect.

Future research should explore how VR can be designed to better support spatial orientation, perhaps by incorporating more navigational challenges and multi-perspective analysis. Longitudinal studies with larger and more diverse samples are also recommended. Additionally, integrating emerging technologies such as AI for personalized learning paths or AR for hybrid real-virtual experiences may offer new avenues for enhancing spatial training.

In summary, VR holds considerable promise as an educational tool in design education, particularly for developing spatial skills. By aligning instructional design with robust theoretical frameworks, educators can maximize their potential to create engaging, effective, and immersive learning experiences.

BIBLIOGRAPHIC REFERENCES

1. Uttal DH, Meadow NG, Tipton E, Hand LL, Alden AR, Warren C, et al. The malleability of spatial skills: a meta-analysis of training studies. Psychol Bull. 2013;139(2):352-402.

2. Mix KS, Levine SC, Cheng Y-L, Stockton JD, Bower CJJoEP. Effects of spatial training on mathematics in first and sixth grade children. 2021;113(2):304.

3. Guevara D, de Laski-Smith D, Ashur SJSSS. Interior design students' perception of virtual reality. 2022;2(8):152.

4. Balalle HJDE. Learning beyond realities: exploring virtual reality, augmented reality, and mixed reality in higher education—a systematic literature review. 2025;4(1):151.

5. Marougkas A, Troussas C, Krouska A, Sgouropoulou CJE. Virtual reality in education: a review of learning theories, approaches and methodologies for the last decade. 2023;12(13):2832.

6. Sweller J. Cognitive load theory. Psychology of learning and motivation. 55: Elsevier; 2011. p. 37-76.

7. Kolb DA. Experiential learning: Experience as the source of learning and development. 2014.

8. Hein GEJIfI. Constructivist learning theory. 1991;14.

9. Serrano-Ausejo E, Mårell-Olsson EJE, Technologies I. Opportunities and challenges of using immersive technologies to support students' spatial ability and 21st-century skills in K-12 education. 2024;29(5):5571-97.

10. Dawson JC, Goldringer IJOcb. Breeding for genetically diverse populations: variety mixtures and evolutionary populations. 2012:77-98.

11. Shadish WRJPm. Revisiting field experimentation: field notes for the future. 2002;7(1):3.

12. Johnson RB, Christensen LB. Educational research: Quantitative, qualitative, and mixed approaches: Sage publications; 2024.

13. Fareed, M., Ahmad A., S. S. M. M., Noor, W. S. W. M. & Isa, M. F. M. What Makes Human Resource Professionals Effective? An Exploratory Lesson from Techno-Based Telco Firms of a Developing Country. Front. Psychol. 2022. 13:774165. https://doi.org/10.3389/fpsyg.2022.774165

14. Fareed, M., Ahmad, A., Salleh, S. S. M. M., & Saoula, O. What makes HR Professionals Effective? Qualitative Evidence from Telecom Sector of a Developing Country. Revista Argentina de Clínica Psicológica. 2019; 28(4), 603-617. https://doi.10.24205/03276716.2019.1141

15. Ramful A, Lowrie T, Logan T. Measurement of Spatial Ability: Construction and Validation of the Spatial Reasoning Instrument for Middle School Students. Journal of Psychoeducational Assessment. 2017;35(7):709-27.

16. Cho JY, Suh J. The Architecture and Interior Design Domain-Specific Spatial Ability Test (AISAT): Its Validity and Reliability. Journal of Interior Design. 2022;47(2):11-30.

17. Legault J, Zhao J, Chi Y-A, Chen W, Klippel A, Li P. Immersive Virtual Reality as an Effective Tool for Second Language Vocabulary Learning. 2019;4(1):13.

18. Cho JY, Suh J. UNDERSTANDING SPATIAL ABILITY IN INTERIOR DESIGN EDUCATION: 2D-TO-3D VISUALIZATION PROFICIENCY AS A PREDICTOR OF DESIGN PERFORMANCE. 2019.

19. Sweller JJEpr. Element interactivity and intrinsic, extraneous, and germane cognitive load. 2010;22:123-38.

20. Assali I, Alaali A. Integrating Technology into Interior Design Education: A Paradigm Shift in Teaching and Learning. Board Diversity and Corporate Governance: Springer; 2024. p. 565-76.

21. Darwish M, Kamel S, Assem A. Extended reality for enhancing spatial ability in architecture design education. Ain Shams Engineering Journal. 2023;14(6).

22. Weisberg SM, Schinazi VR, Ferrario A, Newcombe NSJJoEPL, Memory. Cognition. Evaluating the effects of a programming error on a virtual environment measure of spatial navigation behavior. 2023;49(4):575.

23. Csikszentmihalyi M, Csikszentmihalyi M, Abuhamdeh S, Nakamura JJF, Csikszentmihalyi tfoppTcwoM. Flow. 2014:227-38.

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CONFLICT OF INTEREST
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