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Article

Navigating the Path to AI and Virtual Immersion: An Exploratory Study of Educational Escape Rooms with the ED-SCALE Model

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Abstract

The growing integration of immersive technologies into education is opening new possibilities for teaching and learning, while also raising concerns about the reliability and potential distortion of knowledge in artificial intelligence-mediated environments. Understanding how users perceive and accept AI-generated content in immersive learning systems is therefore essential. This study explores the factors that influence user acceptance of AI-driven virtual reality (VR) educational applications and explains it through a multidimensional framework that extends the Technology Acceptance Model (TAM), the Theory of Reasoned Action (TRA), and the Theory of Planned Behavior (TPB) – a new ED-SCALE model. We innovated the previous models through adding an ergonomic dimension, often overlooked in VR-based education. To test the model, we developed an AI-driven VR educational escape room designed to simulate adaptive and interactive learning experiences. Data were collected from 213 participants through a questionnaire measuring subjective norms, perceived behavioral control, attitudes toward AI-mediated instruction, perceived informational efficacy, and ergonomic quality. The findings show that ergonomic quality, intuitive interfaces, physical comfort, and social influence play an important role in shaping user trust and long-term adoption intentions. The results suggest that the success of AI-driven immersive learning systems depends not only on technological performance but also on user experience and social context, confirming our first hypothesis regarding new variables that are conditional for virtual technology acceptance.

Keywords: immersive technology acceptance; virtual reality ergonomics; immersive learning

1. Introduction

The Metaverse, often initially perceived as an abstract concept, is rapidly evolving into a dynamic paradigm offering new opportunities for both businesses and individuals [1]. Driven by advancements in blockchain, artificial intelligence (AI), 5G, and edge computing [2], the Metaverse represents a disruptive technological framework still in its early stages [3,4]. Within this digital space, users - represented by avatars - can overcome physical limitations to engage in work, play, and social interactions [5]. Virtual and augmented reality technologies enable highly realistic online interactions, fostering creative and personalized experiences [6]. In education, the Metaverse facilitates the merging of real and virtual environments, offering adaptive and immersive learning opportunities [7,8]. Despite its potential, adoption and user acceptance remain below expectations, highlighting a critical need to understand the factors influencing engagement [9]. AI integration in education offers benefits such as personalization, accessibility, and efficiency, but also introduces challenges, including data privacy concerns, algorithmic bias, and potential inaccuracies in AI-generated content [10]. Research shows that user acceptance is a primary determinant of successful integration, influenced by factors like perceived usefulness, ease of use, social presence, and

technological readiness [11–13]. However, studies indicate a gap in understanding how immersive VR-based learning environments affect user acceptance and educational outcomes.

Building on foundational models - Technology Acceptance Model (TAM) [14], Theory of Reasoned Action (TRA) [15,16], and Theory of Planned Behavior (TPB) [17,18] - this study introduces ED-SCALE, an expanded framework incorporating ergonomics as a critical variable affecting user experience in immersive learning. Ergonomics encompasses device comfort, ease of use, and physical effort, ensuring a sustainable and engaging interaction.

The aim of this work is to investigate user interactions and learning outcomes within a 3D AI-driven educational escape room, evaluating how ergonomic design, personalized content, **and social context influence acceptance and educational effectiveness. By analyzing quantitative** and observational data, this study provides insights for designing AI-driven immersive technologies that are both effective and engaging across diverse learner populations.

2. Theoretical Background

2.1. Educational Potential of AI-Driven Immersive Technologies

The convergence of artificial intelligence (AI) and virtual reality (VR) offers a completely new vision for education. This technological integration with elements from online gaming has the potential to revolutionize learning by stimulating engagement, enhancing accessibility, and promoting personalized experiences [19]. These advancements offer significant potential for developing innovative methodologies to improve educational quality [20]. Research by [21–24] indicate that AI and VR technologies can significantly enhance student engagement, improve knowledge retention, and facilitate skill development, underlying the transformative impact of the Metaverse on educational practices, including its ability to create social connections and persistent virtual spaces. Virtual reality and gamified learning environments have been shown to positively impact emotional engagement while reducing anxiety and enhancing learning outcomes [25]. Previous research on the pedagogical potential of immersive technologies has highlighted several critical factors influencing user adoption and learning outcomes, including interaction design, system usability, privacy and security concerns, accessibility, inclusivity, and the social dynamics embedded within virtual spaces [26–29]. While some authors have focused on practical aspects such as the impact of immersive experiences on user engagement and motivation [30–33], others have examined theoretical frameworks or other methodological approaches to better understand user acceptance, human-technologies interaction, and to provide robust support and guidance for practical applications and decision-making processes [34–36].

AI technologies, particularly those based on generative models enable real - time personalization, adaptive feedback, and autonomous generation of learning content. Furthermore such systems promote intercultural teamwork [37], and personal learning through context-specific environments and risk-free skill simulations [38], paving the way toward a truly engaging and empowering future of education [39].

Unlike traditional digital-based education, the Metaverse offers an immersive, continuous learning environment across various fields. For example, using VR the student is engaged in medical or nursing skills training [40,41], participating in real-time surgical procedures [42], military training [43], industrial manufacturing training and maintenance [44]. A significant use case is language learning in the Metaverse, which, for example, allows EFL (English as a Foreign Language) learners to immerse themselves in an English-speaking virtual environment, integrating learning with daily activities [45]. Other notable applications include visualizing historical events and figures, enabling students to witness virtual recreations of historical events and interact with historical characters [46]. In medical education, students can explore the human body in 3D, performing experiments on digital objects to understand complex anatomical structures [47,48]. Interactive science experiments using AR/VR allow students to simulate physical phenomena and observe chemical reactions, fostering hands-on learning [49,50]. Virtual trips to global locations, including inaccessible sites like the Great

Barrier Reef, provide instant access to detailed information [51]. Virtual laboratories offer a safe, controlled environment for conducting experiments, complementing physical labs [52].

The integration of AI and immersive technologies in the educational process enhances users' engagement and learning outcomes [53]. Research indicates that these technologies increase motivation and improve academic performance [54]. The integration of AI in education opens new possibilities, such as personalized learning experiences, real-time feedback, automation of routine tasks, and in-depth analysis of learner needs. AI-driven adaptive learning tools can dynamically adjust content based on individual progress, providing instant feedback and customized instructional materials.

Despite their advantages, these new technologies encounter several challenges that delay effective implementation in education. A primary concern is the cost, as the necessary hardware and software can be prohibitively expensive for many academic settings [46]. Accessibility and cybersecurity are critical concerns: unequal access to VR/AR technology may worsen educational inequality [55,56], while data privacy and security, especially for children, require careful attention [57–59]. Besides the cost, AI rises many ethical challenges and risks such as integrity, transparency and reliability of AI generated content. In the context of generative models embedded in educational XR experiences, algorithm may curate or synthesize information, which may lack clear provenance or factual validation or introduce cognitive biases, which may introduce a vulnerability for information disorder and undermining the epistemic truth. Current studies have advanced our understanding of the AI generated content in immersive technologies' educational context, but a more nuanced view of how adoption factors affect this process, especially from the user acceptance, is needed. Additionally, research has largely focused on factors that facilitate adoption, often neglecting user resistance and barriers to non-adoption.

2.2. Need for a New Model

[60] found that students expressed greater enjoyment and a stronger intention to use VR for learning, noting that VR's realistic simulations and interactive features enhance engagement. [58] and [61] observed that user-friendly VR experiences lead to more favorable attitudes and higher adoption intentions, underscoring the importance of perceived ease of use in technology acceptance.

In the process of testing the developed application, a broader perspective on the evaluation of educational applications based on virtual reality was adopted. We used the technology acceptance model - TAM, the theory of reasoned action - TRA and Theory of Planned Behavior - TPB as starting points. The Technology Acceptance Model (TAM) is a widely used framework for predicting technology adoption and user behavior [62]. It has been extensively applied in educational technology research [63,64], though studies suggest that additional context-specific factors may be needed for a more complete understanding [8]. Research indicates that students generally favor technology in education, with VR being particularly engaging and effective for immersive learning [65]. The Technology Acceptance Model states that perceived usefulness and ease of use are key determinants of users' attitudes and intentions toward a system [14]. Usefulness is shaped not only by ease of use, but also by external factors such as user characteristics, training, system development, and organizational support. It reflects the extent to which a person believes that a system will enhance performance, while ease of use refers to the expected level of effort required to operate the technology efficiently. This framework enables researchers to anticipate adoption behaviors after users have had the opportunity to interact with a system.

In turn, the Theory of Reasoned Action (TRA) is used by social sciences to predict human behaviors based on their previous intentions and experiences and it was introduced by [15] and extended later by [16,66]. TRA adds subjective norms (the social pressure to perform a behavior or not) to the attitude toward behavior (favorable or unfavorable) and considers these two variables to be the main predictors of behavior. An important extension of TRA is the Theory of Planned Behaviors (TPB) [17] which introduces another important variable - perceived behavioral control, as

the perception of the difficulty to do something. Individuals' experiences and the anticipated obstacles condition this perception.

Existing technology adoption models, such as TAM, TRA, and TPB have been widely used to study digital learning environments. However, these do not completely capture the multisensory and immersive nature of the immersive technologies, where both cognitive and physical experiences influence user engagement. While previous models emphasize usability and intention, they do not address the critical role of ergonomics in VR-based education. This study proposes a new model, ED-SCALE, which integrates key adoption factors from prior models while introducing ergonomics as a core determinant of acceptance in VR learning environments.

Usability frameworks such as Nielsen's Heuristics for User Interface Design [67] and ISO 9241-11 usability principles have been widely applied in evaluating digital interfaces. These models focus on core factors like learnability, efficiency, error prevention, and satisfaction, which are critical for general software usability. Traditional usability models do not account for physical strain factors, since they were designed for 2D screen-based interactions rather than fully immersive environments. Although these usability principles were considered for measuring our participant's satisfaction, AI&VR-based learning environments introduce new dimensions of user experience that go beyond traditional usability metrics.

a. Brief comparison between ED-SCALE and existing models

Technology acceptance in AI&VR-based educational environments has traditionally been analyzed using well-established models, including TAM, with its extensions TAM2 [68] and TAM3 [69], TRA and TPB. Each of these models provides a framework for understanding user intentions, motivations, and barriers in adopting new technologies. However, these models were primarily designed for generic digital technologies and do not fully account for the complex, immersive, and multisensory nature of merging technologies-based education.

To address these context-specific limitations, the ED-SCALE model expands on top of them by integrating an additional key dimension - Ergonomics (E) - that is critical for user acceptance in VR environments but remains underdeveloped in prior models. Below, we outline how ED-SCALE improves upon TAM, TRA and TPB in the context of VR-based learning:

Comparison with TAM. While TAM effectively predicts the acceptance of general digital tools, it does not fully account for the unique physical, cognitive, and sensory challenges posed by immersive VR environments. VR-based learning applications require not only intuitive navigation but also physical comfort, reduced motion sickness, and interaction with 3D spaces, aspects that are largely absent from the original TAM framework. Moreover, TAM assumes that ease of use is primarily a cognitive factor (e.g., interface simplicity, learnability), whereas in VR, ergonomics plays a crucial role in determining whether users engage with or abandon an application. In ED-SCALE, ergonomics (E) expands TAM's focus on usability by integrating physical comfort, immersion fatigue, and device adjustability into the technology acceptance equation.

Comparison with TRA. It suggests that behavioral intention is the primary predictor of actual behavior, meaning that if an individual has a favorable attitude toward using a technology and perceives social approval, they are more likely to adopt it. While TRA is effective for understanding general decision-making processes, it does not account for external barriers such as usability constraints, technological complexity, or physical challenges, which are particularly relevant in the context of VR-based learning environments. ED-SCALE provides a more holistic framework to VR-based education, considering both psychological and technological factors that affect user acceptance and learning outcomes.

Comparison with TPB. The Theory of Planned Behavior (TPB) states that user behavior is influenced by their belief in their ability to perform an action. However, TPB lacks technology-specific determinants, making it less effective for assessing VR-based learning environments. While TPB considers perceived ease of performing an action, ED-SCALE breaks this down into two complementary dimensions:

- Perceived Behavioral Control (C) → ease of interaction with the VR environment (software side)

- Ergonomics (E) → ease of physical immersion and device adaptability (hardware side)

This dual approach offers a more precise explanation for why some users disengage from VR applications due to physical discomfort, even when they recognize its educational benefits.

Compared with existing models the proposed ED-SCALE model integrates a broader range of variables, capturing the complex interplay of factors that influence technology acceptance in learning processes as outlined in Table 1:

Table 1. Comparison of ED-SCALE with foundational models.

Dimensions	TAM	TRA	TPB	ED-SCALE
User Attitude (A)	X	X	X	X
Social Influence (S)	-	X	X	X
Perceived Behavioral Control (C)	-	-	X	X
Immersive Device Ergonomics (E)	-	-	-	X
Engagement & Learning Effectiveness (L)	-	-	-	X

By integrating ergonomic considerations (E) alongside perceived usefulness, behavioral control, and social influence, ED-SCALE provides a more adapted model for evaluating VR-based educational adoption, ensuring both usability and physical comfort are considered in long-term adoption.

3. Methodology for Evaluating Interactions in AI-Driven Immersive Reality

3.1. The New ED-SCALE Research Model

Based on previous studies [70,71] and existing approaches in the literature, in this research we propose a model that builds upon established technology acceptance frameworks (TAM, TRA, TPB) to understand the way ergonomics of virtual reality devices and the subjective contexts of individuals may influence their behavior.

TAM is widely recognized as the most influential framework for predicting the acceptance and use of virtual learning environments, effectively clarifying individual acceptance through core concepts like perceived usefulness and ease of use, while also highlighting the need to consider critical organizational factors, such as the ergonomics, to ensure that educational institutions make informed investments in technologies that will be fully utilized and not abandoned. TRA is a prominent theory in social psychology underlining that intention to perform a behavior is highly dependent on favorable /not favorable attitude towards that behavior and of the perceived expectations from significant others. To this perspective, TPB added the assessment of the individual regarding that behavior in terms of the difficulty to perform it.

Upon the variables of previous theories we expanded by introducing an additional one that we consider at least as important for the acceptance of immersive technologies which we named Ergonomics. This category included those characteristics of immersive devices that offer a comfortable and tireless experience, and are easy to use without requiring a considerable effort on the part of the individual.

Factors influencing user acceptance include attitudes, preferences, behaviors, needs, and experiences as individuals interact with virtual environments. With recent advancements in virtual and augmented reality, understanding these factors leads to more intuitive and engaging Metaverse experiences [72,73]. Studies indicate that 80% of users are more likely to engage with platforms that prioritize customer centric experiences [74]. Tailoring virtual spaces and interactions to individual preferences is emerging as a highly effective strategy for boosting user engagement and loyalty.

Virtual experiences are shaped by various factors that collectively influence users' acceptance of technology. To effectively evaluate this impact, researchers require appropriate tools that offer a comprehensive perspective on assessing virtual reality-based educational applications. The present

paper is based on an exploratory study, utilizing questionnaires as an assessment tool for data collection.

The primary aim of this study is to explore user interactions and expectations within a 3D educational escape room in the AI-driven immersive reality. We propose a new research model (ED-SCALE) that combines variables proposed by TAM, TRA and TPB, to which we added and emphasized ergonomics of virtual reality instruments, as a new variable that we consider very important for user acceptance. By employing the proposed research model, this work evaluates user acceptance and learning outcomes in virtual reality environments. The study focuses on understanding how user-centered design can enhance the educational effectiveness of VR applications. Through quantitative data collection, including surveys and observational data, the research identifies key factors that influence acceptance and the overall success of immersive educational tools. Analyzing user experience and educational impact, this study contributes to the advancement of AI-driven immersive technologies in educational settings, ensuring they are both effective and engaging for diverse learner needs.

Based on this model and the analysis of other virtual reality application evaluation tools, a VR-based educational application evaluation framework was developed to assess user experience, engagement, and learning outcomes. This framework integrates multiple criteria, including usability, perceived usefulness, ease of use, and satisfaction, to provide a robust mechanism for evaluating the effectiveness of VR educational tools. Data collected from the questionnaires were rigorously analyzed using statistical methods to validate the reliability and validity of the evaluation framework.

Our conceptual model has 5 dimensions influencing behavioral intention: subjective norms, perceived behavioral control (perceived difficulty), attitude toward behavior, perceived effectiveness (learning effectiveness), ergonomic quality (Figure 1).

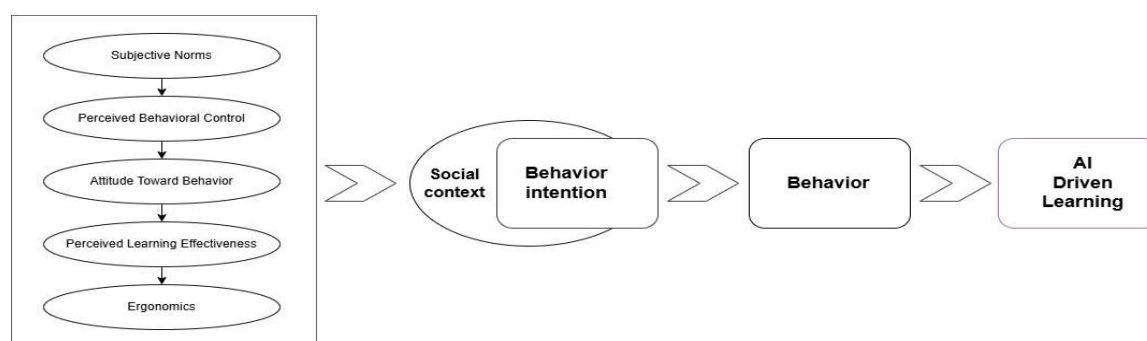


Figure 1. ED-SCALE research model.

Subjective norms (S) are the individual's perceptions of whether the people they consider important believe they should engage in a specific behavior or not, and also one's personal evaluation to comply or not with these expectations [16] (p.302). In traditional e-learning models, social influence is mainly limited to instructor and peer recommendations. Prior studies have shown that perceived social influence significantly affects students' willingness to adopt emerging learning technologies [75]. In collaborative virtual spaces, avatars, and AI driven learning experiences shape new social norms.

Control (C) is a model dimension based on perceived behavioral control (TPB) or perceived ease of use (TAM) referring to the degree to which a person believes that using a particular system would be effortless. In the case of virtual reality-based e-learning applications, C is related to easy understanding and use of the main functions of the system. Students must feel confident when operating, customizing, and troubleshooting VR devices [76] while they acquire new navigation, gesture control, and spatial interaction skills.

Attitude toward behavior (A) refers to favorable or unfavorable assessment of the behavior, including an evaluation of the possible outcomes of either performing a behavior or not. Research

indicates that affective engagement in VR-based learning leads to higher motivation and long-term retention [77–79]. VR environments trigger stronger emotional responses than traditional learning platforms, and positive emotions can increase willingness to adopt VR, while negative emotions may create barriers to acceptance.

The perceived learning effectiveness (L) of educational applications based on virtual reality is measured by the rate of achievement of the educational objectives proposed by the learners. In this research, through learning effectiveness we try to measure the perception of educational utility of applications based on virtual reality. Immersive learning environments can increase the knowledge retention compared with traditional learning [78].

The ergonomics of VR devices (E) is an important component of usability. In this context, the usability of virtual reality applications must be as high as possible, especially since these applications are very complex and need robust devices to run smoothly. Unlike standard e-learning, VR requires users to wear headsets, use controllers, and move physically, which introduces new usability challenges. Poor ergonomics can stimulate cyber sickness [80], reduce session duration, increase fatigue, and negatively impact adoption rates. Nevertheless, usability is a necessary but not sufficient condition for virtual reality applications to be accepted by learners.

Intention to use (INT) of VR applications in education is the next step towards their effective use (ED). The actual use of a VR system is determined by the behavioral intention to use, which is determined by the joint action of two factors: perceived usefulness and attitude.

These variables have been complemented by the ergonomics variable of virtual technology, resulting in a model that explains the perception and acceptance of technology, which we have named ED-SCALE. (Figure 1).

3.2. The Procedure Methodology

To empirically assess technology acceptance in AI-driven -based education, we conducted an experimental study using ICI EDscape Room, an AI-driven virtual reality educational application that we developed to simulate interactive learning experiences. This application was designed as an immersive escape room, where participants engage in problem-solving tasks related to ICT knowledge and digital competencies. The development was based on the framework design for reinforcing the potential of XR technologies in transforming inclusive education, which we proposed in [81]. The ICI EDscape Room has interactive challenges and real-time decision-making, aiming to enhance user engagement and retention of educational content.

The app integrates curated AI elements, ensuring that the AI-driven components of the application provided accurate, unbiased, and pedagogically sound learning experiences. The AI features in ICI EDscape Room were carefully designed and reviewed to maintain the integrity and reliability of educational content. AI-driven adaptations in the application were implemented to enhance personalization and engagement while preventing misinformation or unintended biases.

Our study employed this application as a controlled test environment to evaluate user acceptance, perceived usability, and learning effectiveness within AI-driven VR education. By applying the ED-SCALE model, we analyzed participants' interactions and behavioral responses to assess the critical factors influencing the adoption of virtual learning technologies.

The research aims to evaluate the usability and learning outcomes of participants through an exploratory experimental study. The experimental design includes a single group of participants who use the ICI EDscape room and then complete a questionnaire. Before data collection, the participants were familiarized with the virtual reality technology, focusing on the use of the educational application developed on the Meta Quest 2 devices.

Then, each participant tested the application, based on the tasks received. App usage time was quantified for each individual participant. The subjects were asked to explore the features offered by the app for each task.

After testing, participants were asked to respond to the evaluation questionnaire by rating the items on a 5-point Likert scale (1-strongly disagree, 2-agree, 3-neutral, 4-agree and 5-strongly agree).

The objectives of the study are:

- ✓ Exploring how AI-generated content in VR influences user perceptions.
- ✓ Evaluating attitudes towards AI-driven VR and the perceived level of control in VR.
- ✓ Analyzing the perceived educational effectiveness introduced by AI-generated learning content.
- ✓ Assessing the impact of VR ergonomics on technology adoption.

The hypothesis serving as foundational premise of our experimental study:

H1: Exposure to AI-driven VR learning environments through friends or colleagues positively influences users' intention to adopt this technology.

H2: The use of AI-generated content in VR increases engagement and motivation for learning.

H3: The use of AI-driven virtual reality in education improves engagement and the perception of learning effectiveness.

H4: A higher perception of control over the AI-personalized VR interactions increases the likelihood that users will want to use the technology frequently.

H5: Users with a positive attitude toward new technologies will perceive interaction with AI-generated VR interactions as more intuitive and easier to use.

H6: The level of physical comfort experienced during VR use positively influences users' intention to adopt the technology in the long term.

3.3. The Data Collection Tool

To empirically test the ED-SCALE model, we developed an evaluation instrument which includes specific questions for each dimension of the proposed model [71], and also descriptive items related to age, gender, education level, and previous experience with VR applications. Table 2 presents the operationalization of constructs.

In addition, each participant was asked to self-rate the time spent using the VR app.

Table 2. Model dimensions and variables.

Dimensions/ Constructs	Items	Variables
Subjective Norms (S)	S1	I have friends who have used virtual reality already.
	S2	Generally speaking, I care a lot about what my friends are expecting for me to do.
Perceived Behavioral Control (C)	C1	The AI-driven virtual reality application is intuitive.
	C2	It is easy to interact with AI-personalized virtual reality content.
	C3	In the future, it will be easy to remember how to use AI-driven virtual learning environments.
	C4	Identifying and understanding the cues in AI-generated learning scenarios is easy.
	C5	Reading AI-generated educational content is easy.
	C6	Selecting a menu item is easy.
Attitude toward Behavior (A)	A1	The virtual learning environment is comfortable.
	A2	I like testing AI-enhanced educational applications.
	A3	I would like to frequently use AI-generated virtual learning environments.
Perceived learning effectiveness (L)	L1	Using the AI-driven VR application helps in quicker knowledge assimilation.
	L2	Learning can be more engaging using the AI-personalized VR content.
	L3	Overall, I believe the AI-driven VR system will be useful for learning.
	L4	The feeling of immersion in the virtual world was intense.
	E1	Adjusting virtual reality (VR) devices is easy.

Ergonomics (E)	E2	Using the controllers in the VR application is easy.
	E3	Adjusting the sound is easy.
	E4	Observing virtual elements is clear.
	E5	I felt comfortable with the headset and controllers.
	E6	I experienced dizziness during use.
Intention to Use in education (ED)	ED1	I intend to use AI-driven VR applications for learning..
	ED2	I will recommend other colleagues to use AI-generated learning content in VR applications.

3.4. Participants

All participants were volunteers, recruited at different technical events between April 2024 and November 2025. The decision to select participants from tech events is because immersive technologies are still in an early stage of adoption in Romania. Considering the curve of innovation adoption [82], we targeted this category of participants based on the premise that they represent the pioneers in using generative AI and implementing immersive technologies in education. Evaluating their perceptions through this exploratory study allows us to better understand the pace at which this innovation can be integrated into the Romanian education system. The sample consists of 213 persons - 94 women and 119 men, and the participants' ages ranged from 20 to 60 years, with an average age of 36,5. Among the participants, 113 were familiar with AI and VR technology, while 100 reported having never used AI-driven VR applications.

3.5. Results and Discussions

Internal consistency of the scale

The value of the Cronbach's Alpha coefficient that assess the internal consistency of our questionnaire items is 0.803 which indicates a good internal reliability of the instrument (the closer the value is to 1, the greater the consistency between items).

Descriptive statistics

Table 3 shows the descriptive statistics indicators calculated based on the answers given by the participants. As can be seen, the mean values for the ergonomics items (E1-E6) are relatively high (between 3.98 and 4.42), indicating a general positive perception of the ergonomics of virtual reality devices. Item E4 ("Observation of virtual items is clear") has the highest mean (4.4231), suggesting that participants consider the observation of virtual items to be clear. The lowest mean is recorded for item E3 (Sound adjustment is easy), at 3.9808, and suggests that participants find sound adjustment relatively easy, but not as easy as other aspects of ergonomics. The high mean of collected answers regarding ergonomics supports the Hypothesis 6, indicating that ergonomics is an important factor of the way technology may be accepted or not.

Table 3. Descriptive statistics for ED-SCALE model.

	N	Minimum	Maximum	Mean	Std. Deviation
S1	213	1	5	2.1362	0.80988
S2	213	1	5	3.2535	0.77188
C1	213	2	5	4.3192	0.65980
C2	213	2	5	4.3850	0.77834
C3	213	3	5	4.3756	0.64411
C4	213	1	5	4.2311	0,89144
C5	213	2	5	4.3005	0.70299

C6	212	2	5	4.5283	0.64884
A1	213	2	5	4.2441	0.79889
A2	213	2	5	3.6485	0.64853
A3	213	1	5	3.9718	0.90552
L1	213	1	5	3.8779	0,73596
L2	213	1	5	3.6714	0.87144
L3	213	1	5	4.4460	0.68208
L4	213	3	5	4.4413	0.65343
E1	213	2	5	4.5305	0.64080
E2	213	2	5	4.2770	0.84858
E3	213	2	5	3.9155	0.70201
E4	213	2	5	4.4883	0.58769
E5	213	1	5	4.3568	0.74252
E6	212	2	5	4.1132	0.69964
ED1	213	1	5	3.5540	1.02015
ED2	213	1	5	4.0939	0.92686

Subjective Norms Cluster (S1-S2): the values for these two questions show how social perceptions and group pressures can influence the use of VR technology (H1). The low mean of responses to the question S1 *"I have friends who have used virtual reality already"* indicates that exposure to virtual reality is limited among respondents in this sample. At the same time, respondents acknowledge being influenced by their friends' expectations, which shape their behaviors (S2). The limited adoption of virtual reality technology, currently a characteristic for Romanian people, can have as a explanatory variable the limited social exposure to VR. These data support hypothesis H1, suggesting that broader exposure to AI driven VR would increase the potential for adopting this technology.

Perceived Behavioral Control (C1-C6): the high means of items in this cluster (around 4.23 to 4.52) indicate that participants perceive the AI-driven VR application as easy to use and intuitive and they have a strong perception of control during application use.

Attitude Toward Behavior Cluster (A1-A3): the mean scores for questions in this cluster also reflect a generally positive attitude toward using VR applications, which may be a result of the participant to tech events profile (maybe more prone to technology). A high-to-medium score on A2 suggests openness to experimenting with new technologies, while a high score on A3 indicates a strong intention to use AI & VR frequently in the future; however, the results also imply the presence of a certain level of apprehension that tempers responses, preventing them from being overwhelmingly positive. The intention to frequently use AI&VR in the future strongly correlates with Perceived Behavioural Control (C) cluster. Our analysis reveals correlations between the desire to frequently use AI&VR applications (A3) and several ease-of-use factors: the intuitiveness (C1: $r = 0.285$, $p \leq 0.000$), ease of identifying and understanding cues (C4: $r = 0.220$, $p \leq 0.001$) and ease of using the menu (C6: $r = 0.385$, $p \leq 0.000$). These findings support Hypothesis 4, suggesting that a greater sense of control over AI personalized VR interactions increases the likelihood of frequent usage.

Learning Perceived Effectiveness Cluster (L1-L4): High scores in this cluster reflect perceptions of the AI driven VR application's pedagogical effectiveness, particularly in enhancing engagement and motivation for learning. Additionally, high scores in this area suggest that participants recognize VR's positive impact on the learning process, with L3 and L4 likely yielding the highest average scores - highlighting an appreciation for the technology's utility and immersive nature. This reinforces *Hypothesis 2*, which posits that AI-generated content in VR use increases engagement and motivation in educational contexts. These findings further indicate a favorable perception of both engagement

and learning effectiveness, supporting *Hypothesis 3*, which asserts that AI driven VR enhances educational engagement and improves the perceived effectiveness of learning. A significant correlation underlines the connection between the perception that AI-driven VR systems are useful for learning and the perceived ease of interaction with AI-personalized VR content (with C1 ($r = 0.269$, $p \leq 0.000$) and with C6 ($r = 0.426$, $p \leq 0.000$)). These findings support *Hypothesis 5*, indicating that users with a positive attitude toward new technologies are more likely to perceive AI-generated VR interactions as intuitive and easy to navigate. Also, they reinforce the hypothesis that VR ergonomics plays a crucial role in technology acceptance.

Ergonomics Cluster (E1-E6): the average mean values for this cluster indicate a generally positive perception regarding the ergonomics of our AI driven virtual reality devices (mean values ranging from 3.91 to 4.53). The highest means were recorded for E1 (4.5305) and E4 (4.4231), which suggests that the clarity of virtual elements is good and easy to adjust and the lowest average score was for E3 (3.9155), indicating that sound adjustment should be more attentively constructed. Significantly variable results were recorded for E6, which reflects discomfort (dizziness), suggesting that some participants experienced physical difficulties related to the use of VR devices.

Furthermore, a considerable number of items were found to correlate strongly with the six variables included in the ergonomics cluster (E1-6), providing robust evidence of the central role of this construct. This convergence suggests that ergonomics is not a peripheral factor, but rather a key dimension influencing users' perceptions and interactions with immersive technologies. Among these correlated items, particular attention is given to the intention to use in education such technologies, which emerges as a highly relevant indicator. This reinforces the argument that ergonomics should be systematically incorporated into any theoretical model aiming to explain and understand the acceptance of immersive technologies, as it captures essential aspects that directly influence users' willingness to adopt and continue using these systems.

Table 4. Correlations of Ergonomics cluster with intention to use VR in education (** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed)).

	E1	E2	E3	E5	ED 1	ED 2
E1 Pearson Correlation	1	0.440**	0.118	0.383**	0.294**	0.310**
Sig. (2-tailed)	–	0	0.086	0	0	0
N	213	213	213	213	213	213
E2 Pearson Correlation	0.440**	1	0.142*	0.464**	0.255**	0.275**
Sig. (2-tailed)	0	–	0.038	0	0	0
N	213	213	213	213	213	213
E3 Pearson Correlation	0.118	0.142*	1	0.121	0.149*	0.168*
Sig. (2-tailed)	0.086	0.038	–	0.079	0.029	0.014
N	213	213	213	213	213	213
E4 Pearson Correlation	0.211**	0.125	0.054	0.247**	0.071	0.078
Sig. (2-tailed)	0.002	0.069	0.437	0	0.303	0.257
N	213	213	213	213	213	213
E5 Pearson Correlation	0.383**	0.464**	0.121	1	0.313**	0.371**
Sig. (2-tailed)	0	0	0.079	–	0	0
N	213	213	213	213	213	213
E6 Pearson Correlation	0.098	0.004	-0.03	0.097	0.035	0.048
Sig. (2-tailed)	0.157	0.955	0.661	0.161	0.615	0.484
N	212	212	212	212	212	212
ED 1 Pearson Correlation	0.294**	0.255**	0.149*	0.313**	1	0.623**

Sig. (2-tailed)	0	0	0.029	0	–	0
N	213	213	213	213	213	213
ED 2 Pearson Correlation	0.310**	0.275**	0.168*	0.371**	0.623**	1
Sig. (2-tailed)	0	0	0.014	0	0	–
N	213	213	213	213	213	213

Intention to Use in Education Cluster (ED1-ED2): this cluster measures the participant's intention to continue using generative AI and VR technology and to recommend it to others. High scores indicate a strong tendency toward future adoption and promotion of these technologies in the future.

A significant positive correlation was found between feeling comfortable with the headset and controllers (E5) and: 1. the intention to use AI-driven VR for learning (ED1) ($r = 0.313$, $p \leq 0.000$) and 2. recommendation to use this technology to other colleagues (ED2) ($r = 0.371$, $p \leq 0.000$). This finding supports *Hypothesis 6*, which suggests that the level of physical comfort experienced during the use positively influences users' long-term adoption intentions. In other words, users who feel comfortable using VR are more likely to integrate it into their learning experiences.

Age:

An inversely proportional correlation was identified between age and several key perceptions related to AI-driven VR. Specifically, as age decreases, respondents report a higher perceived ease of use of VR devices, including adjusting the equipment and using controllers (C1: $r = -0.194$, $p \leq 0.005$; C4: $r = -0.189$, $p \leq 0.006$). Younger participants also perceive VR as more comfortable to use, indicating greater agreement with feeling at ease with the headset and controllers (A1: $r = -0.555$, $p \leq 0.000$; A2: $r = -0.314$, $p \leq 0.000$) and intention to use them frequently (A3: $r = -0.456$, $p \leq 0.000$). In addition, age is negatively correlated with the perceived effectiveness of VR for learning, as younger individuals are more likely to agree that AI-personalized VR content enhances engagement (L1: $r = -0.432$, $p \leq 0.000$; L2: $r = -0.399$, $p \leq 0.000$; L3: $r = -0.446$, $p \leq 0.000$; L4: $r = -0.501$, $p \leq 0.000$). This can be explained by the fact that older participants developed their learning habits during periods when such technologies were not available, relying instead on more traditional study methods. As a result, they may find it more difficult to adapt to and fully appreciate newer, immersive tools, whereas younger individuals, who are more accustomed to digital environments, perceive them as more engaging and effective. This trend also extends to younger participants' greater openness toward further experimentation with such technologies and their intention to use VR in educational contexts (ED1: $r = -0.277$, $p \leq 0.000$; ED2: $r = -0.350$, $p \leq 0.000$). They are more likely to express a clear willingness to adopt this technology in the future and to promote it among peers and acquaintances, reinforcing their role as early adopters. Overall, this suggests that younger users not only find VR easier and more comfortable to use, but also perceive it as a more valuable and desirable learning tool.

Studies level:

The Pearson coefficient reveals a significant inverse correlation between education level and the perception that using virtual reality devices is easy (E2: $r = -0.279$, $p \leq 0.000$) and comfortable (E5: $r = -0.292$, $p \leq 0.000$). While this finding may seem counterintuitive, it can be understood in the context of digital natives' greater familiarity with AI and VR technology, suggesting that the ease of adjusting devices is less related to formal education and more to practical experience with ICT devices. In fact, VR technologies appear particularly valuable for individuals with lower formal education, as they can provide an alternative to traditional learning methods and help bridge gaps for those who did not fully engage with conventional study approaches. These results highlight the critical importance of ergonomics, confirming that ease of use and comfort are essential factors in making VR an effective and accessible learning tool for all users, regardless of educational background.

Perception of time in the AI-driven immersive reality

Table 5 shows the average time (expressed in minutes) spent by study participants to test the AI driven VR application. Actual time is the time measured for each test participant by the researchers

who organized the experimental sessions. Perceived time is the time each participant estimated they spent using the app, thus reflecting each participant's subjective perception.

Table 5. Perception of time in the AI driven VR application.

Time perception					
	N	Minimum	Maximum	Mean	Std. deviation
Real Time	213	2.00	25.00	11.1737	5.04909
Perceived Time	213	2.00	30.00	9.5587	4.73073

The real time ranged from 2 to 25 minutes testing the app, while participants estimated that they spent between 2 and 30 minutes. On average, subjects spent approximately 11 minutes using the VR app and estimated, on average, that they spent approximately 9.5 minutes testing the VR app. Interpretation of these values indicates that the perceived time is generally less than the actual time spent using the app. It is possible that immersion in the VR space and active engagement in the app's activities created the feeling that they spent less time than actual duration. However, the variation is quite large, suggesting that some subjects may perceive the time spent differently than others.

3.6. Limitations

A limitation of this study is the selection bias introduced by the recruitment of participants from tech events. Usually, these events primarily attract technology enthusiasts, professionals, and researchers, which means that participants were more likely to have a positive predisposition toward VR and emerging digital tools. Although the findings offer meaningful insights into AI-driven VR acceptance, they may not be fully representative of a broader educational audience. Future research will include a more diverse participant sample, incorporating individuals from various educational backgrounds, age groups, and levels of prior VR experience.

Another limitation is the lack of a control group for comparison with non-AI&VR learning methods. However, the study specifically aimed to evaluate user perceptions after firsthand experience with VR headsets in an AI-driven e-learning application. Unlike comparative learning studies, which assess knowledge retention or performance differences between AI&VR and traditional methods, this research focuses on user acceptance, usability, and perceived effectiveness within a fully immersive learning environment. Future studies could explore comparative experimental designs, but such an approach would require a different research focus, shifting from perception-based evaluation to an outcome-based assessment of learning effectiveness. In the context of this study, the absence of a control group does not diminish the validity of the findings, as the primary objective was to assess factors influencing user adoption within a VR-enhanced educational setting through the lens of ED-SCALE model.

The ED-SCALE model was developed based on current technological trends, but AI and VR environments continue to evolve rapidly. Future studies should explore how this model can be adapted to emerging technologies, such as multi-user collaborative VR environments, and mixed-reality applications. Evaluating ED-SCALE's applicability across different educational domains and learning scenarios will contribute to refining its predictive accuracy and practical relevance.

4. Conclusions

The present study reveals valuable insights into user interactions within the AI-driven immersive reality. By specifically focusing on the users' interactions and experiences within the AI-driven educational escape room, we worked on systematically evaluating the usability, engagement, and learning outcomes of educational applications based on new technologies. An expected outcome of our research is the critical role of user-centered design for an engaging VR experience. Participants in our study consistently pointed out the ease of navigation and intuitive interfaces as key factors

that maintained their engagement and contributed to the overall experience. This aspect reinforces the necessity for VR developers to prioritize intuitive design elements that satisfy user preferences and behaviors.

Our empirical study was based on the educational potential of escape rooms in serious games. The escape room game, blending challenge and interaction, proved to be an effective educational tool that can transform traditional learning paradigms. The immersive nature of these environments not only attracts participants but also significantly improves knowledge retention and engagement. These results are consistent with prior research that appreciates the virtues of immersive learning environments in promoting active and experiential learning.

The ED-SCALE research model has proven effective but can benefit from further refinement and expansion. The ERGONOMICS of the used devices emerged as a main element in user satisfaction. Participants reported high levels of comfort and ease of use, suggesting that current technologies are well-received, due to their simplicity. We also examined the impact of sociodemographic variables and found that age significantly influences technology acceptance, a finding that can be explained by previous frequent interactions with technology, as well as a highly favorable attitude towards its use among digital natives. They also believe that learning is much more intense and engaging when using immersive tools like those tested in this study. Those who found the experience educationally effective tended to spend more time in the application—not approaching it as mere entertainment, but with the seriousness of someone deeply committed to learning.

Future research should explore how a multi criteria analysis or structural equations modeling can be customized to assess different types of educational content and delivery methods within the AI&VR based learning environments. Also, longitudinal studies are needed to assess the long-term impact of the such applications on learning outcomes and user engagement. Understanding how sustained usage of such apps influences knowledge retention and skill development over time will provide deeper insights into the effectiveness of emerging technologies in educational settings.

Understanding societal impacts of emerging technologies can guide the development of policies and regulations that support their responsible and equitable growth, ensuring that its benefits are widely distributed and its challenges are effectively managed. We consider such investigations should be continued, and addressing this gap is the primary aim of our forthcoming study, which seeks to complement existing research in this area.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by Ethics Committee of the PN 23380601 on 20.02.2024.

Informed Consent Statement: In this non-interventional study, participants were informed, in the introductory section of the questionnaire that all responses were anonymous and could not be linked to their identity. Participation was voluntary, and respondents were free to discontinue the questionnaire or the VR experience at any time without any consequences. They were explicitly informed that no personal data, no sensitive information, and no audio or video recordings were collected at any stage of the study. Completing and submitting the questionnaire was considered to constitute informed consent.:

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy and ethical restrictions (e.g., participant confidentiality).

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Abbreviations

The following abbreviations are used in this manuscript:

TAM	Technology Acceptance Model
TRA	Theory of Reasoned Action
TPB	Theory of Planned Behavior
ED-SCALE:	Education – Subjective norm / Behavioural control (perceived) / attitude toward behaviour/ learning effectiveness (perceived) / Ergonomics

References

- Dwivedi, Y. K.; Hughes, L.; Baabdullah, A. M.; Ribeiro-Navarrete, S.; Giannakis, M.; Al-Debei, M. M.; Dennehy, D.; Metri, B.; Buhalis, D.; Cheung, C.M.K.; Conboy, K.; Doyle, R.; Dubey, R.; Dutot, V.; Felix, R.; Goyal, D.P.; Gustafsson, A.; Hinsch, C.; Jebabli, M.; Kim, Y.G.; Kim, J.; Koos, S.; Kreps, D.; Kshetri, N.; Kumar, V.; Ooi, K.B.; Papagiannidis, S.; Pappas, I.O.; Polyviou, A.; Park, S.M.; Pandey, N.; Quiroz, M.M.; Raman, R.; Rauschnabel, P. A.; Shirish, A.; Sigala, M.; Spanaki, K.; Tan, W.H.G.; Tiwari, M.K.; Viglia, G. & Wamba, S. F. Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy. *International Journal of Information management* 2022, 66, 102542.
- Song, C.; Shin, S-Y.; Shin, K-S. Exploring the Key Characteristics and Theoretical Framework for Research on the Metaverse. *Applied Sciences* 2023. 13. 7628. 10.3390/app13137628.
- Talin, B. *The Metaverse explained – Definition, Introduction and Examples* 2023. Available online: <https://morethandigital.info/en/the-Metaverse-explained-definition-introduction-and-examples/> [Accessed on 15th June 2024].
- McKinsey & Company. *What is the Metaverse?* 2022, Available online: <https://www.mckinsey.com/featured-insights/mckinsey-explainers/what-is-the-Metaverse#/> [Accessed on 15th June 2024].
- Ball, M. *The metaverse: and how it will revolutionize everything*. Liveright Publishing, 2022.
- Lee, B.K. The Metaverse world and our future. *The Korea Contents Association Review* 2021, 19, 13–17.
- Zamfiroiu, A.; Sharma, R. C.; Ciupercă, E. M. Educational Innovations Based on Metaverse in the Development of Smart Cities. In *Proceedings of International Conference on Informatics in Economy* (pp. 85–96). Bucharest, Romania, Singapore: Springer Nature Singapore 2023.
- Zhang, X.; Chen, Y.; Hu, L.; Wang, Y. The metaverse in education: Definition, framework, features, potential applications, challenges, and future research topics. *Frontiers in Psychology* 2022, 13. <https://doi.org/10.3389/fpsyg.2022.1016300>
- Sun, H.; Xiao, X. User acceptance of virtual technologies. *End-User Computing: Concepts, Methodologies, Tools, and Applications*. IGI Global 2008; pp. 1065-1073.
- Cardona, M. A.; Rodríguez, R. J.; Ishmael, K. Artificial intelligence and the future of teaching and learning: Insights and recommendations 2023.
- Toraman, Y. User acceptance of metaverse: Insights from technology acceptance model (TAM) and planned behavior theory (PBT). *EMAJ: Emerging Markets Journal* 2022, 12(1), 67-75.
- Toraman, Y.; Gecit, B. User Acceptance of Metaverse: An Analysis for e-Commerce in the Framework of Technology Acceptance Model (TAM). *Sosyoekonomi* 2023. 31. 85-104. 10.17233/sosyoekonomi.2023.01.05.
- Adhini, N.; Prasad, C. Perceptions and drivers of the metaverse adoption: A mixed-methods study. *International Journal of Consumer Studies* 2024. 48. 10.1111/ijcs.13069.

14. Davis, F. D. Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly* 1989, 13(3), 319-340.
15. Fishbein, M. Attitude and the prediction of behavior. In *Readings in attitude theory and measurement*. Fishbein M. (ed.); John Wiley, New York, USA, 1967; pp. 477–492.
16. Fishbein, M.; Ajzen, I. Belief, attitude, intention and behavior: An introduction to theory and research. *Addison-Wesley*, Boston, USA, 1975.
17. Ajzen, I. From intentions to actions: A theory of planned behavior. In *Action control: From cognition to behavior* Heidelberg: Springer Berlin Heidelberg, Berlin, Germany, 1985, pp. 11-39.
18. Ajzen I. The Theory of planned behavior. *Organizational Behavior and Human Decision Processes* 1991, 50:179–211.
19. Murala, D.K.; Panda, S.K. Metaverse. In A. Chandrashekhar, S.H. Saheb, S.K. Panda, S. Balamurugan & S.-L. Peng(eds.) *Metaverse and Immersive Technologies*. 2023, <https://doi.org/10.1002/9781394177165.ch1>
20. Ahmad, I.; Sharma, S.; Singh, R.; Gehlot, A.; Priyadarshi, N.; Twala, B.. MOOC 5.0: A Roadmap to the Future of Learning. *Sustainability* 2022. 14. 11199. 10.3390/su141811199.
21. Farooq, S.; Ishaq, K.; Shoaib, M.; Khelifi, A.; Atal, Z. (2023). The Potential of Metaverse Fundamentals, Technologies, and Applications: A Systematic Literature Review. *IEEE Access.*, pp. 1-1, 10.1109/ACCESS.2023.3338627.
22. Chalkiadakis, A.; Seremetaki, A.; Kanellou, A.; Kallishi, M.; Morfopoulou, A.; Moraitaki, M.; Mastrokourou, S. Impact of artificial intelligence and virtual reality on educational inclusion: A systematic review of technologies supporting students with disabilities. *Education Sciences* 2024, 14, 11: 1223.
23. Familoni, B.; Onyebuchi, N. Augmented and virtual reality in U.S. education: a review: analyzing the impact, effectiveness, and future prospects of AR/VR tools in enhancing learning experiences. *International Journal of Applied Research in Social Sciences* 2024, 6. 642-663. 10.51594/ijarss.v6i4.1043.
24. Rong, Q.; Lian, Q.; Tang, T. Research on the Influence of AI and VR Technology for Students' Concentration and Creativity. *Frontiers in psychology* 2022, 13, 767689.
25. Hawes, D.; Arya, A. Technology solutions to reduce anxiety and increase cognitive availability in students. *IEEE Transactions on Learning Technologies* 2023, 16(2), 278-291.
26. Lin, H.; Gan, Z.; Gan, W.; Qi, Z.; Wang, Y.; Yu, P. Interaction in Metaverse: A Survey, in 2023 *IEEE International Conference on Big Data (BigData)*, 2023, Sorrento, pp. 2473-2482. doi: 10.1109/BigData59044.2023.10386876
27. Giaretta, A. Security and privacy in virtual reality-a literature survey. *arXiv preprint* 2022.
28. Lee, J.; Kim, J.; Choi, J. Y. The adoption of virtual reality devices: The technology acceptance model integrating enjoyment, social interaction, and strength of the social ties. *Telematics and Informatics* 2019, 39, 37-48.
29. Al-kairy, M.; Alomari, A.; Al-Bashayreh, M.; Alfandi, O.; Tubishat, M. Unveiling the Metaverse: A Survey of User Perceptions and the Impact of Usability, Social Influence and Interoperability. *Heliyon* 2024. 10. e31413. 10.1016/j.heliyon.2024.e31413.
30. Margam, M. Beyond reality: Metaverse technologies revolutionizing libraries and elevating user engagement, *Library Hi Tech News* 2024, Vol. ahead-of-print No. ahead-of-print. <https://doi.org/10.1108/LHTN-12-2023-0217>.
31. Lee, H.-W.; Chang, K.; Uhm, J.-P.; Owiro, E. How Avatar Identification Affects Enjoyment in the Metaverse: The Roles of Avatar Customization and Social Engagement. *Cyberpsychology, behavior and social networking* 2023. 26. 10.1089/cyber.2022.0257.
32. Zhang, G.; Wu, J.; Jeon, G.; Chen, Y.; Wang Y.; Tan, M. Towards Understanding Metaverse Engagement via Social Patterns and Reward Mechanism: A Case Study of Nova Empire, in *IEEE Transactions on Computational Social Systems* 2023, 10 (5), 2165-2176, doi: 10.1109/TCSS.2022.3211679.
33. Yu, H. Why people use Metaverse? A uses and gratification theory perspective. *Telematics and Informatics* 2024, 89, 102110, <https://doi.org/10.1016/j.tele.2024.102110>.
34. Othman, A.; Chemnad, K.; Hassanien, A.E.; Tlili, A.; Zhang, C.Y.; Al-Thani, D.; Altinay F.; Chalghoumi H.S.; Al-Khalifa, H.; Obeid, M.; Jemni, M.; Al-Hadhrami, T.; Altinay, Z. Accessible Metaverse: A Theoretical

- Framework for Accessibility and Inclusion in the Metaverse. *Multimodal Technologies and Interaction* 2024, 8(3):21. <https://doi.org/10.3390/mti8030021>
35. Al-Sharafi, M. A.; Al-Emran, M.; Al-Qaysi, N.; Iranmanesh, M.; Ibrahim, N. Drivers and Barriers Affecting Metaverse Adoption: A Systematic Review, Theoretical Framework, and Avenues for Future Research. *International Journal of Human-Computer Interaction* 2023, 1–22. <https://doi.org/10.1080/10447318.2023.2260984>.
 36. Maghaydah, S.; Al-Emran, M.; Maheshwari, P.; Al-Sharafi, M. A. Factors affecting Metaverse adoption in education: A systematic review, adoption framework, and future research agenda. *Heliyon* 2024, 10. e28602. [10.1016/j.heliyon.2024.e28602](https://doi.org/10.1016/j.heliyon.2024.e28602).
 37. Guillén-Yparrea, N.; Ramírez-Montoya, M.S. The Use of Metaverse for Intercultural Collaboration in Higher Education. In *International Conference on Mobile and Ubiquitous Multimedia MUM '23*, December 03–06, Vienna, Austria. ACM, New York, NY, USA, 4 p., <https://doi.org/10.1145/3626705.3632614>
 38. Dahan, N.A.; Al-Razgan, M.; Al-Laith, A.; Alsoufi, M.A.; Al-Asaly, M.S.; Alfakih, T. Metaverse Framework: A Case Study on E-Learning Environment (ELEM). *Electronics* 2022, 11(10): 1616. <https://doi.org/10.3390/electronics11101616>
 39. Zhong, J.; Zheng, Y. Empowering future education: Learning in the Edu-Metaverse. In *2022 International Symposium on Educational Technology (ISET)*, pp. 292–295.
 40. Hwang, G. J.; Chang, C. C.; Chien, S. Y. A motivational model-based virtual reality approach to promoting learners' sense of presence, learning achievements, and higher-order thinking in professional safety training. *British Journal of Educational Technology* 2022, 53(5), 1343–1360.
 41. Li, T., Yan, J., Gao, X., Liu, H., Li, J., Shang, Y, Tang, X. Using virtual reality to enhance surgical skills and engagement in orthopedic education: systematic review and metanalysis. *Journal of Medical Internet Research* 2025, 27, e70266, <https://doi.org/10.2196/70266>.
 42. Koo, H. Training in lung cancer surgery through the Metaverse, including extended reality, in the smart operating room of Seoul National University Bundang hospital, Korea. *J. Educ. Eval. Health Prof.* 2021, 18:33. doi: 10.3352/jeehp.2021.18.33
 43. Díaz, J.; Saldaña, C.; Avila, C. Virtual world as a resource for hybrid education. *International Journal of Emerging Technologies in Learning (ijET)* 2020, 15(15), 94–109.
 44. Bordegoni, M.; Ferrise, F. Exploring the intersection of Metaverse, digital twins, and artificial intelligence in training and maintenance. *Journal of Computing and Information Science in Engineering* 2023, 23(6), 060806.
 45. Chien, S. Y.; Hwang, G. J.; Jong, M. S. Y. Effects of peer assessment within the context of spherical video-based virtual reality on EFL students' English-Speaking performance and learning perceptions. *Computers & Education* 2020, 146, 103751.
 46. Nguyen, V. T.; Jung, K.; Yoo, S.; Kim, S.; Park, S.; Currie, M. Civil War Battlefield Experience: Historical Event Simulation using Augmented Reality Technology, *IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR)* 2019, San Diego, CA, USA, pp. 294–2943, doi: 10.1109/AIVR46125.2019.00068.
 47. Venkatesan, M.; Mohan, H.; Ryan, J. R.; Schürch, C. M.; Nolan, G. P.; Frakes, D. H.; Coskun, A. F. Virtual and augmented reality for biomedical applications. *Cell reports. Medicine* 2021, 2(7), 100348. <https://doi.org/10.1016/j.xcrm.2021.100348>
 48. Layona, R.; Yulianto, B.; Tunardi, Y. Web based Augmented Reality for Human Body Anatomy Learning, *Procedia Computer Science* 2018, 135, 457–464, <https://doi.org/10.1016/j.procs.2018.08.197>.
 49. Al-Ansi, A. M.; Askar Garad, M. J.; Al-Ansi, A. Analyzing augmented reality (AR) and virtual reality (VR) recent development in education, *Social Sciences & Humanities Open* 2023, 8 (1), <https://doi.org/10.1016/j.ssaho.2023.100532>.
 50. Hemme, C. L.; Carley, R.; Norton, A.; Ghumman, M.; Nguyen, H.; Ivone, R.; Menon, J. U.; Shen, J.; Bertin, M.; King, R.; Leibovitz, E.; Bergstrom, R.; Cho, B. Developing virtual and augmented reality applications for science, technology, engineering and math education. *BioTechniques* 2023, 75(1), 343–352. <https://doi.org/10.2144/btn-2023-0029>.

51. Calisto, M.; Sarkar, S. A systematic review of virtual reality in tourism and hospitality: The known and the paths to follow, *International Journal of Hospitality Management* 2024, 116, 103623, <https://doi.org/10.1016/j.ijhm.2023.103623>.
52. Alnagrati, A. J. A.; Ismail, R. C.; Idrus, S. Z. S. The Opportunities and challenges in virtual reality for virtual laboratories. *Innovative Teaching and Learning Journal* 2022, 6(2), 73-89.
53. Sun, J. C. Y.; Ye, S. L.; Yu, S. J.; Chiu, T. K. Effects of wearable hybrid AR/VR learning material on high school students' situational interest, engagement, and learning performance: The case of a physics laboratory learning environment. *Journal of Science Education and Technology* 2023, 32(1), 1-12.
54. Alizadehsalehi, S.; Hadavi, A.; Huang, J. C. Assessment of AEC students' performance using BIM-into-VR. *Applied Sciences* 2021, 11(7), 3225.
55. Prakash, A.; Haque, A.; Islam, F.; Sonal, D. Exploring the Potential of Metaverse for Higher Education: Opportunities, Challenges, and Implications. *Metaverse Basic and Applied Research* 2023, 2, 40. <https://doi.org/10.56294/mr202340>
56. Chen, Z. Exploring the application scenarios and issues facing Metaverse technology in education. *Interactive Learning Environments* 2022, 1-13.
57. Letafati, M.; Otoum, S. On the privacy and security for e-health services in the Metaverse: An overview. *Ad Hoc Networks* 2023, 103262.
58. Chen, B.; Wang, Y.; Wang, L. The Effects of Virtual Reality-Assisted Language Learning: A Meta-Analysis. *Sustainability* 2022, 14 (6), 3147.
59. Di Pietro, R.; Cresci, S. Metaverse: Security and privacy issues. In 2021 third IEEE international conference on trust, privacy and security in intelligent systems and applications (TPS-ISA) 2021, pp. 281-288.
60. Ping, L.; Liu, K. Using the technology acceptance model to analyze K-12 students' behavioral intention to use augmented reality in learning. *Texas Education Review* 2020.
61. Tang, X.; Zhu, E.; Li, J. Investigating the factors influencing college students' intention to use virtual reality for learning: An extension of the technology acceptance model. *Interactive Learning Environments* 2020, 28(2), 206-220.
62. Granić, A.; Marangunić, N. Technology acceptance model in educational context: A systematic literature review. *British Journal of Educational Technology* 2019, 50(5), 2572-2593. <https://doi.org/10.1111/bjet.12864>.
63. Shen, S.; Xu, K.; Sotiriadis, M.; Wang, Y. 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. *Journal of hospitality leisure sport & tourism education* 2022, 30, 100373. <https://doi.org/10.1016/j.jhlste.2022.100373>
64. Al-Adwan, A. S. Investigating the drivers and barriers to MOOCs adoption: The perspective of TAM. *Education and information technologies* 2020, 25(6), 5771-5795. <https://doi.org/10.1007/s10639-020-10250-z>
65. Lee, C.; Chang, C.; Hou, H. The effect of virtual reality on students' learning motivation and achievement. *Journal of Educational Technology & Society* 2019, 22(2), 75-84
66. Ajzen, I.; Fishbein, M. Understanding attitudes and predicting social behavior. *Englewood Cliffs, NJ: Prentice Hall, 1980*.
67. Nielsen, J. Usability Engineering. *Morgan Kaufmann, 1994*.
68. Venkatesh, V.; Davis, F. D. A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management science* 2000, 46(2), 186-204.
69. Venkatesh, V.; Bala, H. Technology acceptance model 3 and a research agenda on interventions. *Decision sciences* 2008, 39(2), 273-315.
70. Balog, A.; Pribeanu, C. The Role of Perceived Enjoyment in the Students' Acceptance of an Augmented Reality Teaching Platform: a Structural Equation Modeling Approach. *Studies in Informatics and Control* 2010, 19 (3), 319-330.
71. Iordache, D. D. Evaluation of virtual reality-based applications in education. In *Conference proceedings of eLearning and Software for Education (eLSE)2020*, 16 (1), 499-504, Carol I National Defence University Publishing House.
72. Kim, Y.M.; Rhiu, I.; Yun, M.H. A systematic review of a virtual reality system from the perspective of user experience. *International Journal of Human Computer Interaction* 2020, 36, 893-910.

73. Zhou, Z.; Chen, Z.; Jin, X.-L. A review of the literature on the Metaverse: definition, technologies, and user behaviors, *Internet Research* 2024, 34 (1), 129-148. <https://doi.org/10.1108/INTR-08-2022-0687>.
74. Prabhakar, R. *The Customer-Centric Imperative: Designing digital Experiences That Delight*. 2024. <https://www.xerago.ai/insights/customer-centric-digital-experience-design> [Accessed: 25.02.2026].
75. Al-Adwan, A. S.; Albelbisi, N. A.; Hujran, O.; Al-Rahmi, W. M. Extending the Technology Acceptance Model (TAM) to Predict University Students' Intentions to Use Metaverse-Based Learning Platforms. *Education and Information Technologies* 2021, 28, 15381–15413.
76. Lee, E. A.-L.; Wong, K. W. How does desktop virtual reality enhance learning outcomes? A structural equation modeling approach. *Computers & Education* 2020, 55(4), 1424–1442. Lee, J., Kim, J. & Choi,
77. Chen, J.; Fu, Z.; Liu, H.; Wang, J. Effectiveness of virtual reality on learning engagement: A meta-analysis. *International Journal of Web-Based Learning and Teaching Technologies (IJWLTT)* 2024, 19(1), 1-14.
78. Makransky, G.; Petersen, G. B. The Cognitive Affective Model of Immersive Learning (CAMIL): A Theoretical Research-Based Model of Learning in Immersive Virtual Reality. *Educational Psychology Review* 2024, 33(3), 937–958.
79. Jiang, J.; Fryer, L. K. The effect of virtual reality learning on students' motivation: A scoping review. *Journal of Computer Assisted Learning* 2024, 40(1), 360-373.
80. Souchet, A. D.; Lourdeaux, D.; Pagani, A.; Rebenitsch, L. A narrative review of immersive virtual reality's ergonomics and risks at the workplace: cybersickness, visual fatigue, muscular fatigue, acute stress, and mental overload. *Virtual Reality* 2023, 27(1), 19-50.
81. Barbu, M.; Iordache, D. D.; Petre, I.; Barbu, D. C.; Băjenaru, L. Framework Design for Reinforcing the Potential of XR Technologies in Transforming Inclusive Education. *Applied Sciences* 2025, 15(3), 1484.
82. Rogers, E. M. *Diffusion of innovations* (5th ed.). New York, NY: Free Press 2003.

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