American Journal of Educational Research, *2024, Vol. 12, No. 5, 176-186*
Available online at http://pubs.sciepub.com/education/12/5/2
Published by Science and Education Publishing
DOI:10.12691/education-12-5-2

Incorporating Mobile Augmented Reality into Ubiquitous Learning Models to Enhance Student Experience in Interior Design Education

Felicia Wagiri*, Ronald Hasudungan Irianto Sitindjak

Department of Interior Design, Petra Christian University, Surabaya, Indonesia
*Corresponding author: felicia_wagiri@hotmail.com

Received April 18, 2024; Revised May 20, 2024; Accepted May 27, 2024

Abstract The shift towards more adaptable learning approaches in design education, particularly remote and online learning, has been significant following the pandemic. This study explores the integration of mobile augmented reality (MAR) in ubiquitous learning settings with a focus on interior design education. We involved 163 undergraduate students in experiments to assess their use of MAR tools such as SketchUp and Fologram within Rhinoceros-Grasshopper. Their experiences were evaluated using the User Experience Questionnaire (UEQ), and a chi-squared test analyzed the relationship between these MAR tools and two educational models: the traditional classroom (Model-I) and the flipped classroom (Model-II). Results showed a preference for SketchUp across both models due to its user-friendly interface, while Fologram was preferred in the traditional classroom for its innovative features. The study underlines the importance of balancing advanced technology with effective teaching strategies to improve learning outcomes. Future research is recommended to enhance design education in distance-learning environments.

Keywords: *ubiquitous learning, distance learning; mobile augmented reality, interior design education, user experience questionnaire*

Cite This Article: Felicia Wagiri, and Ronald Hasudungan Irianto Sitindjak, “Incorporating Mobile Augmented Reality into Ubiquitous Learning Models to Enhance Student Experience in Interior Design Education.” *American Journal of Educational Research*, vol. 12, no. 5 (2024): 176-186. doi: 10.12691/education-12-5-2.

1. Introduction

The outbreak of COVID-19 has greatly accelerated the shift toward online and remote learning, firmly establishing ubiquitous learning (u-learning) as the contemporary standard in education [1,2,3,4]. U-learning integrates education seamlessly into everyday life, enabling learning anytime and anywhere, supported by technologies [5,6] such as mobile devices and augmented reality (AR). This model is exceptionally advantageous for dynamic disciplines like interior design, providing personalized and immersive learning experiences. U-learning allows students to learn at their own pace in various settings, shifting away from traditional, location-bound education towards a flexible, learner-centric approach [7]. The incorporation of multimedia content and real-time communication tools fosters a transition from passive to active learning, enhancing engagement and retention [8,9,10].

Studies indicate that technologies such as building information modeling (BIM) and extended reality (XR), including augmented reality (AR), improve knowledge retention more effectively than traditional methods like presentations [11,12,13] With the widespread availability of mobile devices, mobile augmented reality (MAR) has gained popularity in educational settings due to its accessibility and cost-effectiveness [14,15]. For instance, in Singapore, the use of an AR application called MUSE allowed students to create virtual galleries, enriching their learning experience through multimedia elements [16]. In the interior design sector, MAR is invaluable for enhancing collaboration among designers, clients, and fabricators, streamlining the design process from concept to construction [17,18,19]. It addresses challenges such as accurately capturing client preferences, which are crucial for design decisions regarding style and color schemes [20,21]. Miscommunications in these areas can lead to client dissatisfaction; MAR mitigates this risk by improving visualization capabilities, allowing designers to present virtual representations of furniture within actual spaces, thus obviating the need for impractical physical models in remote settings [22].

Our study aims to assess the effectiveness of u-learning and MAR technologies in interior design education by comparing two educational models: the traditional classroom model (Model-I) and the flipped classroom model (Model-II). We seek to determine which MAR technologies best enhance motivation, engagement, and satisfaction, and which educational model is most conducive to u-learning environments within interior design education. Through an analysis of student experiences, this research endeavors to refine educational models and offer insights into the successful integration of advanced technologies (specifically, MAR) and innovative teaching methods.

2. Literature Review

In traditional classrooms, the teaching approach is primarily teacher-centered, where instruction is mainly delivered through direct teaching methods [23]. The teacher is the central figure, often utilizing conventional tools like textbooks. Students typically assume a passive role, focusing on listening to lectures and teacher explanations. Homework in this model generally aims to reinforce classroom concepts through practice problems, reading, or predefined projects [24]. This model tends to limit student interaction and engagement with higher-order thinking tasks during class time.

In contrast, the flipped classroom model restructures the traditional educational approach. It requires students to first familiarize themselves with new material independently, often through online lectures and digital resources [24,25]. Classroom time is then dedicated to enhancing understanding through interactive activities such as discussions, problem-solving, and practical projects [26]. This approach leverages technology to allow students to access learning materials anytime and anywhere, thus enabling them to progress through course materials at their individual speed beyond the traditional classroom setting. The in-class time becomes a period for more dynamic and collaborative learning [27,28]. This model promotes continuous, independent learning and provides opportunities for personalized guidance from teachers during class [29].

Studies indicate that the flipped classroom model can substantially enhance academic performance, often resulting in higher exam scores and final grades compared to traditional methods [30]. Students engaged in flipped classrooms generally exhibit increased motivation, self-efficacy, and collaborative skills [25,27,31]. A detailed comparison of these two educational models is provided in Table 1.

Table 1. Comparison of Traditional and Flipped Classroom Models

Criteria	Traditional Classroom	Flipped Classroom	References
Approach	Teacher-centered; instructor-led lectures	Student-centered; active learning	[2], [25]
Teaching Format	Lectures in class, homework for practice	Lectures at home (videos), interactive and collaborative activities in class	[24], [32]
Tasks	Passive listening, note-taking	Active problem-solving, discussions	[23], [29]
Tools and Platforms	Textbooks, whiteboard, physical handouts	Digital content (videos), online platforms, interactive tools	[24], [25]
Learning Focus	Understanding theoretical concept, memorization	Practical application, real-world scenario, problem-solving, critical thinking, creativity	[27], [31]
Student Engagement	Often passive, limited interaction with teacher	Actively engaged, interactive learning environment	[28], [33]
Collaboration	Limited interaction among students; mostly individual work	Encourages group work and peer interaction	[7], [34]
Assessment	Individual assignment, traditional exams, quizzes	Diverse methods including tests, projects, presentations	[30], [35]

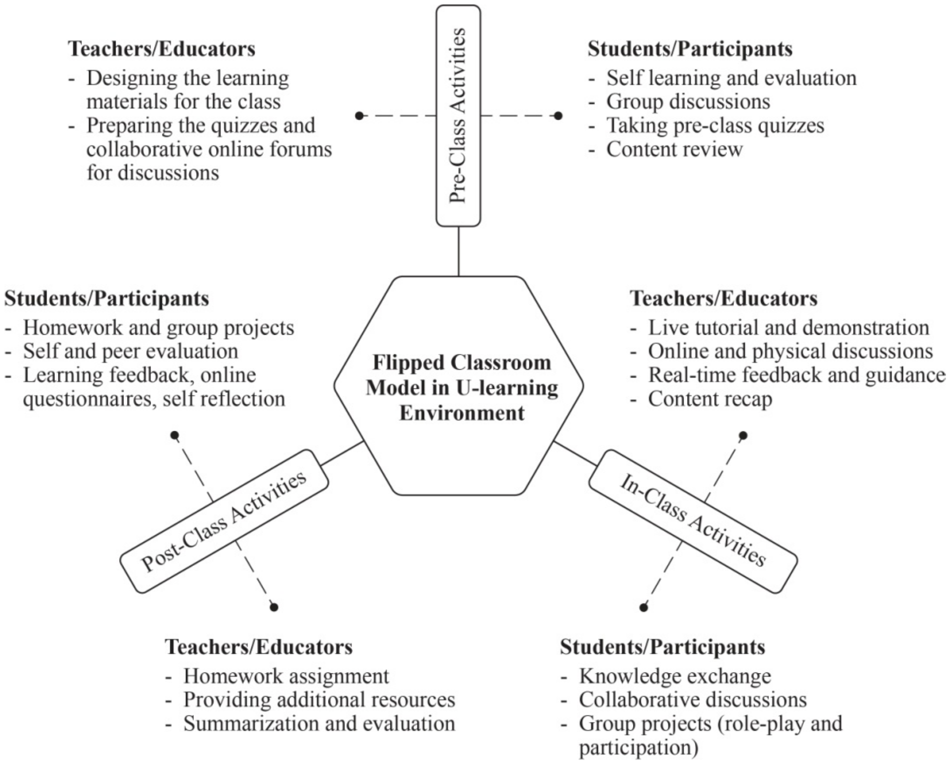

Figure 1. Research framework

3. Methods

3.1. Flipped Classroom Model in a Ubiquitous Learning Environment

In designing a flipped classroom for interior design education that uses MAR tools, we organized the course into three main phases: pre-class, in-class, and post-class activities. The in-class activities were conducted in a hybrid setting, allowing students to either attend in person at the university or join online. Both the pre-class and post-class activities were conducted ubiquitously. We used MAR tools like SketchUp and Fologram, along with online platforms such as Zoom, Lentera Cloud, and YouTube. Figure 1 illustrates the research framework for our flipped classroom model within a u-learning environment, where students and teachers play various roles in each activity.

3.1.1. Pre-Class Activities

Access to learning resources: Students access necessary presentation files and videos uploaded to Lentera Cloud, a platform that facilitates the distribution of educational content across different locations. This ensures that students who need more time can review the materials at their own pace. Additionally, AR tutorials are posted on YouTube and notifications are sent through WhatsApp, which is also used for quick communications and scheduling meetings.

Pre-class quizzes: To assess understanding, teachers create quizzes related to the AR content on Quizizz.com. Students can access these quizzes via smartphones or tablets, allowing them to review the material independently and complete tasks at their convenience.

Collaborative online forums and groups: Students engage with online forums and social groups to discuss insights or ask questions about the AR tutorials they have completed. This fosters a collaborative environment among students and teachers, enhancing the learning experience. Such interactions not only deepen students' understanding of the material but also better prepare them for upcoming in-class activities.

Preparation for in-class activities: Before class, students are expected to review all AR content and note any questions or challenges they might have encountered. This preparation helps teachers gauge the students' comprehension and tailor the class activities to meet individual needs, thereby enhancing the effectiveness and focus of the learning experience.

3.1.2. In-Class Activities

Content recap and AR-enhanced demonstrations: Each session begins by reviewing the pre-class materials to clarify any unresolved issues. Teachers then conduct live demonstrations on how to build interactive 3D models using MAR, allowing students to visualize their designs instantly on their mobile devices. To accommodate different internet speeds and learning paces, these demonstrations are recorded and later uploaded to YouTube for convenient student access.

Group projects: Students are grouped to work on hands-on projects that involve designing interior-related objects using tools such as SketchUp and Rhinoceros-Grasshopper, integrating MAR to enhance the understanding and visualization of their designs. This method not only applies their preliminary learning but also enhances teamwork skills through role-playing exercises (Figure 2). Teachers provide real-time guidance and encourage peer-to-peer support to overcome any technical challenges, further enriching the learning environment.

Peer review and discussion: After project completion, each group presents their AR-enhanced designs to the class. This is followed by peer review sessions led by the teachers, where students critique and discuss each other's work. The focus of these discussions is to identify strengths and weaknesses in the designs, emphasizing how AR can improve the interior design process. This activity fosters constructive feedback and deepens students' understanding of AR applications in interior design.

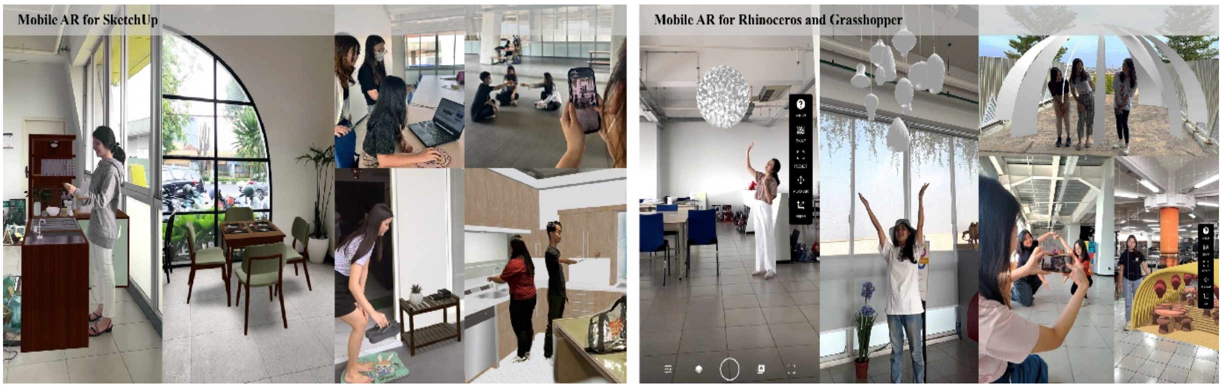

Figure 2. Examples of students' exploration and role-playing activities using MAR tools for SketchUp and Rhinoceros-Grasshopper

3.1.3. Post-Class Activities

Extended AR design task: After class, students are required to enhance their in-class projects. This involves adding more complex elements or rethinking the spatial design to refine their skills in AR design. To aid in this process, we provide students with additional tutorials on AR design tools, which support the development of their technical abilities and creativity.

Peer and self-review: Students must upload their revised designs for another peer review. This stage promotes a culture of constructive feedback and self-assessment. We guide students to critically analyze their work and the work of their peers, based on specific criteria and insights gained from the extended AR design task. This helps enhance their evaluative skills and deepen their understanding of design principles.

Post-class evaluation and feedback: To gauge knowledge retention and understanding, we assign additional quizzes and tasks through Google Forms, an efficient platform for managing and analyzing responses. Teachers provide detailed feedback on both the extension projects and students' reflective journals, aimed at further enhancing their learning and development. Screenshots of these online tests and questionnaires, which illustrate the tools used for assessment and learning support, are provided in Figure 3.

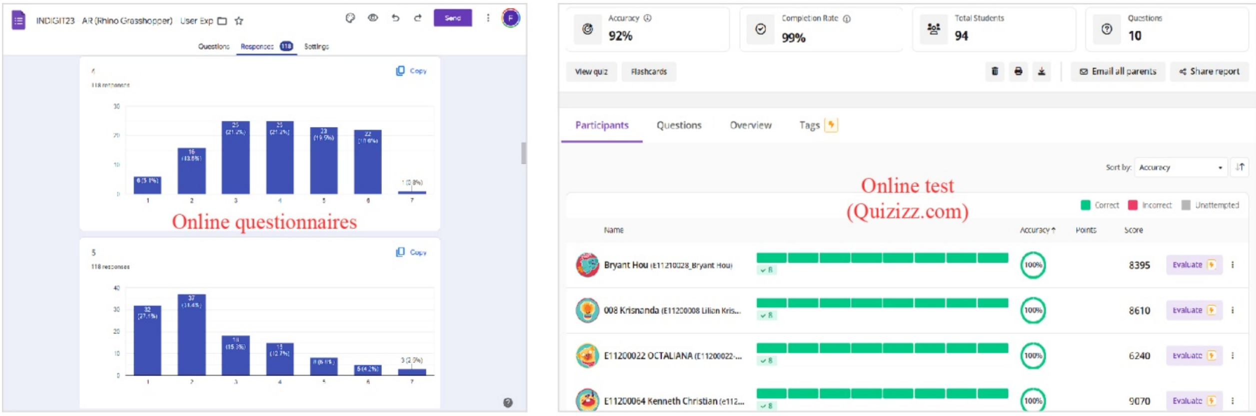

Figure 3. Samples of online assessments and evaluations

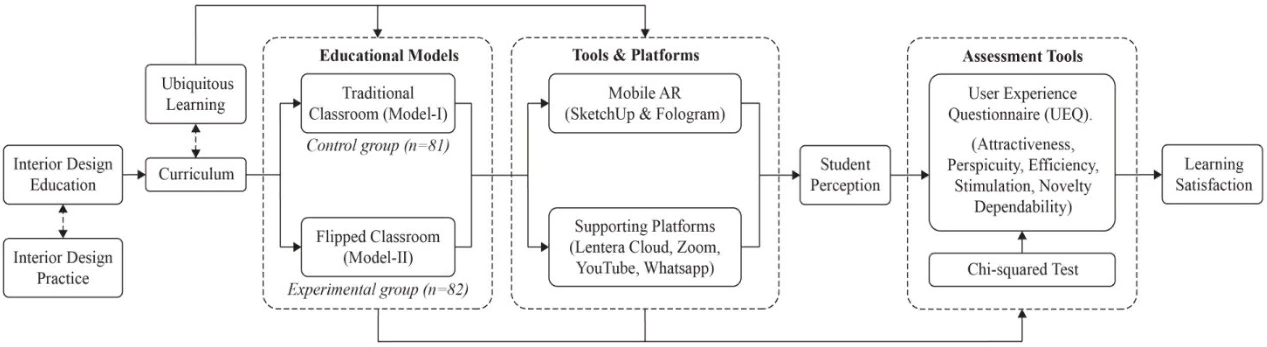

Figure 4. Assessment tools

3.2. Assessments

We utilized two types of MAR tools, SketchUp and Fologram, across two educational models: the traditional classroom model (Model-I) and the flipped classroom model (Model-II). To evaluate the effectiveness of these tools and methods, we collected student feedback through the User Experience Questionnaire (UEQ). Additionally, we conducted a chi-squared test to analyze the relationship between the MAR tools and the educational models. This analysis provided insights into student satisfaction, perception, and learning outcomes in relation to the educational models. The details of our research and its assessment tools are illustrated in Figure 4.

3.2.1. Participants

This study included undergraduate students from the interior design department at an Indonesian university during the 2021-2022 and 2022-2023 academic periods. These students participated in a compulsory 16-week course called "Digital Innovation," which consisted of both in-person and remote sessions lasting 120 minutes each. Initially, 199 students enrolled in the study, but after screening the surveys for completeness and reliability, 36 were excluded, resulting in 163 participants. The experimental group comprised 82 students from the 2022-2023 cohort, while the control group included 81 students from the 2021-2022 cohort. Predominantly, these students were in their sixth semester and were proficient in design. To assess the similarity in baseline knowledge between the two cohorts, we administered a pre-test, which resulted in a t-value of 1.23 and a p-value greater than .05, indicating no significant difference in initial knowledge levels, confirming the groups were well-matched for a comparative analysis.

3.2.2. Experimental Procedures

The study evaluated two educational models within a u-learning environment, focusing on how students use MAR tools, specifically SketchUp and Fologram in Rhinoceros-Grasshopper. In Model-I, the traditional approach, students followed the teacher's instructions, engaged in class discussions, and completed individual assignments, culminating in a final task to create 3D models as defined by the teachers. This model provided clear guidance but restricted creative freedom. Conversely, Model-II adopted a more dynamic approach, where students worked in groups on a final project without predefined outcomes, allowing them to choose their own designs and address unique challenges. This model promoted hands-on learning, teamwork, and peer interaction, aiming to create a more engaging and collaborative environment. At the course's conclusion, questionnaires were distributed to assess the effectiveness of the MAR tools in enhancing learning across these different educational approaches.

3.2.3. Measurement Tools

The User Experience Questionnaire (UEQ) is a commonly used tool in human-computer interaction that evaluates user engagement and satisfaction [36], [37]. It is designed to assess the subjective user experience of interactive systems, products, or services across six dimensions or scales (Figure 5). The UEQ includes 26 questions, each representing a pair of contrasting attributes (e.g., "pleasant" vs. "unpleasant"), which users rate on a seven-point Likert scale [38]. It is important to highlight that positive attributes like "easy to learn" or "efficient" can be situated on either side of the scale, depending on the context. This setup helps gauge pragmatic quality (how well a product functions and supports task completion) and hedonic quality (how much personal enjoyment or stimulation the product provides).

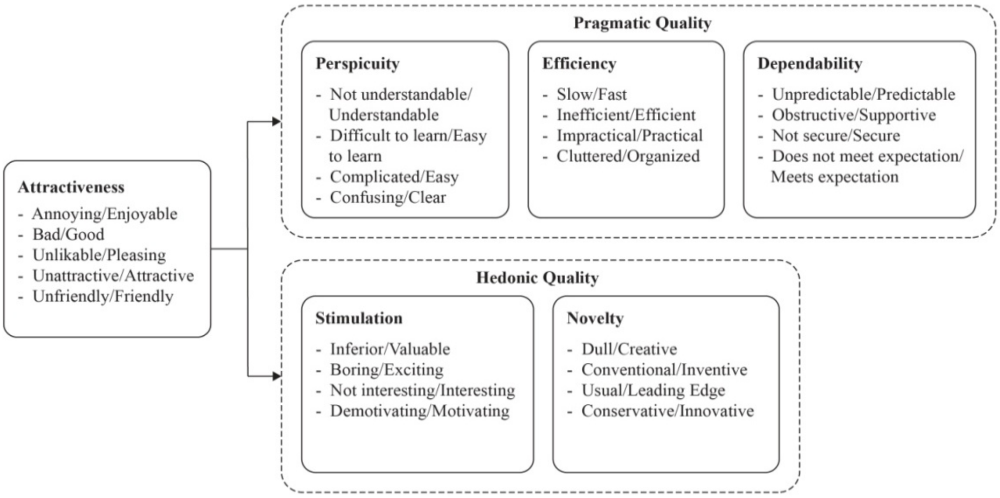

Figure 5. Scale structure of the UEQ [39]

Responses to the UEQ are analyzed to produce quantitative data that compares different interactive systems. The analysis tools and the questionnaire are available on the UEQ's official website (https://www.ueq-online.org/). To validate statistical results, particularly to determine if differences between expected and observed frequencies in our study data are significant, we used the chi-squared test [40], [41]. This test is essential for identifying relationships between categorical variables, such as the correlation between educational models (Model-I and Model-II) and preferred MAR tools (SketchUp and Fologram in Rhinoceros-Grasshopper). The chi-squared statistic (X^2), is calculated using the formula (1) below:

$$X^2 = \sum \frac{(O_i - E_i)^2}{E_i} \quad (1)$$

Where O_i is the observed frequency in each cell of a contingency table, E_i is the expected frequency, assumed under the null hypothesis, and the sum ($\sum$) is taken over all cells in the table. To calculate the expected frequencies for a 2x2 contingency table, we can implement the formula (2) below:

$$E_{ij} = \frac{r_i * r_j}{r} \quad (2)$$

Where E_{ij} is the expected frequency for cell in row i and column j, r_i is the total of observations in row i, r_j is the total in column j and r is the total number of observations. After calculating the chi-squared statistic, we compare it to a critical threshold from the chi-squared distribution table, which is determined by the degrees of freedom, usually calculated as (number of rows – 1) * (number of columns – 1) and the targeted significance level (e.g., 0.05). If the calculated statistic is less than or equal to the critical value, the null hypothesis is not rejected, suggesting no significant difference or association between the variables.

On the other hand, if the statistic surpasses the critical threshold, we reject the null hypothesis, signifying a significant association or relationship. Additionally, we gathered qualitative data by interviewing twenty randomly selected students to gain insights into their experiences, challenges, and suggestions. This qualitative feedback was analyzed to further understand the effectiveness of the MAR tools within the educational models.

4. Results

4.1. User Experience Questionnaire (UEQ)

The UEQ employs a rating scale that ranges from 1 to 7, translating these ratings into values from -3 (incredibly poor) to +3 (exceptionally good). This scale facilitates a comprehensive evaluation of user experiences across various dimensions [36]. It is common to observe extreme values, either greater than 2.0 or less than -2.0, reflecting the wide range of respondent opinions and priorities. A mean score exceeding 0.8 is viewed as favorable, one below -0.8 as unfavorable, and a score ranging from -0.8 to 0.8 represents a neutral assessment [42,43]. The accuracy and reliability of these average scores are further assessed using confidence intervals; narrower intervals indicate greater precision in the results [43].

According to Table 2 and Figure 6, both SketchUp and Rhinoceros-Grasshopper received generally positive evaluations in attributes such as attractiveness, efficiency, dependability, and stimulation in Model-I. However, there were some notable differences. SketchUp's clarity (perspicuity) was rated as "Below Average" (M=1.12, SD=0.67), indicating some challenges in ease of use. Conversely, SketchUp's novelty received an "Above Average" rating (M=0.93, SD=0.54), suggesting that users found it relatively innovative. Rhinoceros-Grasshopper was highly praised for its novelty, rated as "Excellent" (M=1.72, SD=0.62). However, its clarity (perspicuity) scored the lowest among the attributes (M=0.76, SD=0.57), reflecting its complexity and the learning challenges associated with it.

Table 3 and Figure 7 show that in Model-II, users had a positive perception of MAR tools in SketchUp across all dimensions. Stimulation was rated "Excellent" (M=1.74, SD=0.88), followed by attractiveness, efficiency, and dependability rated as "Good." Moreover, perspicuity and novelty received "Above Average" ratings. In contrast, Rhinoceros-Grasshopper showed lower average ratings across all dimensions. It scored lowest in perspicuity (M=0.20, SD=0.64), indicating users found the tool complex and challenging to understand. However, its highest rating was in novelty (M=1.59, SD=0.61), reflecting users' views of the tool as innovative and creative.

In terms of confidence interval analysis, narrow intervals, as seen in the attractiveness and novelty ratings for both tools in both models, indicate consistent user perceptions. In contrast, wider intervals, particularly in the efficiency and stimulation ratings for both tools in Model-II, suggest greater variability in user experiences. Generally, SketchUp displays wider confidence intervals than Rhinoceros-Grasshopper in Model-II, implying that the flipped classroom model may introduce more variability in how users perceive and interact with the tool, possibly due to their learning styles, pace, and interests.

Table 2. Mean and Confidence Interval per Scale for Model-I

	MAR in SketchUp						MAR in Rhinoceros-Grasshopper					
Scales	Mean	Std. Dev.	N	Confidence	Confidence Interval		Mean	Std. Dev.	N	Confidence	Confidence Interval	
Attractiveness	1.68	0.70	81	0.15	1.53	1.83	1.30	0.61	81	0.13	1.17	1.43
Perspicuity	1.12	0.67	81	0.15	0.98	1.27	0.76	0.57	81	0.12	0.64	0.89
Efficiency	1.49	0.81	81	0.18	1.31	1.66	1.26	0.69	81	0.15	1.11	1.41
Dependability	1.51	0.70	81	0.15	1.36	1.66	1.13	0.75	81	0.16	0.97	1.29
Stimulation	1.69	0.69	81	0.15	1.54	1.84	1.50	0.86	81	0.19	1.31	1.68
Novelty	0.93	0.54	81	0.12	0.81	1.05	1.72	0.62	81	0.14	1.58	1.85

Table 3. Mean and Confidence Interval per Scale for Model-II

	MAR in SketchUp						MAR in Rhinoceros-Grasshopper					
Scales	Mean	Std. Dev.	N	Confidence	Confidence Interval		Mean	Std. Dev.	N	Confidence	Confidence Interval	
Attractiveness	1.72	0.95	82	0.21	1.52	1.93	1.22	0.75	82	0.16	1.05	1.38
Perspicuity	1.62	0.80	82	0.17	1.44	1.79	0.20	0.64	82	0.14	0.06	0.34
Efficiency	1.61	0.89	82	0.19	1.41	1.80	1.09	0.85	82	0.18	0.91	1.28
Dependability	1.52	0.74	82	0.16	1.36	1.68	1.08	0.83	82	0.18	0.90	1.26
Stimulation	1.74	0.88	82	0.19	1.55	1.93	1.32	0.92	82	0.20	1.12	1.52
Novelty	1.05	0.55	82	0.12	0.93	1.16	1.59	0.61	82	0.13	1.45	1.72

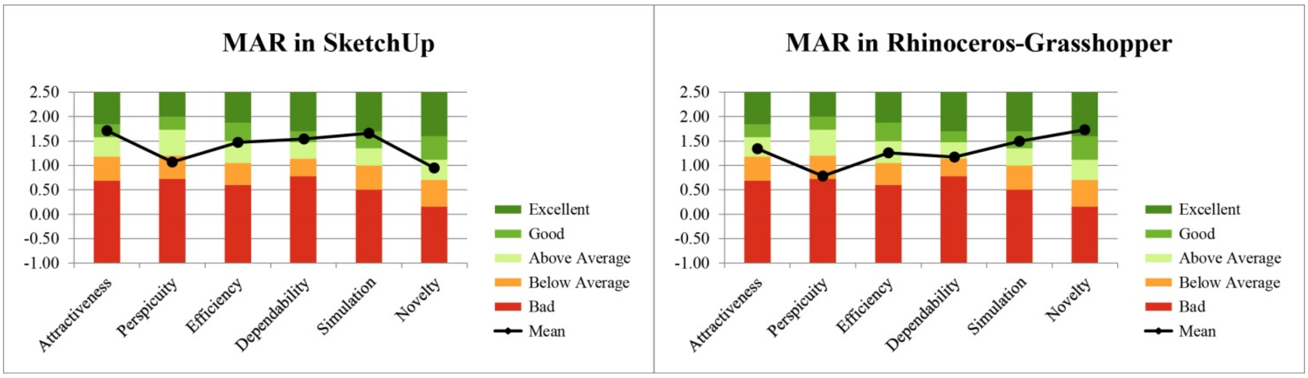

Figure 6. Six scales benchmark of the UEQ (Model-I)

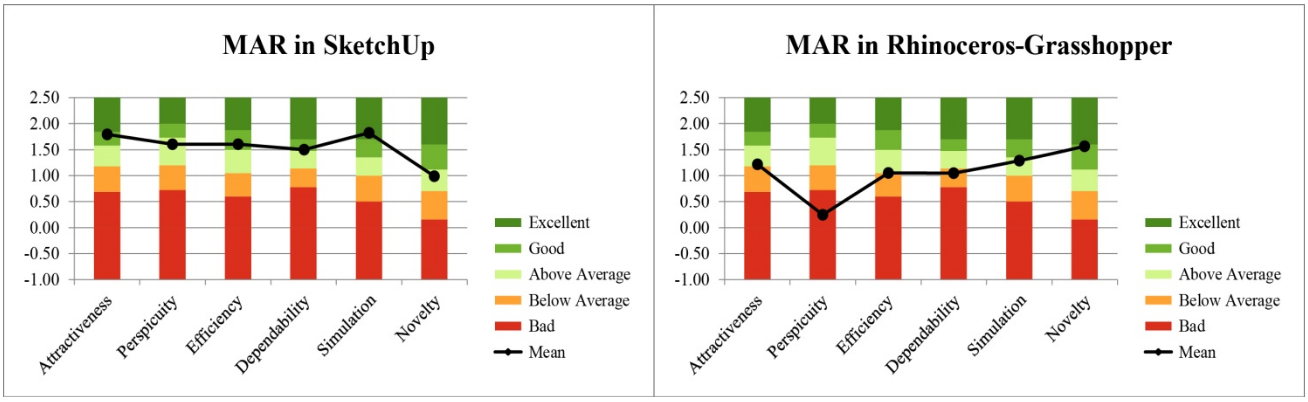

Figure 7. Six scales benchmark of the UEQ (Model-II)

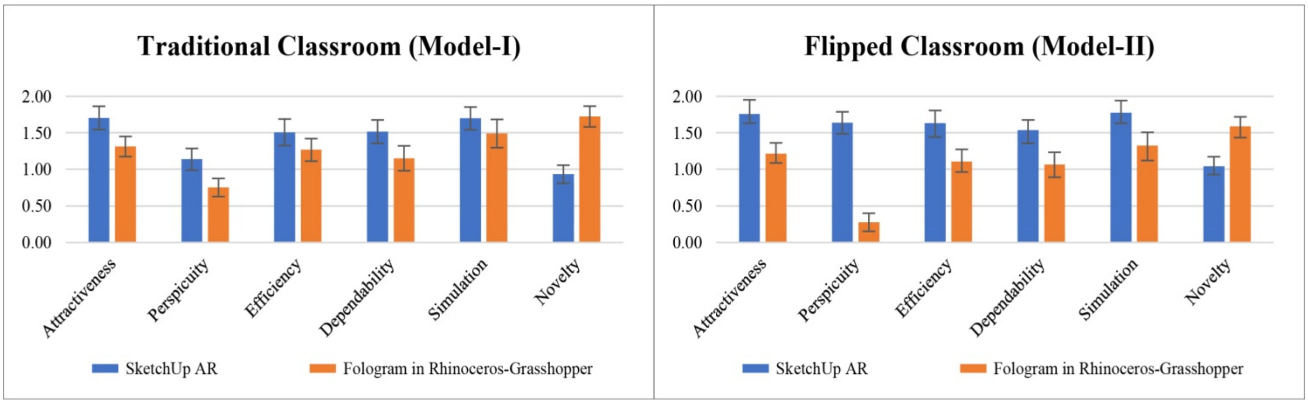

Figure 8. Comparison of scale means of two distinct academic periods

Table 4. The Result of Chi-Squared Test

	Observed Frequencies			Expected Frequencies E_{ij}		Chi-Squared Points X^2	
	SketchUp	Fologram	Total	SketchUp	Fologram	SketchUp	Fologram
Model-I	47	34	81	54.166	26.834	0.948	1.913
Model-II	62	20	82	54.834	27.166	0.936	1.890
Total	109	54	163				

The comparative analysis of MAR tools, SketchUp and Rhinoceros-Grasshopper, across two educational models (Model-I and Model-II) within a ubiquitous learning environment reveals distinct user experiences (Figure 8). In both models, SketchUp typically performs better, particularly in Model-II, where it shows significant improvement in pragmatic qualities such as perspicuity and efficiency. This suggests that Model-II may enhance SketchUp's usability, making it more comprehensible and efficient for users. On the other hand, Rhinoceros-Grasshopper exhibits varied performance. In Model-I, it is noted for its high novelty, reflecting its hedonic quality. However, it scores lower in pragmatic qualities like perspicuity and dependability, indicating usability and reliability challenges. In Model-II, while it retains a high novelty score, Rhinoceros-Grasshopper continues to struggle with perspicuity, receiving a very low mean score. This indicates that flipped classroom model (Model-II) might not sufficiently address the complexities of Rhinoceros-Grasshopper for learners.

4.2. Chi-Squared Test

The chi-squared test was used to investigate the association between educational models (Model-I and Model-II) and students' preferences for different MAR tools. The test included additional UEQ questions to determine the preference for MAR tools, SketchUp or Rhinoceros-Grasshopper, using a scale from left to right. Preferences towards the left indicate a preference for SketchUp, while those towards the right suggest a preference for Rhinoceros-Grasshopper. According to Table 4, the chi-squared statistic of 5.688 exceeds the critical value of 3.841 (the threshold at a 0.05 significance level with one degree of freedom). This indicates a statistically significant association between the educational models and preferences for MAR tools, suggesting that the preference for SketchUp or Rhinoceros-Grasshopper is influenced by the educational model rather than occurring by chance.

The significant results of the chi-squared test warrant further investigation into how and why each educational model influences MAR tool preference. To explore the factors leading to these preferences and to examine the specific attributes of each MAR tool that may make them more suitable for one educational model over another, we conducted qualitative research. This involved interviewing 20 randomly selected students. The findings from these interviews will be discussed in the following section.

4.3. Student Interviews

Interviews revealed that students generally prefer ubiquitous learning (u-learning) environments to traditional classrooms, attributing their preference to the engaging nature of MAR, which contrasts with the monotony of standard lectures. Students noted that MAR tools like Grasshopper and Fologram initially offer exciting, interactive experiences. However, one student highlighted the stress associated with the unpredictability and complexity of parametric design in Grasshopper, stating, "*Initially, using parametric design in Grasshopper is fun due to its interactive and innovative features. However, I struggle to predict the outcomes of my 3D modeling, and this unpredictability becomes stressful over time. The learning process demands substantial time and effort, often requiring me to watch YouTube videos and seek other learning resources outside of class due to limited instructional time*." This comment reflects a shift from initial enthusiasm to stress due to the steep learning curve and the need for additional resources outside of class time.

Another student preferred using recorded tutorials for learning, explaining, "*I prefer watching recorded class tutorials rather than diving straight into 3D modeling and MAR. This way, I can practice with my friends at our own pace, pausing the video as needed to better understand the lessons and tutorials. Yet, remembering all the functionalities of the tools, especially in Grasshopper, remains challenging.*" The flipped classroom model (Model-II) emphasizes self-paced, collaborative learning, which addresses some concerns but still presents challenges with tools like Rhinoceros-Grasshopper that require deeper understanding and more time to master. Relying only on online tutorials or recorded videos also has drawbacks, such as reduced direct interaction with teachers, making it difficult to ask questions when challenges arise.

In terms of tool-specific feedback, students appreciated Fologram in Rhinoceros-Grasshopper for its support of multi-user experiences, enhancing collaborative interactions in AR, particularly beneficial in Model-II. Conversely, SketchUp was favored for its user-friendliness and straightforward navigation, as one student expressed: "*I love using SketchUp because it is easier to understand compared to Fologram and Grasshopper. However, I miss interacting with my models alongside my friends in SketchUp. Once I transfer my model to the MAR environment in the SketchUp viewer, I cannot edit it anymore*." Despite its ease of use and visual appeal, a significant limitation of SketchUp is its inability to edit objects in real-time within the AR environment, requiring a return to the desktop application for modifications, which lengthens and restricts the design process.

5. Discussions

The rise of MAR in u-learning is influenced by several factors such as task value, technological features, and pedagogical models. This section seeks to deepen our understanding of these dynamics by examining these three aspects, taking into account the results from both quantitative analysis of the UEQ and qualitative analysis from interviews.

5.1. The Impact of Task Value on Students' Perception and Motivation

The impact of task value on students' perception and motivation in educational settings, especially when using MAR technology, is profound. The design of these tasks, whether they align with students' end goals, personal interests, or fit their workflows, significantly influences their engagement and motivation.

Tasks designed to foster creativity not only enhance the learning experience by making it enjoyable but also add meaning by allowing students to apply their knowledge in novel ways and develop a sense of ownership over their work. However, in traditional educational models (Model-I), tasks that are too rigid or overly predefined can limit creative exploration, potentially reducing student engagement and motivation. For instance, students often find SketchUp more engaging in Model-II than in Model-I due to the greater freedom to experiment and explore the tool. Conversely, with more complex tools like Rhinoceros-Grasshopper, students appreciate the structured and guided tasks of Model-I, which help manage its steep learning curve and extensive functionalities.

Collaboration also plays a crucial role, influenced by task value. Tasks that promote teamwork and collective problem-solving can significantly enhance the learning experience [7,44], especially in a u-learning environment. Collaborative tasks using MAR tools provide a platform for students to integrate diverse perspectives and skills, enhancing learning outcomes and motivation through peer interaction [12,45,46]. This approach is particularly effective in Model-II, where the structure of pre-class, in-class, and post-class activities emphasizes collaboration and peer review. Additionally, ensuring that tasks integrate seamlessly with MAR tools allows students to efficiently translate their ideas into action, enhancing both the effectiveness and enjoyment of the learning process [47,48]. For instance, SketchUp is often favored for its user-friendliness, which lets students concentrate on exploring design concepts rather than struggling with technology.

Aligning tasks with students' future goals and interests is essential for maintaining motivation [24]. When students see a direct connection between their tasks, the use of MAR tools, and their personal or professional aspirations, they are more likely to be engaged and motivated. The relevance of these tasks to real-world applications and career paths increases their meaningfulness, boosting intrinsic motivation and commitment to learning. Furthermore, providing opportunities for students to receive feedback from industry professionals can bridge the gap between academic learning and professional requirements.

5.2. The Impact of MAR Tools on U-learning Environments

The integration of MAR technologies significantly influences student perception and motivation within a u-learning environment. These tools affect learning through their technological features and the manner in which they are implemented in teaching strategies. SketchUp, known for its user-friendly interface, boosts student satisfaction across both educational models due to its ease of use and efficient navigation. These qualities lead to high ratings in pragmatic aspects such as usability and efficiency, enhancing overall student satisfaction. This positive experience with SketchUp generally encourages further exploration, fostering curiosity and self-directed learning. In Model-I, where traditional teaching methods prevail, SketchUp complements these methods effectively. However, the structured and predefined tasks in this model may restrict the level of stimulation and novelty experienced by students. In contrast, Model-II's collaborative settings, which provide greater freedom, allow SketchUp to foster more engagement and interaction among students.

Fologram, paired with Grasshopper, offers advanced parametric and computational capabilities that allow for real-time 3D model manipulation [22,49]. This feature appeals to students' creative instincts, providing high levels of novelty and stimulation. However, Fologram's complex interface and steep learning curve pose challenges, especially in Model-II, where self-directed learning is emphasized. This often leads to lower perspicuity scores in the UEQ, indicating difficulties students face in navigating the tool. In a structured environment like Model-I, Grasshopper's complexities are more manageable, resulting in a more positive perception. Additionally, the hedonic qualities of MAR tools, such as aesthetic appeal and the excitement they generate, play a crucial role in fostering creativity and exploration. Tools that are enjoyable and meet personal learning preferences are likely to be used more consistently, enhancing the educational experience across different models [1,24]. For instance, while some students prefer SketchUp for its visual simplicity, others might find Grasshopper's challenges more engaging.

5.3. The Efficacy of Educational Models for an Enhanced U-learning Experiences

The integration of MAR tools is transforming traditional teaching methods within the u-learning model [3,50]. In the conventional Model-I, MAR technology serves mainly as a supplementary tool, enhancing traditional teaching with 3D visualization and interactive simulations. While these features help clarify abstract concepts and improve design understanding, the predominantly teacher-led environment of Model-I may not fully leverage the interactive and immersive capabilities of MAR. This can result in underutilization of the technology, potentially leading to minimal enhancement in student motivation and perception [1,12]. Moreover, Model-I often prioritizes theoretical knowledge, which may encourage students to seek out online tutorials rather than engaging directly with practical applications, thus adding to the perceived complexity of the subject.

In contrast, Model-II employs a flipped, collaborative approach that fosters a student-centered learning environment. This model encourages active participation [7,24], allowing students to freely explore MAR technology and apply it in practical scenarios. Such engagement not only deepens subject understanding but also enhances student motivation by involving them directly in the learning process [9,44]. Model-II also promotes collaboration and support among students, improving the learning experience through teamwork and peer assistance with MAR tools. This focus on collaboration enriches the user experience by emphasizing practical application and immediate feedback, supported by accessible tutorials and interactive class discussions [7,46]. Enjoyable and interactive learning experiences tend to enhance memory retention and comprehension, positively impacting educational outcomes [2,10].

6. Conclusions

Reflecting on the key aspects discussed, we can draw several conclusions about the role of MAR in interior design education and the effectiveness of tools like SketchUp and Fologram in Rhinoceros-Grasshopper across different educational models:

- Impact of MAR: MAR has revolutionized interior design education, making it more practical and interactive. By integrating MAR, educators can create immersive experiences that bridge theoretical knowledge with real-world applications. This approach not only engages students but also allows them to experiment with and visualize their designs in real time, enhancing learning retention.
- Student engagement: The use of MAR significantly boosts student motivation and engagement. The interactive features of MAR tools captivate students' attention, encouraging deeper involvement in their projects and coursework. This heightened engagement is crucial for creating an effective learning environment.
- Tool-specific strengths: SketchUp is known for its user-friendly interface, SketchUp stimulates students and is ideal for both traditional (Model-I) and flipped classroom (Model-II) settings due to its ease of use. On the other hand, Rhinoceros-Grasshopper with Fologram offers advanced parametric and computational design capabilities, adding a layer of novelty. Its complexity, however, may be more manageable in Model-I, where structured learning helps students navigate its features effectively. In contrast, the self-directed, exploratory nature of Model-II may present challenges due to its steep learning curve.
- Adaptation of teaching strategies: Educators should recognize the strengths and limitations of various MAR tools and adapt their teaching strategies accordingly. It is essential to choose tools that align well with the educational model, learning objectives, and student needs to fully leverage their educational potential.

While this study provides insightful observations on the use of MAR in interior design education, its findings are specific to the context examined. These results may not directly apply to other educational settings or disciplines, highlighting the need for additional research to address these unique challenges.

Our research has shown promising results regarding the effectiveness of MAR tools in enhancing student experiences in interior design education. However, the findings must be considered within the context of the limitations posed by our sample size. To address this, further studies with larger and more diverse samples are necessary to confirm these results across different demographics and learning environments. Additionally, the employment of a broader spectrum of statistical analyses, including more advanced tests beyond the Chi-square, will be crucial in substantiating the robustness of our conclusions and providing a more comprehensive understanding of how these technologies impact learning outcomes.

7. Recommendations

- Enhance training for educators: To maximize the benefits of MAR tools like SketchUp and Fologram within Rhinoceros-Grasshopper, it's crucial to offer comprehensive training for educators. Training should focus on both the technical aspects of these tools and pedagogical strategies for integrating them effectively in both traditional and flipped classrooms.
- Develop custom learning modules: Create tailored learning modules that leverage the strengths of specific MAR tools. For instance, modules that utilize SketchUp can focus on basic design and visualization skills, while those that use Fologram can delve into advanced computational and parametric design techniques. This approach will help cater to varying student needs and learning paces.
- Foster collaboration with industry: Develop partnerships with MAR technology providers and professional design firms. Such collaborations can lead to internship opportunities for students, real-world project engagements, and even direct feedback from industry professionals on curriculum and tool effectiveness.
- Evaluate and adapt to new technologies: Regularly assess emerging technologies and evaluate their potential integration into the curriculum. This proactive approach will keep the educational program current and relevant, ensuring that students are well-prepared for the evolving technological landscape in interior design.

ACKNOWLEDGEMENTS

We would like to express our sincere gratitude to all the students who participated in this study and completed the questionnaire. Your valuable contributions and feedback have been instrumental in advancing this research.

References

[1] H. Zhang, Y. Zhang, T. Xu, and Y. Zhou, "Effects of VR instructional approaches and textual cues on performance, cognitive load, and learning experience," *Educ. Technol. Res. Dev.*, Oct. 2023.

[2] A. Abuhmaid, I. Kaur, and S. Joordens, "The Convertible Learning System: A Certainty for Uncertain Times," *J. Educ.*, vol. 203, no. 4, pp. 947–960, Oct. 2023.

[3] A. Ruiz-Calleja *et al.*, "Orchestrating ubiquitous learning situations about Cultural Heritage with Casual Learn mobile application," *Int. J. Hum.-Comput. Stud.*, vol. 170, p. 102959, Feb. 2023.

[4] R. N. Keswani, A. Sethi, A. Repici, H. Messmann, and P. W. Chiu, "How To Maximize Trainee Education During the Coronavirus Disease-2019 Pandemic: Perspectives From Around the World," *Gastroenterology*, vol. 159, no. 1, pp. 26–29, Jul. 2020.

[5] P. Vallejo-Correa, J. Monsalve-Pulido, and M. Tabares-Betancur, "A systematic mapping review of context-aware analysis and its approach to mobile learning and ubiquitous learning processes," *Comput. Sci. Rev.*, vol. 39, p. 100335, Feb. 2021.

[6] A. Alkhafaji, S. Fallahkhair, and E. Haig, "A theoretical framework for designing smart and ubiquitous learning environments for outdoor cultural heritage," *J. Cult. Herit.*, vol. 46, pp. 244–258, Nov. 2020.

[7] M. C. Ruiz-Jiménez, R. Martínez-Jiménez, and A. Licerán-Gutiérrez, "Students' perceptions of their learning outcomes in a flipped classroom environment," *Educ. Technol. Res. Dev.*, Oct. 2023.

[8] H. Peng, S. Jager, and W. Lowie, "Narrative review and meta-analysis of MALL research on L2 skills," *ReCALL*, vol. 33, no. 3, pp. 278–295, Sep. 2021.

[9] Y.-C. Chen, C.-J. Chen, and M.-Y. Lee, "Effects of a Moodle-based E-learning Management System on E-collaborative Learning, Perceived Satisfaction, and Study Achievement among Nursing Students: A Cross-sectional Study." Apr. 19, 2022.

[10] G. Aydın and O. Mutlu, "Project-Based Learning and Flipped Classroom Model Supported Project-Based Learning's Impact on Academic Success, Retention, and Individual Innovation Competence," *Int. J. Contemp. Educ. Res.*, vol. 10, no. 4(Online First), pp. 823–833, Oct. 2023.

[11] F. Kharvari and L. E. Kaiser, "Impact of extended reality on architectural education and the design process," *Autom. Constr.*, vol. 141, p. 104393, Sep. 2022.

[12] J.-Q. Guan, W.-Z. Wang, X.-F. Wang, J. Zhu, and G.-J. Hwang, "Effects of a VR-based collaborative painting approach on primary students' creativity and collaborative quality in art courses," *Educ. Technol. Res. Dev.*, Apr. 2024.

[13] F. Wagiri, S.-G. Shih, K. Harsono, T.-W. Cheng, and M.-K. Lu, "Exploration of Building Information Modeling and Integrated Project Cloud Service in early architectural design stages," *VITRUVIO - International Journal of Architectural Technology and Sustainability*, vol. 8, no. 2, pp. 26–37, Dec. 2023.

[14] O. Saidani Neffati *et al.*, "An educational tool for enhanced mobile e-Learning for technical higher education using mobile devices for augmented reality," *Microprocess. Microsyst.*, vol. 83, p. 104030, Jun. 2021.

[15] S. Shen, K. Xu, M. Sotiriadis, and Y. Wang, "Exploring the factors influencing the adoption and usage of Augmented Reality and Virtual Reality applications in tourism education within the context of COVID-19 pandemic," *J. Hosp. Leis. Sport Tour. Educ.*, vol. 30, p. 100373, Jun. 2022.

[16] A. Tesolin and A. Tsinakos, "Opening Real Doors: Strategies for Using Mobile Augmented Reality to Create Inclusive Distance Education for Learners with Different-Abilities," in *Mobile and Ubiquitous Learning*, S. Yu, M. Ally, and A. Tsinakos, Eds., in Perspectives on Rethinking and Reforming Education. , Singapore: Springer Singapore, 2018, pp. 59–80.

[17] Y. Song, R. Koeck, and S. Luo, "Review and analysis of augmented reality (AR) literature for digital fabrication in architecture," *Autom. Constr.*, vol. 128, p. 103762, Aug. 2021.

[18] A. H. Kyaw, A. H. Xu, G. Jahn, N. Van Den Berg, C. Newnham, and S. Zivkovic, "Augmented Reality for high precision fabrication of Glued Laminated Timber beams," *Autom. Constr.*, vol. 152, p. 104912, Aug. 2023.

[19] H. Vo and A. Asojo, "Feedback in interior design studio and students' creativity," *J. Creat.*, vol. 31, p. 100009, Dec. 2021.

[20] A. Kandil, B. Al-Jumaah, and I. Doush, "Enhancing User Experience of Interior Design Mobile Augmented Reality Applications:," in *Proceedings of the 5th International Conference on Computer-Human Interaction Research and Applications*, Online Streaming, --- Select a Country ---: SCITEPRESS - Science and Technology Publications, 2021, pp. 101–108.

[21] M. Banaei, A. Ahmadi, K. Gramann, and J. Hatami, "Emotional evaluation of architectural interior forms based on personality

differences using virtual reality," *Front. Archit. Res.*, vol. 9, no. 1, pp. 138–147, Mar. 2020.

[22] G. Lee, "Code-Bothy: Mixed reality and craft sustainability," *Front. Archit. Res.*, vol. 11, no. 4, pp. 681–690, Aug. 2022.

[23] R. Shanthi Priya, P. Shabitha, and S. Radhakrishnan, "Collaborative and participatory design approach in architectural design studios," *Soc. Sci. Humanit. Open*, vol. 2, no. 1, p. 100033, 2020.

[24] C. Torres-Martín, C. Acal, M. El-Homrani, and Á. C. Mingorance-Estrada, "Implementation of the flipped classroom and its longitudinal impact on improving academic performance," *Educ. Technol. Res. Dev.*, vol. 70, no. 3, pp. 909–929, Jun. 2022.

[25] D. Shen and C.-S. Chang, "Implementation of the flipped classroom approach for promoting college students' deeper learning," *Educ. Technol. Res. Dev.*, vol. 71, no. 3, pp. 1323–1347, Jun. 2023.

[26] F. Xi, H. Ma, Z. Pi, Y. Dong, J. Sun, and R. Jin, "Integrating the engineering design process into the conceive-design-implement-operate model for promoting high school students' STEM competence," *Educ. Technol. Res. Dev.*, Apr. 2024.

[27] M. Gashoot, B. Eve, and T. Mohamed, "Implementing Technology for Teaching: The Use of a Mobile/Tablet Approach for Enhancing Students' Learning (Design Interaction) Technology-Enhanced Learning (TEL)," *J. Educ.*, vol. 203, no. 1, pp. 230–241, Jan. 2023.

[28] P. Strelan, A. Osborn, and E. Palmer, "The flipped classroom: A meta-analysis of effects on student performance across disciplines and education levels," *Educ. Res. Rev.*, vol. 30, p. 100314, Jun. 2020.

[29] S. Naik and K. Gajjar, "Applying and Evaluating Engagement and Application-Based Learning and Education (ENABLE): A Student-Centered Learning Pedagogy for the Course Database Management System," *J. Educ.*, vol. 203, no. 2, pp. 410–422, Apr. 2023.

[30] D. C. D. Van Alten, C. Phielix, J. Janssen, and L. Kester, "Effects of flipping the classroom on learning outcomes and satisfaction: A meta-analysis," *Educ. Res. Rev.*, vol. 28, p. 100281, Nov. 2019.

[31] H. Al-Samarraie, A. Shamsuddin, and A. I. Alzahrani, "A flipped classroom model in higher education: a review of the evidence across disciplines," *Educ. Technol. Res. Dev.*, vol. 68, no. 3, pp. 1017–1051, Jun. 2020.

[32] C. K. Lo, "Grounding the flipped classroom approach in the foundations of educational technology," *Educ. Technol. Res. Dev.*, vol. 66, no. 3, pp. 793–811, Jun. 2018.

[33] V. M. Fife-Demski, "Embracing to Creating Curriculum: Levels of Engagement Among Student Teachers," *J. Educ.*, vol. 203, no. 2, pp. 317–330, Apr. 2023.

[34] Y. Oliveras-Ortiz, D. E. Bouillion, and L. Asbury, "Learning Spaces Matter: Student Engagement in New Learning Environments," *J. Educ.*, vol. 201, no. 3, pp. 174–182, Oct. 2021.

[35] I. Kazanidis, N. Pellas, P. Fotaris, and A. Tsinakos, "Can the flipped classroom model improve students' academic performance and training satisfaction in Higher Education instructional media design courses?," *Br. J. Educ. Technol.*, vol. 50, no. 4, pp. 2014–2027.

[36] A. Hinderks, M. Schrepp, F. J. Domínguez Mayo, M. J. Escalona, and J. Thomaschewski, "Developing a UX KPI based on the user experience questionnaire," *Comput. Stand. Interfaces*, vol. 65, pp. 38–44, Jul. 2019.

[37] M. Kuhar and T. Merčun, "Exploring user experience in digital libraries through questionnaire and eye-tracking data," *Libr. Inf. Sci. Res.*, vol. 44, no. 3, p. 101175, Jul. 2022.

[38] S. Aydin and B. Aktaş, "Developing an Integrated VR Infrastructure in Architectural Design Education," *Front. Robot. AI*, vol. 7, p. 495468, Oct. 2020.

[39] M. Schrepp, A. Hinderks, and J. Thomaschewski, "Construction of a Benchmark for the User Experience Questionnaire (UEQ)," *Int. J. Interact. Multimed. Artif. Intell.*, vol. 4, no. 4, p. 40, 2017.

[40] H. M. Yousof, K. Aidi, G. G. Hamedani, and M. Ibrahim, "Chi-squared type test for distributional censored and uncensored validity with numerical assessments and real data applications," *Jpn. J. Stat. Data Sci.*, vol. 6, no. 2, pp. 729–758, Nov. 2023, doi: 10.1007/s42081-023-00219-w.

[41] J. M. Luna-Romera, M. Martínez-Ballesteros, J. García-Gutiérrez, and J. C. Riquelme, "External clustering validity index based on chi-squared statistical test," *Inf. Sci.*, vol. 487, pp. 1–17, Jun. 2019.

[42] M. Rohandi, "An User Experience Analysis of UNG E-Learning Using User Experience Questionnaire Tool:," presented at the 1st World Conference on Social and Humanities Research (W-SHARE 2021), Makassar, Indonesia, 2022.

[43] M. Schrepp and J. Thomaschewski, "Design and Validation of a Framework for the Creation of User Experience Questionnaires," *Int. J. Interact. Multimed. Artif. Intell.*, vol. 5, no. 7, p. 88, 2019.

[44] J. Hanham, C. B. Lee, and T. Teo, "The influence of technology acceptance, academic self-efficacy, and gender on academic achievement through online tutoring," *Comput. Educ.*, vol. 172, p. 104252, Oct. 2021.

[45] J. P. Muñoz Miguel, C. Simón De Blas, F. Anguita Rodríguez, and A. E. García Sipols, "Collaborative learning in management subjects to university students: A multi-level research to identify group profile, engagement and academic performance," *Int. J. Manag. Educ.*, vol. 21, no. 1, p. 100762, Mar. 2023.

[46] G. Gyamfi, B. E. Hanna, and H. Khosravi, "Impact of an instructional guide and examples on the quality of feedback: insights from a randomised controlled study," *Educ. Technol. Res. Dev.*, Feb. 2024.

[47] C. Rosa and J. Ferreira, "The distant studio: a survey of design students' experience with distance educational formats," *Int. J. Technol. Des. Educ.*, vol. 33, no. 5, pp. 2019–2043, Nov. 2023.

[48] R. Mantooth, E. L. Usher, and A. M. Love, "Changing Classrooms Bring New Questions: Environmental Influences, Self-Efficacy, and Achievement: (511122018-001)." 2018.

[49] J. Chen *et al.*, "Sustainable interior design: A new approach to intelligent design and automated manufacturing based on Grasshopper," *Comput. Ind. Eng.*, vol. 183, p. 109509, Sep. 2023.

[50] Y. O' Connor and C. Mahony, "Exploring the Impact of Augmented Reality on Student Academic Self-Efficacy in Higher Education." 2023.