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Design and Evaluation of a Virtual Reality Learning Game for Interior Design Styles

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Abstract

Public understanding of interior design styles is still limited because conventional two-dimensional (2D) media cannot adequately represent spatial depth, perspective, and the distinguishing characteristics of each style. This limitation often leads to misconceptions when identifying interior design concepts and elements. Therefore, this study aims to design and evaluate a Virtual Reality (VR)-based learning game as an immersive medium for introducing interior design styles. The system was developed using the Mechanics, Dynamics, and Aesthetics (MDA) framework and implemented in Unity with the XR Interaction Toolkit for the Meta Quest 2 platform. The application includes five interior design styles—modern, minimalist, industrial, natural, and rustic—and provides interactive tasks that allow users to explore, manipulate, and apply interior elements in a virtual environment. To evaluate its effectiveness, a pretest–posttest experiment was conducted with 30 participants. The results show that the average score increased from 31.25% in the pretest to 56.25% in the posttest, indicating an improvement of 25 percentage points. A paired-samples t-test also showed a statistically significant improvement, with $p < 0.001$. These findings suggest that the proposed VR learning game has the potential to improve users' understanding of interior design styles.

1. Introduction

Interior design plays an important role in creating comfort, aesthetics, and functionality within a space [1], [2], [3]. Each interior design style, such as modern, minimalist, industrial, natural, and rustic, has distinct characteristics in terms of color, materials, layout, and supporting elements. A proper understanding of these styles is essential for the general public, especially for individuals who intend to design or renovate their living spaces, as it helps them determine suitable concepts based on their needs and preferences [4].

However, in practice, public understanding of interior design styles remains limited [5], [6]. This issue is mainly caused by reliance on two-dimensional (2D) media, such as internet images, as the primary reference source. In interior design education, understanding spatial information requires the ability to interpret and transform 2D representations into 3D spatial understanding, including depth, perspective, object relationships, and the overall experience of a room [7], [8]. Static visual media may therefore be insufficient for users who need to understand interior design styles as spatial and experiential concepts, often leading to misconceptions about interior design styles and their elements [9]. Preliminary analysis of questionnaires also indicates that many respondents remain uncertain about distinguishing between different interior design styles, even though they have a general idea of their desired room concepts.

With advances in technology, Virtual Reality (VR) has emerged as a promising solution to overcome the limitations of conventional learning media. VR enables users to experience immersive three-dimensional (3D) environments, helping them better understand spatial arrangements, objects, and interactions in a more realistic way [10], [11]. In addition, game-based learning (GBL) approaches, particularly serious games, have been widely used to enhance user engagement through interactive, enjoyable learning experiences [12], [13].

Previous studies have shown that VR can support learning by providing immersive visualization, spatial exploration, and interactive engagement [14], [15]. In design-related learning contexts, VR has been used to improve users' ability to understand spatial relationships, object arrangement, and environmental experience [9]. However, most existing studies focus on general spatial visualization, architectural walkthroughs, or professional design training. Limited studies have specifically examined VR-based game learning for introducing interior design styles to non-expert users, particularly through interactive tasks that require users to identify, manipulate, and apply design elements in a virtual room [16], [17].

Therefore, the gap addressed in this study lies in the integration of immersive VR, game-based learning, and interior style recognition for general users. Unlike conventional visual references or passive VR walkthroughs, the proposed system allows users to actively explore interior styles, interact with design elements, and complete style-based tasks. This study contributes by designing a VR learning game based on the MDA framework and evaluating its potential to improve users' understanding of interior design styles through a pretest–posttest approach.

Given these challenges, this study aims to design and develop a Virtual Reality-based learning game to introduce various interior design styles and their elements. The system is designed using the Mechanics, Dynamics, and Aesthetics (MDA) framework and implemented in Unity, with support from the XR Interaction Toolkit. Through this game, users can explore virtual spaces, learn about interior elements, and interact directly with objects in a 3D environment. Furthermore, this study also aims to evaluate the effectiveness of the developed VR game in improving users' understanding of interior design styles. The evaluation is conducted using a pretest–posttest design with participants, allowing measurement of changes in users' understanding before and after using the application. Therefore, this research is expected to contribute to the development of immersive technology-based learning media, particularly in interior design.

2. Research Method

This study employed a system development approach, combined with quantitative evaluation, to design, implement, and assess a VR-GBL to introduce interior design styles. The research methodology was structured to ensure that both the development process and the evaluation results could be clearly understood and replicated by other researchers. The overall research process consisted of several stages, including requirement analysis, system design, implementation, and evaluation.

2.1 Research Design

The research design followed a structured development process consisting of four main stages, as shown in Figure 1. The first stage involved requirement analysis through questionnaires and interviews with an interior designer. This stage aimed to identify common misconceptions, user needs, and limitations of existing media used for learning interior design styles.

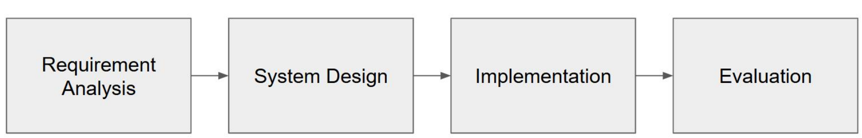


Figure 1. Development Process

The second stage focused on system design using the Mechanics, Dynamics, and Aesthetics (MDA) framework to define gameplay mechanics, user interactions, and the intended learning experience. In this study, the MDA framework was used as a structured approach to translate the learning objectives into concrete gameplay elements. Mechanics refer to the rules, controls, and system features provided to users, such as teleportation, object selection, object manipulation, item purchasing, budget limitation, and task completion rules. Dynamics refer to the user behaviors that emerge when interacting with these mechanics, including exploring virtual rooms, comparing interior design styles, selecting appropriate furniture, arranging objects, and correcting mistakes based on task requirements. Aesthetics refer to the intended user experience and learning outcomes, such as immersion, curiosity, engagement, spatial understanding, and satisfaction after completing the interior design tasks. The operationalization of the MDA framework in the developed VR learning game is presented in Table 1.

The third stage involved implementing the system using appropriate development tools, including Unity and the XR Interaction Toolkit. The fourth stage was evaluation, which used a pretest–posttest design to measure changes in users' understanding of interior design styles after using the developed VR game.

Table 1. Operationalization of the MDA Framework in the VR Learning Game

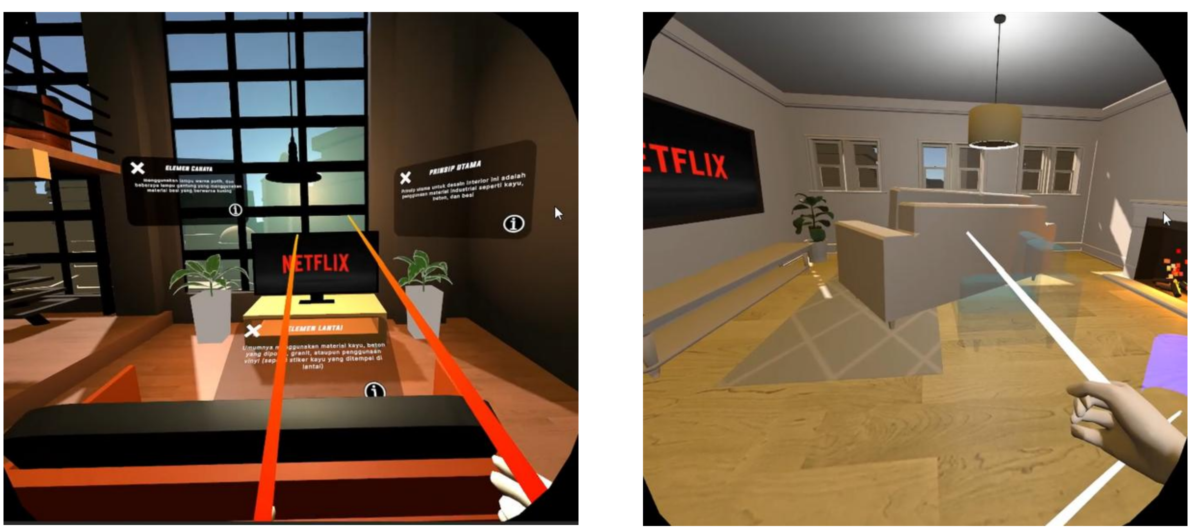
MDA Component	Definition in This Study	Operationalization in the VR Learning Game	Implemented Features
Mechanics	The rules, controls, and system elements that structure the gameplay and learning activities.	Mechanics were designed to guide users in navigating the VR environment, accessing learning materials, interacting with interior objects, and completing design-related tasks.	Teleportation movement, ray-based interaction, controller-based object grabbing, object rotation, texture modification, item purchasing, budget limitation, task instructions, and win/lose conditions.
Dynamics	The behaviors and interactions that emerge when users engage with the game mechanics.	Dynamics emerged when users explored different rooms, compared design styles, selected suitable items, arranged furniture, and adjusted interior elements according to task requirements.	Room exploration, comparison of modern, minimalist, industrial, natural, and rustic styles, furniture selection, spatial arrangement, object placement, error correction, and client-based task completion.
Aesthetics	The emotional, experiential, and learning responses expected from users during and after gameplay.	Aesthetics were targeted by creating an immersive, engaging, and meaningful learning experience that helped users understand interior design styles through direct experience rather than passive observation.	Sense of presence, curiosity, engagement, enjoyment, spatial awareness, improved visualization, better understanding of design characteristics, and satisfaction after completing tasks.

As shown in Table 1, each MDA component was connected to specific learning and interaction features in the VR application. The Mechanics component provided the basic rules and interaction structure that allowed users to move, select, manipulate, and arrange interior elements. These mechanics then produced Dynamics in the form of active exploration and problem-solving activities, where users had to interpret the characteristics of each interior design style and apply them in the task room. Finally, the Aesthetics component was reflected in the intended learning experience, where users were expected to feel immersed, engaged, and more capable of understanding spatial relationships and interior design characteristics. Therefore, the MDA framework served as a bridge between the learning objectives and the actual gameplay design implemented in the VR environment.

2.2 System Development

The VR learning game was developed using Unity 2021.3.15f1 as the main development platform. The XR Interaction Toolkit was utilized to support user interaction, navigation, and object manipulation within the virtual environment. The application was designed to run on the Meta Quest 2 device to provide a fully immersive experience. The system consists of three main environments: a technical room for navigation and instructions, an interior introduction room for exploring five interior design styles (modern, minimalist, industrial, natural, and rustic), and an interior task room where users complete interactive activities. These activities include placing furniture, modifying textures, and arranging interior elements to match specific design styles, thereby enhancing both engagement and learning outcomes.

Figure 2 illustrates the implementation of the VR environment and user interaction within the application. As shown in Figure 2(a), the interior introduction room provides users with interactive information panels that explain key elements of each design style, such as color, lighting, and material. Users can access this information through ray-based interaction, allowing them to learn the characteristics of each interior style in an immersive manner. Meanwhile, Figure 2(b) shows the interior task room, where users perform hands-on activities by interacting directly with virtual objects. In this environment, users can manipulate furniture placement and adjust interior elements using VR controllers. This interactive process enables users to apply their understanding in a practical context, reinforcing learning through experiential interaction rather than passive observation.



(a) (b)

Figure 2. (a) Interior introduction environment with interactive information panels, (b) Interior task environment with object interaction and spatial manipulation

2.3 Respondent Characteristics & Data Collection

The evaluation phase involved 30 participants selected using convenience sampling. The participants were members of the general public who commonly relied on online resources, such as images and websites, as references for interior design styles. None of the participants had professional expertise in interior design, ensuring that the evaluation focused on typical non-expert users. Most participants were within the productive age range of approximately 19–40 years old and had diverse educational and occupational backgrounds.

The use of 30 participants was considered appropriate for an initial formative evaluation of the developed VR learning game. The purpose of this evaluation was to obtain preliminary evidence regarding users' learning improvement and experience after using the application, rather than to make broad statistical generalizations. However, the use of convenience sampling and the relatively small sample size should be acknowledged as limitations. Therefore, the findings of this study should be interpreted as preliminary evidence of the potential of the VR learning game to support interior design style learning.

This study used a one-group pretest–posttest design, in which the same participants completed a pretest before using the VR application and a posttest after using it. This design was selected to measure changes in participants' understanding before and after interacting with the developed VR learning game. However, no separate control group was included in this study. As a result, the evaluation cannot fully isolate the effect of the VR application from other possible factors, such as test familiarity, short-term learning effects, or participants' prior exposure to interior design references. Therefore, the results should be interpreted as an indication of learning improvement after using the VR application, rather than as conclusive evidence that VR is superior to conventional learning media.

Data were collected using a pretest–posttest approach to measure participants' understanding before and after interacting with the VR application. The test instrument consisted of eight questions: six multiple-choice questions on identifying interior design styles and elements, and two Likert-scale questions measuring participants' perceived understanding. Each multiple-choice question consisted of four answer options. The pretest was administered before participants used the VR application, while the posttest was administered immediately after the interaction session.

In addition to the main test, the posttest included several Likert-scale questions to evaluate user experience aspects, including ease of use, clarity of interaction, spatial visualization, object visualization, and the perceived effectiveness of VR in supporting interior design style learning. These questions were used as supplementary formative feedback to understand participants' immediate perceptions of the developed application.

2.4 Data Validity, Reliability, and Analysis

The test instrument was developed based on the learning objectives of the VR application and key concepts of interior design styles introduced in the learning content. The questions were designed to measure participants' understanding of interior design characteristics, including style identification, design elements, materials, colors, and spatial arrangement. To support content validity, the instrument was reviewed in relation to the learning materials and discussed with an interior design practitioner during the requirement analysis stage. This process helped ensure that the questions were aligned with the concepts presented in the VR application.

However, formal expert validation using Content Validity Ratio (CVR) or Content Validity Index (CVI) was not conducted in this study. In addition, statistical reliability testing such as Cronbach's alpha was not performed because the knowledge test consisted of a limited number of items and was primarily used for an initial formative evaluation. Therefore, the validity and reliability of the instrument should be interpreted with caution. Future studies should involve multiple experts and apply formal validity and reliability testing to strengthen the quality of the measurement instrument.

The user experience questionnaire was developed as a supplementary formative evaluation tool to capture participants' immediate perceptions after using the VR application. The items focused on aspects directly related to the system objectives, including ease of use, control clarity, spatial visualization, object visualization, task difficulty, motion sickness, and perceived understanding improvement. However, the questionnaire was not adapted from standardized instruments. Therefore, the UX results should be interpreted as descriptive user feedback rather than as a fully validated usability, user experience, or presence measurement. Future studies should consider adopting standardized instruments to obtain more robust and comparable UX evaluation results.

Reliability in the data collection process was supported through a standardized testing procedure. All participants followed the same sequence of activities, consisting of the pretest, interaction with the VR application, and posttest. The same instructions, test format, and interaction procedure were applied to all participants to reduce procedural inconsistency and improve comparability across participants.

The collected data were analyzed using both descriptive and inferential statistical methods. Descriptive analysis was used to compare the percentages of correct answers between the pretest and posttest, providing an overview of changes in participants' understanding. User experience data were analyzed descriptively using average Likert-scale scores for each evaluation aspect. To determine whether the observed difference between pretest and posttest scores was statistically significant, a paired-samples t-test was conducted. This test was selected because it compares two related measurements obtained from the same participants. A significance level of 0.05 was used to determine whether the difference between the two sets of scores was statistically meaningful.

3. Result and Discussions

3.1 System Results

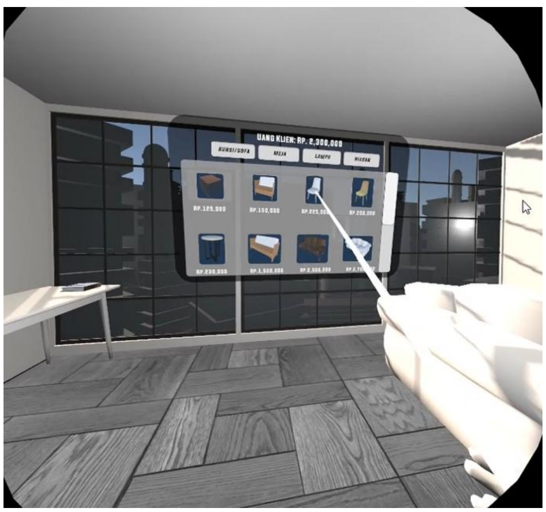
The developed VR learning game was successfully implemented and tested on the Meta Quest 2 device. The system consists of three main environments: the technical room, the interior introduction room, and the interior task room. Functional verification was conducted to ensure that all core features operated properly, including navigation, user interface interaction, object manipulation, and task completion mechanisms.

In the technical room, users are first introduced to the system through an onboarding interface that explains controller usage. As shown in Figure 3, the system provides a visual guide for both left and right controllers, allowing users to understand interaction methods such as teleportation, object selection, and menu navigation. This onboarding stage plays an important role in helping users adapt to VR interaction before entering the main learning environment.

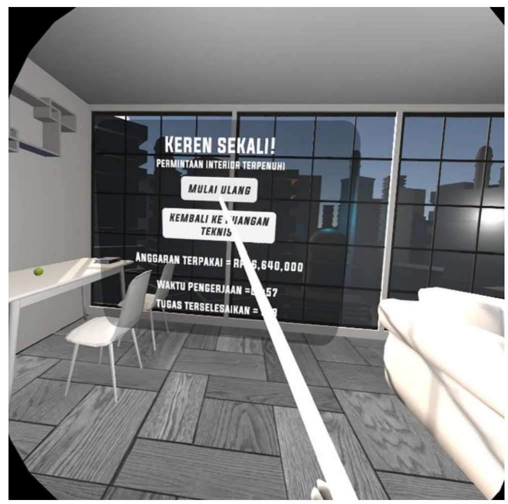
Figure 3. Controller usage interface in the technical room

In the interior introduction room, users can explore five interior design styles: modern, minimalist, industrial, natural, and rustic. Each environment contains interactive information panels that explain key elements such as color, lighting, walls, and materials. The teleportation system and ray-based interaction function properly, allowing users to move between rooms and access information intuitively. This environment supports exploratory learning, where users can freely observe and compare different interior styles.

Meanwhile, the interior task room provides a more interactive learning experience where users complete tasks based on client requirements. As shown in Figure 4(a), users can interact with objects through an in-game store to purchase interior items, while Figure 4(b) illustrates the completion state when all tasks are successfully achieved. The tasks are divided into three phases: cleaning the room, modifying interior elements (such as textures), and arranging furniture according to specific design styles. Users can interact with objects using VR controllers, including picking up, placing, rotating, and purchasing items. The system also includes win and lose conditions based on task completion and budget constraints. Overall, the verification results indicate that all system functionalities operate as expected, and the application is ready to be used as an interactive learning medium for interior design styles.



(a)



(b)

Figure 4. (a) Object interaction and purchasing interface, (b) Task completion interface

3.2 Learning Outcome Evaluation

To evaluate the potential learning effect of the VR application, a one-group pretest–posttest evaluation was conducted with 30 participants. The test consisted of eight questions, including six multiple-choice questions and two Likert-scale questions. Each multiple-choice question consisted of four answer options, resulting in an estimated chance level of 25% for random guessing. The pretest was conducted before participants used the VR application, while the posttest was conducted immediately after the interaction session.

The results indicate an improvement in participants' understanding of interior design styles after using the VR application. The average percentage of correct answers increased from 31.25% in the pretest to 56.25% in the posttest, indicating an improvement of approximately 25 percentage points. As presented in Table 2, the comparison between pretest and posttest results illustrates the increase in participants' performance after using the VR application.

Table 2. Comparison of Pretest and Posttest Results

Test Type	Average Score (%)	Improvement
Pretest	31.25%	-
Posttest	56.25%	+25 percentage points

The relatively low pretest score suggests that participants had limited prior knowledge of interior design styles before using the VR application. Since each multiple-choice question consisted of four answer options, the estimated chance level for random guessing was approximately 25%. Therefore, the pretest average of 31.25% was only slightly above the chance level, indicating a possible floor effect. This condition should be considered when interpreting the magnitude of the learning improvement.

To confirm whether the difference between pretest and posttest scores was statistically significant, a paired-samples t-test was conducted. The result showed a statistically significant difference between the pretest and posttest scores, with $p < 0.001$. This finding indicates that participants' understanding improved after using the VR learning game. However, because this study did not include a separate control group, the result should be interpreted as preliminary evidence of potential learning improvement rather than conclusive evidence that VR is superior to conventional learning media.

3.3 User Experience Analysis

User experience evaluation was conducted using additional Likert-scale questions in the posttest. The user experience results should be interpreted as descriptive feedback because the questionnaire was developed as a supplementary formative evaluation tool and was not adapted from a standardized UX instrument. The results show that participants generally had a positive experience when using the VR application, particularly in terms of understanding, visualization, and interaction.

Participants reported that the VR application helped them better understand the differences between interior design styles, with an average score of 4.13. In addition, users were able to visualize spatial perspectives and interior objects more clearly, with average scores of 4.10 and 4.16, respectively. These findings are consistent with previous studies indicating that VR can support spatial perception and design-related visualization by allowing users to experience spatial components, object relationships, and room-scale environments in an immersive three-dimensional setting [18], [19]. In the context of interior design and architecture, VR has also been reported to support the communication and understanding of spatial objects and components through a high sense of presence, immersion, and interactive manipulation [9]. Therefore, the findings of this study suggest that VR may support spatial cognition and visual understanding by allowing users to observe interior elements, room layout, and design characteristics in a more immersive environment. Table 3 presents the results of the user experience evaluation, showing that most assessed aspects achieved relatively high scores and indicating that the VR application provides a generally positive user experience.

Table 3. User Experience Evaluation Results

No	Evaluation Aspect	Average Score (1–5)
1	Motion sickness level	3.83
2	Understanding improvement	4.13
3	Spatial visualization	4.10
4	Object visualization	4.16
5	Control usability	3.96
6	Control understanding	3.86
7	Ease of use	3.76
8	Task difficulty suitability	3.66

The motion sickness score should be interpreted carefully because cybersickness is an important issue in VR-based learning environments. Cybersickness commonly refers to discomfort symptoms that may occur during or after VR exposure, such as nausea, dizziness, headache, eyestrain, and disorientation [20]. Although participants generally reported positive learning and visualization experiences, the motion sickness score indicates that some users may still experience discomfort during VR interaction. This discomfort may be caused by unfamiliarity with VR devices, individual susceptibility, visual-motion mismatch, movement mechanisms, or prolonged exposure to the virtual environment [20], [21]. Therefore, cybersickness has important implications for user comfort, safety, accessibility, and practical deployment, especially for users who are sensitive to immersive motion or have limited prior experience with VR technology.

Several usability-related issues were also identified. Some participants reported initial difficulties in understanding controller usage and interacting with objects. In addition, some interaction elements, such as purchasing items or pressing buttons, were considered less responsive. These issues indicate that usability improvements are still needed, particularly in relation to onboarding, interaction feedback, and control responsiveness. This is consistent with prior VR studies showing that locomotion, interaction design, and usability can affect user comfort, task experience, and the overall quality of immersive learning environments [21], [22].

To reduce cybersickness and improve usability in future versions, the application should provide more comfortable locomotion and interaction options, such as teleportation-based movement, adjustable movement speed, shorter learning sessions, clearer controller tutorials, visual comfort settings, and optional rest breaks. Teleportation and carefully designed locomotion methods are commonly discussed as approaches to reduce discomfort in VR because locomotion design can influence cybersickness and user comfort [21], [22]. Improving object interaction responsiveness and providing clearer feedback when users successfully select, purchase, or place an item may also help reduce confusion and improve the overall learning experience. These improvements are important to ensure that the VR learning game can be used safely and comfortably by a wider range of users.

The results of this study indicate that the developed VR learning game has the potential to support users' understanding of interior design styles. The increase in the average score from 31.25% in the pretest to 56.25% in the posttest suggests that participants were able to better identify and understand interior design characteristics after interacting with the VR application. This finding is consistent with previous studies showing that VR can support spatial learning by allowing users to experience spatial components, object relationships, and room-scale environments through immersive three-dimensional interaction [9], [18], [23]. In the context of interior design and architecture, VR has also been reported to support the communication and understanding of spatial objects and components by providing a high sense of presence, immersion, and opportunities for spatial interaction [24].

The improvement in learning outcomes can be attributed to the combination of immersive visualization and interactive task-based learning. Unlike static 2D references, the VR environment allowed users to observe room layouts, compare interior styles, manipulate objects, and apply design elements directly in a virtual room. This aligns with previous studies indicating that immersive technologies and digital game-based learning can provide situated and interactive learning environments that enhance learning experiences and support deeper learning [15]. In this study, the task room functioned as an experiential learning space where participants were not only exposed to information about interior styles but were also required to apply that information through object selection, arrangement, and task completion. Therefore, the learning improvement may be related to the active interaction between users and interior design elements, rather than passive observation alone.

The user experience findings also support the role of VR in improving visualization and engagement. Participants gave relatively high scores for understanding improvement, spatial visualization, and object visualization. These findings are in line with prior interior design and architecture studies suggesting that VR can provide users with a more vivid perception of spatial relationships and three-dimensional environments [24], [9]. In addition, previous research on interior design VR has shown that immersive environments can support design review, spatial perception, and user experience by allowing users to experience a space from an egocentric perspective rather than only through desktop or static representations [18]. This supports the argument that VR is particularly relevant for interior design learning because interior design requires users to understand depth, perspective, object relationships, materials, and the atmosphere of a room.

However, the findings should be interpreted cautiously. Although the average score increased by approximately 25 percentage points, a direct quantitative comparison with previous VR learning studies is limited. Learning gains in VR-based learning research may vary depending on the learning domain, test instrument, intervention duration, participant characteristics, VR hardware, interaction design, and experimental design. For example, studies on VR game-based learning in other domains, such as STEM education, may report learning improvement, but their assessment instruments and learning objectives differ from those used in interior design style recognition [25]. Therefore, the improvement observed in this study should be interpreted as preliminary evidence that VR-based game learning has potential to support interior design style understanding, rather than as conclusive evidence of superiority over other learning methods.

Several limitations must also be considered. First, the study used a one-group pretest–posttest design without a separate control group. As a result, the improvement in posttest scores cannot be attributed solely to the VR application because other factors, such as test familiarity, short-term learning effects, or prior exposure to interior design references, may also influence the results. Second, the study involved only 30 participants selected using convenience sampling, which limits the generalizability of the findings. Third, the learning assessment and user experience questionnaire were developed for formative evaluation and were not fully validated using formal procedures such as CVR, CVI, Cronbach's alpha, SUS, UEQ, Presence Questionnaire, or SSQ. Therefore, future studies should involve larger and more representative samples, include a control or comparison group, apply standardized and validated instruments, and examine long-term knowledge retention.

In addition, the user experience results highlight the importance of managing cybersickness and usability in VR-based learning environments. Although participants generally reported positive learning and visualization experiences, the motion sickness score indicates that some users may still experience discomfort during VR interaction. This finding is consistent with previous studies showing that cybersickness remains a significant issue in head-mounted display-based VR and may affect user comfort, accessibility, and practical deployment [20], [26]. Therefore, future development should improve locomotion design, interaction feedback, onboarding tutorials, session duration, and comfort settings to ensure that the VR learning game can be used safely and comfortably by a wider range of users.

Overall, this study contributes to the development of immersive learning media by integrating VR, game-based learning, and interior design style recognition for non-expert users. While previous studies have largely focused on VR for spatial visualization, design review, professional design support, or studio-based interior design education, this study emphasizes the use of VR game-based tasks to help general users identify, manipulate, and apply interior design elements in an interactive virtual environment. Thus, the proposed application offers a promising direction for introducing interior design concepts through experiential and immersive learning, although further controlled studies are required to confirm its effectiveness.

4. Conclusions and Future Works

This study successfully designed and developed a VR-GBL for introducing interior design styles and their elements. The system was implemented using Unity and the XR Interaction Toolkit, providing an immersive, interactive environment where users can explore and interact with five interior design styles: modern, minimalist, industrial, natural, and rustic. The integration of game-based learning and immersive technology enables users to actively engage with the content rather than passively observe.

The evaluation results suggest that the developed application has the potential to support users' understanding of interior design styles, as indicated by the increase in posttest scores after using the VR learning game. The average percentage of correct answers increased from 31.25% in the pretest to 56.25% in the posttest, indicating an improvement of approximately 25 percentage points. This improvement was statistically significant, as confirmed by the paired-samples t-test ($p < 0.001$). These findings suggest that the developed VR-based learning environment has the potential to support spatial understanding and clearer differentiation of interior design styles. However, due to the use of convenience sampling, the relatively small sample size, and the absence of a control group, further studies involving larger samples and controlled experimental designs are needed to confirm its comparative effectiveness.

Despite these positive results, several limitations were identified. Some users experienced initial difficulties operating the VR controllers and navigating the virtual environment, suggesting that usability and onboarding features need further improvement. In addition, the study was limited to a relatively small number of participants and a specific set of interior design styles, which may affect the generalizability of the findings. For future work, further development can focus on improving user interaction design by providing more intuitive controls and comprehensive tutorials. Expanding the variety of interior design styles and adding a sandbox mode for free exploration could also enhance the learning experience. Moreover, future studies may involve a larger, more diverse sample and investigate long-term learning effects and knowledge retention to further validate the effectiveness of VR-GBL applications.

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