Learning satisfaction in virtual reality: the role of persuasive design

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Learning Satisfaction in Virtual Reality: The Role of Persuasive Design

Isaac Wiafe*[1], Akon Obu Ekpezu[2], Gifty Oforiwaa Gyamera[3], Fiifi Baffoe Payin Winful[1], Elikem Doe Atsakpo[1], Charles Nutropkor[1], Stephen R. Gulliver[4]

[1] Department of Computer Science, University of Ghana; [2]Faculty of Information Technology and Electrical Engineering, Oulu Advanced Research on Services and Information Systems, University of Oulu, Finland; [3]School of Public Service and Governance, Ghana Institute of Management and Public Administration; [4]Business Systems Informatics and Accounting, Henley Business School, University of Reading, Reading-UK

Abstract

Given the positive impact of virtual reality learning environments on students' learning satisfaction, it is imperative to identify the key features within these environments that contribute to such satisfaction. This study examined how persuasive features enhance students' learning satisfaction via psychological outcomes within a persuasive immersive virtual reality learning environment (IVRLE). Using partial least squares structural equation modeling, quantitative data obtained from 115 IVRLE users were analyzed. The results show that by leveraging persuasive features such as unobtrusiveness, design aesthetics, primary task support, credibility support, dialogue support, and perceived persuasiveness, educators can create immersive learning environments that effectively engage students cognitively and emotionally, thereby enhancing learning satisfaction. Among the direct determinants of students' learning satisfaction, perceived enjoyment exhibited the strongest impact. These results underscore the relevance of designing virtual reality learning environments as persuasive educational environments that shape learning behaviors and also caters to the psychological needs of students.

Keywords: Persuasive Systems Design, Immersive Virtual Reality, Learning Satisfaction, Learning Behavior, Technology-Enhanced Learning, Educational Technology

1 Introduction

Recently, particularly post COVID-19, the education landscape has shifted from conventional face-to-face learning in physical classrooms to adopting online learning platforms and immersive and interactive technologies. Immersive technologies, such as virtual reality, imitate the real world using computer-generated simulations. More specifically, immersive virtual reality transforms the teaching and learning experience by creating engaging simulations, promoting experiential learning, and enabling the visualization of complex concepts. Prior studies have argued that learners express greater satisfaction with virtual reality learning environments than with conventional face-to-face learning (Liu et al., 2023; Liu et al., 2020; Ryan & Poole, 2019). Conversely, others argue that learning within virtual reality is distractive and not as satisfying as learning in conventional face-to-face classrooms (Chen et al., 2020; Makransky et al., 2019; Mayer et al., 2023). This dissatisfaction may be attributed to higher levels of emotional and anxiety arousal, which are not typically experienced in conventional classrooms (Mayer et al., 2023). This may also be attributed to the visual fatigue caused by wearing the head-mounted display (Hirota et al., 2019). Learning in immersive virtual environments exerts some level of cognitive burden on users that is unrelated to their learning goals. This distracts them from learning (Makransky et al. 2019; Mayer et al. 2023). Issues of motion sickness also persist, and these decrease users' satisfaction with virtual reality (Gao & Zhu, 2023). Considering the different arguments in the literature and the significant impact of learning satisfaction on continuance learning intention (Wu et al., 2015)and the efficiency and continuance intention to use interactive and immersive learning technologies (Dağhan & Akkoyunlu, 2016; Huang, 2021; Makransky & Petersen, 2021), an in-depth understanding of the factors that influence learning satisfaction in these environments has become imperative.

Prior studies have identified several factors, including presence, flow experience, and immersion (Kim & Ko, 2019; Servotte et al., 2020), as determinants of learning satisfaction in virtual reality. Others have mentioned system factors, application and user interaction factors, individual factors, perception (Burov & Pinchuk, 2023), technology acceptance, and Click or tap here to enter text.cognitive and emotional factors (Chen et al., 2023; Yin et al., 2024). However, there is a lack of explicit integration of pedagogical theories/models into the design of virtual reality learning content (Efendi et al., 2023; Radianti et al., 2020). In addition, virtual reality learning environments are seldom designed with theory-based principles and features specific to them, which significantly impacts learning outcomes (Bohne et al., 2021). This suggests a lack of standardized criteria for evaluating these environments. It is envisaged that incorporating well-established theoretical frameworks into the design of virtual reality environments and their learning contents will provide a referenceable benchmark for assessing their impact on learning satisfaction.

Given that virtual reality is beginning to arouse extensive research interest as a form of persuasive technology (Chow et al., 2017; Wang et al., 2023), this study aims to leverage the persuasive systems design (PSD) model to examine how and to what extent persuasive systems features influence learning satisfaction via psychological outcomes within an immersive virtual reality learning environment (IVRLE). The PSD model (Oinas-Kukkonen & Harjumaa, 2009) was chosen as the main theoretical underpinning of this study because of its widespread use in the design and evaluation of persuasive technology/systems (Merz et al., 2021). Persuasive technology/systems leverage information technology/systems to change users' attitudes and behaviors without coercion (Fogg, 2003; Oinas-Kukkonen & Harjumaa, 2009). Although evidence of how PSD features impact students' learning satisfaction within an IVRLE is limited because they are rarely used in virtual reality educational systems (Devincenzi et al., 2017), they have been demonstrated to positively impact user satisfaction in e-commerce and health (Alhammad et al., 2021; Tikka & Oinas-Kukkonen, 2016). In addition, the potential of PSD features to change user health behavior and enhance their affective response to a primary task has been demonstrated in virtual reality (e.g., Ekpezu, Wiafe, Nutrokpor, et al., 2024).

This study contributes to research on virtual reality as a form of persuasive technology or system by exploring the applicability of system features in the design of an immersive virtual reality learning environment and examining the psychological outcomes associated with these features. It will inform the development of immersive learning environments that promote learning satisfaction and students' learning behavior.

2 The Persuasive Systems Design (PSD) Model and Hypotheses Formulation

The persuasive systems design (PSD) model (Oinas-Kukkonen & Harjumaa, 2009) combines principles and theories from social psychology, social influence, and ICT to create systems that persuade users to adopt specific attitudes and behaviors. The model comprises four main principles (primary task support, dialogue support, credibility support, and social support) that guide the design and evaluation of persuasive systems. It also postulates that a persuasive system should be unobtrusive, easy to use/use, incrementally implemented, open/transparent about its persuasive intent, neutral, consistent in its persuasive strategies, and use direct/indirect routes to influence user behavior.

The model (including its postulates, principles, and features) has demonstrated a significant impact on students' learning outcomes in educational technologies. Studies have reported that persuasive system features can influence different forms of learning behavior, including knowledge sharing (Wiafe et al., 2020) and student engagement (Orji et al., 2019). A common utilization of the PSD model is the incorporation of gamification elements in persuasive educational systems (Murillo-Muñoz et al., 2021). These elements, which align with persuasive features (e.g., progress tracking/self-monitoring, achievement badges/rewards, virtual rewards, leaderboards/recognition), have been demonstrated to make learning more enjoyable and engaging for students in gamified learning platforms (Su & Cheng, 2015). They have also been demonstrated to increase students' attention, competence, and satisfaction in e-learning applications (Hamzah et al., 2015). Studies have also shown that persuasive features such as personalization, feedback, social influence, and self-monitoring can improve students' learning outcomes and self-efficacy in adaptive e-learning environments (Walkington, 2013).

Whereas evidence of the efficacy/effectiveness of persuasive features and principles on students' learning outcomes has been established in the real world, they are not well established within an immersive virtual reality learning environment as determinants of learning satisfaction. Considering the paradigm shift in the educational landscape from traditional classroom learning to the use of emerging educational technologies such as virtual reality, it is imperative to investigate the impact of persuasive features on learning satisfaction in immersive virtual reality learning environments.

The adoption of features from the PSD model to examine students' learning satisfaction in VRLE is primarily based on the assumption that interactions and human behavior in virtual reality tend to imitate real-world situations (Menck et al., 2023). Thus, persuasive system features (i.e., primary task support, dialogue support, credibility support, unobtrusiveness, perceived persuasiveness, and design aesthetics) will influence learning satisfaction, and these influences are expected to be mediated by psychological outcomes (namely cognitive engagement, emotional engagement, and perceived enjoyment) in IVRLE. The proposed research model is presented in Figure 1. Table 1 shows the operational definitions of the constructs and examples of how the features were implemented.

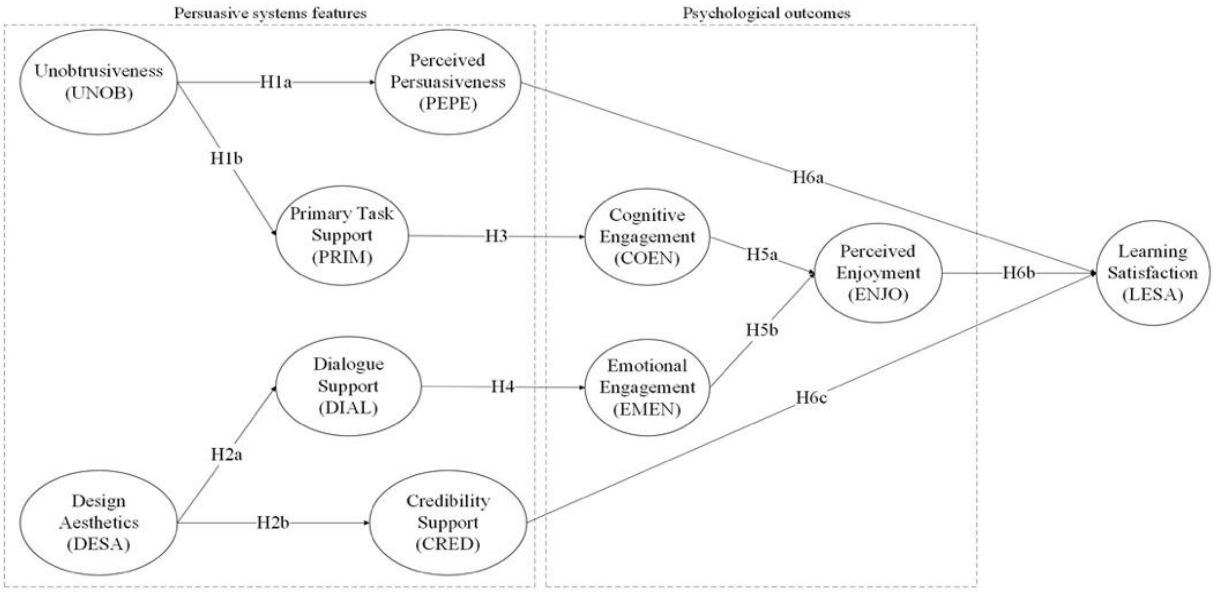

Figure 1: Proposed research model

Table 1: Operational definitions and sample implementation of the features

Construct	Operational definitions	Implementation
Unobtrusiveness (UNOB)	The extent to which an IVRE reduces cognitive load by minimizing distractions and unnecessary interruptions.	The IVRLE was set up in a way that participants only had to wear the headset for the lecture to commence. Potential stressors or anxieties that may arise from a secondary sound or from the use of hand controllers was disabled to avoid distractions.
Design aesthetics (DESA)	It is the subjective evaluation of the extent to which an IVRE is visually appealing to the users.	To provide an appealing visual experience, color textures, the projector screen, ambient lights, and the general appearance of the IVRLE were designed to replicate observed colors and schemes seen by students in the physical classroom.
Primary task support (PRIM)	The extent to which an IVRE facilitates students to perform their primary task (e.g., learning).	The lecture content taught was structured based on the three lower levels of the Bloom's taxonomy and delivered incrementally from simple narratives to complex narratives (tunnelling and reduction).
Dialogue support (DIAL)	The extent to which an IVRE motivates the students to achieve their learning goals.	Designing the IVRLE to imitate a familiar physical classroom, with avatar of the lecturer, lecturing with the same voice as in the physical world (similarity and social role).
Credibility support (CRED)	The extent to which the IVRE and the information provided therein is perceived to be trustworthy and reliable.	An aesthetically appealing virtual reality environment that is an imitation of a familiar lecture room and a purposefully designed lecture content (surface credibility trustworthiness, expertise, and real-world feel).
Perceived persuasiveness (PEPE)	It refers to users' favorable impressions about the IVRE and its influence on them.	Incorporating several persuasive features into the IVRLE was intended to enhance the participant's favorable impression of the influence of the environment.
Cognitive engagement (COEN)	The extent to which an IVRLE optimize thinking activities related to involvement and participation in learning tasks including understanding and application.	To facilitate cognitive, the lecture content was purposefully designed with clear learning objectives. The content was designed based on the lower cognitive levels of Bloom's taxonomy to optimize understanding, application, and knowledge.

Construct	Operational definitions	Implementation
Emotional engagement (EMEN)	It refers to the emotional reactions and affective connection between the students and the learning task/subject.	Compelling narratives that were intended to resonate emotionally with the students were used in the lecture.
Perceived enjoyment (PECO)	It refers to students' affective response to a learning task and (or) the IVRLE reflecting fun, liking, satisfaction, and pleasure.	Realistic textures and visuals were used to make the IVRLE more enjoyable.
Learning satisfaction (LESA)	It is the extent to which students perceive the learning experience within the IVRLE fulfilling, pleasing and satisfactory.	The incorporation of the aforementioned features including purposefully crafted lecture content with clear learning objectives, an environment that closely mimics a physical classroom, and that provides a seamless experience.

2.1 Unobtrusiveness, Perceived Persuasiveness and Primary Task Support

Unobtrusiveness is one of the key postulates behind PSD, which seeks to bridge the intention-behavior gap (Oinas-Kukkonen, 2013; Oinas-Kukkonen & Harjumaa, 2009). This contextual construct shows how a persuasive system fits into the daily lives of users and the environment in which it is used (Lehto et al., 2012). Perceived persuasiveness refers to users' subjective evaluations. It measures the favorable impressions of a system and its influence on users. Considering that persuasive systems seek to motivate behavior change without coercion, this suggests that there is a deliberate effort to balance persuasiveness with unobtrusiveness. An unobtrusive system tends to be less intrusive and facilitates a non-coercive user experience. When a system aligns with a user's environment and needs, it may enhance positive affect. Primary task support provides a means to aid users in their primary tasks (Oinas-Kukkonen & Harjumaa, 2009) and contributes to positive affect by simplifying complex tasks, thereby reducing cognitive load.

Studies on conventional persuasive systems highlight the direct impact of unobtrusiveness on primary task support and perceived persuasiveness (Lehto et al., 2012). Although this relationship has not been established within a virtual reality learning environment, it is logical to assume that an unobtrusive learning environment would reduce the cognitive load by minimizing distractions and unnecessary interruptions. This will form positive effects and favorable impressions on students. Accordingly, this study hypothesizes that:

H1a: Unobtrusiveness influences perceived persuasiveness in IVRLE.

H1b: Unobtrusiveness influences primary task support in IVRLE.

2.2 Design Aesthetics, Dialogue Support, and Credibility Support

Most initial encounters with persuasive systems are visuals; thus, design aesthetics have been established as a significant predictor of user experience, user satisfaction, perceived usefulness, and trust (Chaouali et al., 2019; Ekpezu, Wiafe, & Oinas-kukkonen, 2024; Ramírez-Correa et al., 2018). Design aesthetics is a subjective evaluation of the extent to which a system is visually appealing to users. Visually appealing elements such as realistic and appealing color schemes, typography, layout, metaphors similar to real life, and prompts are elements that enhance computer-human dialogue support. Computer-human dialogue support comprises persuasive design features that facilitate target behavior performance. They provide relevant feedback and suggestions based on user behavior. Studies on conventional persuasive systems have shown a relationship between design aesthetics and dialogue support (Lehto et al., 2012).

Since the working mechanisms of these conventional persuasive systems are similar to the VR environment under study (i.e., the persuasive features), this study hypothesizes that:

H2a: Design aesthetics influence dialogue support in IVRLE.

A well-designed learning environment conveys expertise and trust. Students are likely to trust and rely on feedback and suggestions from an aesthetically appealing environment. The visual attractiveness of an environment may lead to a favorable appraisal of unobservable attributes within that environment. This effect is referred to as "what is beautiful is good" (Lee et al., 2011). This notion indicates that design aesthetics affect users' confidence and trust in a system. Persuasive systems enhance perceptions of trust, confidence, and reliability through the credibility support principle. Users' subjective evaluation of the information provided by a persuasive system as trustworthy and reliable has been shown to be dependent on their perception of the visual appeal of the system (Lehto et al., 2012). This relationship has also been observed on academic social networking sites (Koranteng et al., 2021) and student information systems (Ramírez-Correa et al., 2018). Hence:

H2b: Design aesthetics influence credibility support in IVRLE.

2.3 Primary Task Support and Cognitive Engagement

Primary task support enhances the effective performance of a specific task by reducing complex task into simpler tasks. It has been demonstrated to significantly impact individuals' subjective evaluation of their capabilities to perform a specific activity (Oduor & Oinas-Kukkonen, 2021), and this influences cognitive engagement (Vesga et al., 2021). Cognitive engagement refers to actions taken to optimize various thinking activities related to involvement and participation in learning tasks, including understanding, application, and problem solving. It reflects a student's willingness to invest efforts required to comprehend complex tasks and master difficult skills (Fredricks et al., 2004; Vesga et al., 2021). Students who are Cognitively engaged actively seek in-depth understanding rather than memorizing facts. They utilize learning strategies such as rehearsals, organizing, summarizing, and elaborating (Fredricks et al., 2004). Some of these learning strategies are reflected in the primary task support features.

An IVRLE may provide primary task support in the form of reduction, rehearsals, self-monitoring, and tailoring. These features can reduce the cognitive burden of deciphering a learning task to provide predefined learning goals and varying difficulty levels. They also deliver tailored content and guide students based on their cognitive abilities and performance. Primary task support features promote sustained cognitive engagement by allowing students to focus on a task without being overwhelmed. Hence, it is hypothesized that:

H3: Primary task support influences cognitive engagement in IVRLE.

2.4 Dialogue Support and Emotional Engagement

Dialogue support utilizes computer-human interactions to support and engage users to achieve their target behavior. It provides relevant cues and feedback that encourages students to engage in learning activities (Dabi et al., 2018). Virtual reality may provide dialogue support in the form of suggestions and reminders to perform a learning task, praise/rewards for progress made or for successful completion of tasks, a virtual teacher, or a replicate of a real-world learning environment. Since this support and feedback is most often provided in real time, it may provide students with a sense of personal investment and connection to the subject/learning task, which in turn enhances their motivation to learn. This leads to emotional engagement.

Emotional engagement is the cognitive reactions and affective connections between students, learning tasks/subjects, teachers (Fredricks et al., 2004; Reeve et al., 2020), and sometimes the learning environment. Although the relationship between dialogue support and emotional engagement is yet to be confirmed, it is envisaged that the provision of dialogue support in an IVRLE will impact students' emotional engagement. Thus, it is hypothesized that:

H4: Dialogue support influences emotional engagement in an IVRLE.

2.5 Learning Engagement and Perceived Enjoyment

Learning engagement encompasses three aspects: behavioral, cognitive, and emotional engagement (Fredricks et al., 2004). However, this study only examined cognitive and emotional engagement. Behavioral engagement is observable actions that may be challenging to accurately measure in a one-time study like this. Emotional engagement in a virtual reality learning environment involves leveraging the immersive nature of virtual reality to create experiences that elicit positive emotions, such as fun and pleasure (Mouatt et al., 2020). Cognitive engagement, on the other hand, is facilitated by realistic interactivity and multisensory experiences, including vision, hearing, and the tactile sensations that are provided by virtual reality (Khorasani et al., 2023). Notably, research suggests that interactivity significantly influences involvement and presence (Huang et al., 2021). In addition, the degree of student involvement in a learning task may vary. Possibly, this influences their levels of cognitive engagement, their antecedents to involvement (i.e., interactivity, presence, and immersion), and may evoke emotional engagement (Vesisenaho et al., 2019). When students are cognitively and emotionally engaged in a learning task, they invest the necessary efforts required to comprehend the task and build affective connections towards the task. This heightened cognitive and emotional engagement in the task may lead to an affective response to that task.

Although the impact of cognitive engagement and emotional engagement on perceived enjoyment has not been explicitly examined within an IVRLE, there is a relationship between engagement (encompassing the three aspects) and online class-related enjoyment (Zeng et al., 2023), and between student engagement and teacher enjoyment (Burić & Wang, 2024). Moreira et al. (2022) demonstrated that higher learning engagement significantly leads to higher perceptions of enjoyment, although they did not consider different forms of learning engagement. Thus, this study hypothesizes the following:

H5a: Cognitive engagement influences perceived enjoyment in IVRLE.

H5b: Emotional engagement influences perceived enjoyment in IVRLE.

2.6 Perceived Persuasiveness, Perceived Enjoyment, Credibility Support, and Learning Satisfaction

Perceived persuasiveness is an individual's subjective evaluation of the system's ability to influence them to perform a predefined behavior. It is measured by the presence of persuasive system design features. These features have been demonstrated to play significant roles in explaining customer satisfaction levels (Alhammad et al., 2021).

Learning satisfaction is the extent to which students perceive the learning experience to be fulfilling, pleasing, and satisfactory (Makransky & Lilleholt, 2018). It encompasses various aspects, including the quality of the instructions, course content, and overall learning environment. This study posits that more persuasive learning experiences will lead to higher levels of learning satisfaction. In addition, the more students perceive IVRLE as a valuable learning environment that can influence their learning behavior, the more their satisfaction levels will increase. Thus, it is hypothesized that

H6a: Perceived persuasiveness influences learning satisfaction in IVRLE.

Perceived enjoyment is students' affective response to a learning task or environment, reflecting fun, liking, satisfaction, and pleasure. When students are intrinsically motivated towards a learning task, they perceive it to be enjoyable and derive inner satisfaction after completing the task (Chen & Tu, 2021). According to Ryan and Deci (2000), intrinsic motivation is the drive to engage in a task for the satisfaction of doing so rather than as a means of obtaining a reward. Thus, it is assumed that when students find a learning task enjoyable, they derive higher levels of satisfaction from the learning task. This relationship has been demonstrated in serious games (Cheon et al., 2015), digital textbooks (Joo et al., 2017), and interactive virtual reality learning environments (Makransky & Lilleholt, 2018; Moreira et al., 2022; Yang et al., 2023). To affirm this relationship in IVRLE, we hypothesized that

H6b: Perceived enjoyment influences learning satisfaction in IVRLE.

Credibility support encompasses perceived trust, reliability, authority, verifiability, and expertise in the information provided by a system, in this context, the teacher, and the learning environment. These system features have been demonstrated to play a crucial role in user satisfaction levels across different domains, including e-commerce sites (Alhammad et al., 2021), mobile health applications (Handayani et al., 2020), and student information systems (Ramírez-Correa et al., 2018). Students are more likely to be influenced by feedback or suggestions from a teacher that they perceive as credible, professional (expertise), reliable, and trustworthy (Amerstorfer & Freiin von Münster-Kistner, 2021). This may impact their satisfaction levels. Indeed, persuasive system users are more likely to be satisfied with a system if they perceive that the information provided is verifiable and credible (Alhammad et al., 2021; Handayani et al., 2020). This has been demonstrated in educational information technologies or systems, such as learning management systems (Ohliati & Abbas, 2019), e-learning systems (Al-Fraihat et al., 2020), and student information systems (Ramírez-Correa et al., 2018). Thus, this study hypothesizes that:

H6c: Credibility support influences learning satisfaction in IVRLE.

3 Materials and Methods

3.1 Design of Immersive Virtual Reality Learning Environment (IVRLE)

An IVRLE that replicated the physical classroom in the university where the participants were drawn was designed for this study. A lecture session on a specific topic was recorded in the same physical classroom and rendered in the IVRLE. The dimensions of the real classroom environment were captured with precise measurements. The physical attributes of the classroom, including the height, width, and depth, were considered to accurately replicate these in the virtual model. Using the collected measurements, the physical classroom was recreated using Blender, a 3D modeling software. Foundational elements, such as walls, floors, and ceilings, were created to match the dimensions of the real classroom. This ensured that the virtual space mirrored the physical environment in terms of layout and scale to create a realistic experience for the participants.

To further enhance immersion, elements that were part of the actual classroom were replicated in the virtual environment. This included a projector with a whiteboard acting as a screen. The projector module was carefully placed on a table to ensure accurate representation. A video was superimposed onto the screen to mimic the actual lecture session, allowing participants to experience the lecture as if it were presented in the real classroom. After the design and modeling phase in Blender, the IVRLE was exported to Unity's Universal Render Pipeline (URP) to improve the visual quality of the environment. URP is known for its optimized graphics pipeline, which ensures high-quality rendering with improved performance. This step is crucial for achieving realistic lighting, shading, and overall visual fidelity in virtual classrooms.

A female lecturer was created using a 3D model. The virtual lecturer was animated to perform several gestures and actions typical of those of a real lecturer. This 3D character added a dynamic component to the IVRLE by enhancing the sense of presence and realism. Additionally, 3D characters representing students were strategically placed within the virtual classroom to simulate a more authentic class atmosphere. These characters were positioned to interact with audio components, such as sounds and reactions, contributing to the overall immersive experience. Audiovisual elements were incorporated to further enrich the experience. The original voice of the lecturer was synchronized with a 3D animated character. This added a layer of surface credibility. Ambient sounds, including student reactions and classroom noises, were embedded into the environment. This provides real acoustics of a classroom where students hear the lecturer and subtle sounds and interactions happening around them. Participants' positions were optimized by positioning them within the IVRLE to ensure a virtual representation of neither too far from nor too close to the projected screen or other critical elements of the classroom. This position is essential for maintaining a natural and comfortable experience, helping participants feel as though they are genuinely part of the environment. To facilitate immersion, Oculus Quest 2, a head-mounted display (HMD), was used. This provided a robust virtual reality experience with high-quality graphics and tracking capabilities. Refer to Figure 2 for snippets of the physical classroom (2a) vs designed environment (2b).

Figure 2: (a) Snippets of ongoing lecture in the physical classroom; (b) Snippets of ongoing lecture in the IVRLE

Persuasive system features were incorporated into the IVRLE to enhance students' perceptions of presence and other constructs to be measured during the study. This included fine-tuning various elements of the environment to create a persuasive and engaging experience that aligned with the intended educational outcomes. See Table 1 for examples of how these features were implemented in the IVRE.

3.2 Participants and Experimental Procedure

The study participants were third-year students of the Department of Computer Science at the selected university. Participants were invited to voluntarily participate in the study. One hundred and fifteen students, including 88 males and 27 females between the ages of 18 and 35 years, participated in the study. Refer to Table 2 for participant demographics. They learned about Global Citizen Education (GCE) and the role of university community engagement in the IVRLE.

Table 2: Participants demographics (N=115)

Demographics	Values	Counts (%)
Sex	Male	88 (76.52)
	Female	27 (23.48)
Age	18 to 25	111 (96.52)
	26 to 35	4 (3.48)
Participants who have heard of VR before the study	Yes	111 (96.52)
	No	4 (3.48)
Participants who have experienced a VR environment before the study	Yes	57 (49.57)
	No	58 (50.43)

The study participants were scheduled to attend the virtual reality sessions independently, and they came to the lab at their allocated time for the study. Upon arrival, the participants were required to read and sign an informed consent form. Before the virtual reality learning task (i.e., attending lectures in a virtual reality classroom), participants were encouraged to familiarize themselves with wearing the head-mounted headset and using hand controllers. To ensure that they mastered the controls and were comfortable with the head-mounted headset, they navigated within a pre-installed roller coaster game available on the meta-store for approximately five minutes. This was done to eliminate bias that may arise from confounding variables such as inexperience with virtual reality environments or motion sickness arising from wearing the head-mounted headset. No data was collected at this stage. After the familiarization exercise, the study participants attended a lecture in the IVRLE by wearing the Oculus headset.

Each virtual reality classroom session lasted for approximately 15 minutes, and at least one of the authors was always in the lab with the participants to ensure that the cable attached to the headset was not a tripping hazard. After completing the virtual reality learning task, the study participants completed an online survey that sought to capture their perceptions about the persuasive features, psychological outcomes, and learning satisfaction. This took approximately ten minutes. Each participant session (including familiarization, learning, and survey) lasted between 40 and 50 minutes. The scenes and activities associated with this study are shown in Figure 3.

3: (a) Snippet of IVRLE; (b) a participant experiencing the IVRLE

3.3 Measurement instruments

The questionnaire was designed using Webropol and administered in English. It was divided into two sections. The first section asked questions related to the ten constructs used in this study and was measured using a five-point Likert scale, with five representing strongly agree and one representing strongly disagree. Question items for each construct were adopted from prior studies and rephrased to suit the context of this study. Each construct was measured using a minimum of three questions. A full list of the question items and their sources is provided in Table 3. The second section included demographic questions on age, gender, and virtual reality experience.

4 Data Analysis and Results

The partial least squares structural equation modeling (PLS-SEM) analytic approach was used because of its ability to examine the relationships between dependent and independent variables. PLS-SEM analysis involves an assessment of the measurement and structural model. The R statistical computing language (version 2021.09.0) with an integrated development environment, SEMinR library was used.

To ensure the adequacy of the sample size for PLS-SEM analysis, we employed the 10-times rule. This rule stipulates that the minimum required sample size should be ten times the maximum number of arrowheads pointing to any construct within the proposed PLS path model (Hair et al., 2022). Referring to Figure 1, the maximum number of arrowheads pointing to a construct was three. Consequently, 10 times 3 equals 30. Based on this approach, the sample size for this study (N=115) surpasses the minimum required sample size of 30.

4.1 Measurement model assessment

Assessing the measurement model involves examining the suitability and robustness of the relationships between latent variables. It also involves measuring any correlations or co-variances among the ten latent variables. For reflectively measured constructs, studies recommend assessing the indicator loadings, internal consistency reliability, and convergent and discriminant validity with minimum threshold values of 0.708, 0.700, 0.500, and 0.850, respectively (Hair et al., 2022; Henseler et al., 2015). Table 3 shows that all indicator loadings were above 0.708, indicating that the constructs accounted for more than half of the variance in each item. Hence, there was a correlation between the construct and each of its question items (indicators).

Table 3: Question items and indicator loadings

Constructs	Items	Question items	Loads
UNOB (Lehto et al., 2012)	UNOB1	Using this learning environment fits into my daily life.	0.834
	UNOB2	Using this learning environment disrupts my daily routine.	0.907
	UNOB3	Using this learning environment is convenient for me.	0.829
DESA (Lehto et al., 2012)	DESA1	The screen (i.e., colors, layout, presenters) in this learning environment is attractive.	0.857
	DESA2	The general appearance of this learning environment is appealing.	0.938
	DESA3	This learning environment provides a nice visual experience.	0.890
PEPE (Lehto et al., 2012)	PEPE1	This learning environment has an influence on me	0.763
	PEPE2	This learning environment is personally relevant or me	0.876
	PEPE3	This learning environment makes me reconsider my learning habit.	0.874
PRIM (Wiafe et al., 2022)	PRIM1	This environment makes it easier for me to learn.	0.884
	PRIM2	This learning environment helps me in reaching my learning objectives gradually.	0.900
	PRIM3	This learning environment helps me in keeping track of my learning progress.	0.737

Constructs	Items	Question items	Loads
DIAL (Wiafe et al., 2022)	DIAL1	This environment encourages me to learn.	0.844
	DIAL2	There is a lecturer in the learning environment who supports me to achieve my learning objectives.	0.740
	DIAL3	This learning environment is similar to a physical classroom.	0.858
CRED (Wiafe et al., 2022)	CRED1	I consider this learning environment trustworthy.	0.786
	CRED2	I consider this learning environment believable.	0.768
	CRED3	I consider this learning environment accurate.	0.812
	CRED4	I consider this learning environment professional.	0.741
COEN (O'Brien et al., 2018)	COEN1	I made connections between new information and what I already know.	0.898
	COEN2	I was motivated to achieve a deep understanding of the lecture in this environment.	0.875
EMEN (O'Brien et al., 2018)	EMEN1	I feel a sense of excitement and enthusiasm when learning new topics.	0.761
	EMEN2	I find joy and pleasure in the process of learning.	0.875
	EMEN3	I feel a sense of personal investment and connection to the subject matter.	0.741
	EMEN4	I am eager to explore and learn more about the topics outside of this environment.	0.737
PECO (Chou & Liu, 2005)	ENJO1	I felt less pressure about the virtual reality learning model.	0.726
	ENJO2	The learning ambience in this learning environment was relaxing	0.834
	ENJO3	The learning ambience in this environment was enjoyable.	0.863
LESA (Chou & Liu, 2005)	LESA1	The learning experience with this environment was better than the software lab.	0.859
	LESA2	I was satisfied with the information acquisition in this environment.	0.763
	LESA3	I was satisfied with the overall learning effectiveness in this environment.	0.876
PRIM=primary task support, DIAL=dialogue support, CRED=credibility support, UNOB=unobtrusiveness, PEPE=perceived persuasiveness, DESA=design aesthetics, COEN=cognitive engagement, EMEN=emotional engagement, PECO=perceived enjoyment, LESA=learning satisfaction			

Internal consistency reliability was assessed using reliability coefficient (rhoA), Cronbach's alpha (CA), and composite reliability (rhoC). High rhoA values (above 0.700) indicate that the items within each of the ten constructs consistently measured the variables they were intended to measure. Similarly, the results for CA and rhoC were between 0.700 and 0.950. This indicates the absence of item redundancy (i.e., the question items are not similar to each other) and a possible bias in response patterns in the dataset. Figure 4 provides a visualization of the internal consistency reliability for all constructs.

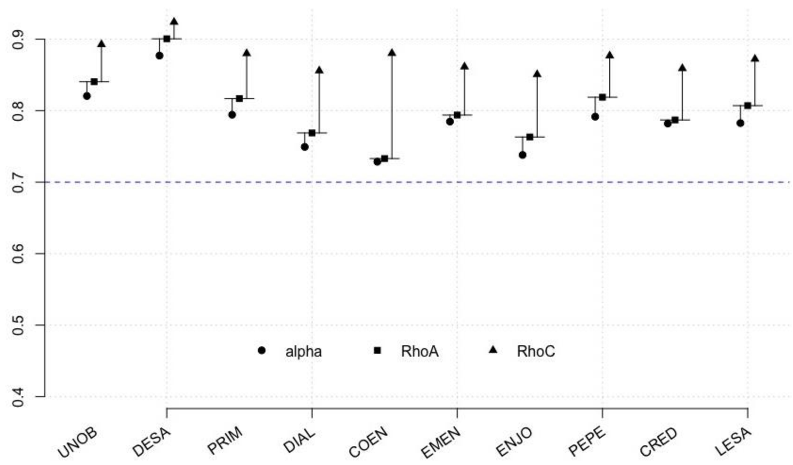

Figure 4: Internal consistency reliability (the horizontal dashed line indicates the common threshold value for the three reliability measures (i.e., 0.700)).

Convergent validity was assessed using Average Variance Extracted (AVE), while discriminant validity was assessed using the heterotrait–monotrait (HTMT) ratio of correlations. The results showed that all AVE values were above 0.500, and most HTMT values were below the conservative value of 0.850, while only two values were below 0.900. These results confirm that each construct is empirically unique and is not represented by other constructs within the model. Table 4 presents the convergent and discriminant validity values.

Table 4: Measurement model metrics

	UNOB	DESA	PRIM	DIAL	COEN	EMEN	ENJO	PEPE	CRED	LESA
UNOB										
DESA	0.580									
PRIM	0.825	0.488								
DIAL	0.668	0.612	0.872							
COEN	0.562	0.415	0.739	0.782						
EMEN	0.533	0.445	0.803	0.791	0.898					
ENJO	0.799	0.729	0.843	0.789	0.660	0.639				
PEPE	0.802	0.565	0.926	0.804	0.638	0.731	0.826			
CRED	0.663	0.578	0.677	0.697	0.594	0.589	0.732	0.614		
LESA	0.633	0.552	0.785	0.622	0.568	0.548	0.836	0.711	0.673	
AVE	0.735	0.802	0.711	0.665	0.786	0.610	0.656	0.704	0.604	0.695
VIF					1.879	1.879	1.953	1.770	1.526	

PRIM=primary task support, DIAL=dialogue support, CRED=credibility support, UNOB=unobtrusiveness, PEPE=perceived persuasiveness, DESA=design aesthetics, COEN=cognitive engagement, EMEN=emotional engagement, PECO=perceived enjoyment, LESA=learning satisfaction, AVE=average variance extracted, VIF=variance inflation factor

4.2 Structural model assessment

The structural model was assessed in four stages namely, an evaluation of: the collinearity of predictor constructs in relation to each endogenous construct, the relevance and significance of the structural paths, the model's explanatory power, and the model's predictive power. These evaluations were based on the threshold values specified in existing studies (Cohen, 1988; Hair et al., 2022; Shmueli et al., 2016).

The collinearity of predictor constructs was evaluated by assessing the variance inflation factor (VIF) values. According to (Hair et al., 2022), VIF values below 3.000 indicate that collinearity among predictor constructs does not exist. Table 4 shows that the VIF values met these criteria. These results indicate that the predictive constructs are not overly correlated with each other; hence, collinearity is not an issue in the model.

The next step involved an evaluation of the relevance and significance of the structural paths as well as their effect sizes based on 10,000 bootstrap subsamples. Path coefficients (β) closer to negative one indicate strong negative relationships, whereas those close to positive indicate strong positive relationships. The effect size (f^2) is similar to the size of the path coefficient. Based on Cohen (1988) criteria, f^2 values of ≥ 0.35, ≥ 0.15, ≥ 0.02, or < 0.02 are considered strong, moderate, weak, or irrelevant, respectively. For the exogenous constructs, unobtrusiveness had a strong positive impact (effect size) on both primary task support (β=0.684, f^2=0.881) and perceived persuasiveness (β=0.659, f^2=0.766). Design aesthetics had a moderate positive impact on dialogue support (β=0.484, f^2=0.305) and credibility support (β=0.486, f^2=0.309). For endogenous constructs, primary task support and dialogue support had a strong positive impact on cognitive engagement (β=0.567, f^2=0.474) and emotional engagement (β=0.613, f^2=0.602), respectively. Both emotional engagement (β=0.313,

f^2=0.074) and cognitive engagement (β=0.275, f^2=0.056) had weak impacts on perceived enjoyment. It was also observed that perceived enjoyment had a moderate positive impact on learning satisfaction (β=0.399, f^2=0168), while credibility support (β=0.201, f^2=0.051) and perceived persuasiveness (β=0.277, f^2=0.051) both had weak impact on learning satisfaction. Based on Cohen 's (1988) criteria, the model had four strong, three moderate, four weak, and zero irrelevant effect sizes. Thus, it can be concluded that the model has practical relevance. Refer to Table 5 for the effect sizes, significance, and relevance of path coefficients.

Table 5: Significance and relevance of path coefficients

Hypotheses	Path coefficients (β)	T – statistics	Effect sizes (f^2)
UNOB→PEPE	0.659	7.681	0.766
UNOB→PRIM	0.684	9.158	0.881
DESA→DIAL	0.484	4.985	0.305
DESA→CRED	0.486	5.581	0.309
PRIM→COEN	0.567	6.827	0.474
DIAL→EMEN	0.613	10.784	0.602
COEN→ENJO	0.275	2.979	0.056
EMEN→ENJO	0.313	3.211	0.074
PEPE→LESA	0.227	2.483	0.055
ENJO→LESA	0.399	4.850	0.168
CRED→LESA	0.201	2.224	0.051

A review of the results for statistical significance revealed several significant relationships at a 5% significance level and t-values greater than 1.960. This indicates that all the path coefficients for exogenous and endogenous constructs were statistically significant, and all hypotheses (H1a, H1b, H2a, H2b, H3a, H3b, H4a, H4b, H5a, and H5b) were supported (see Figure 5).

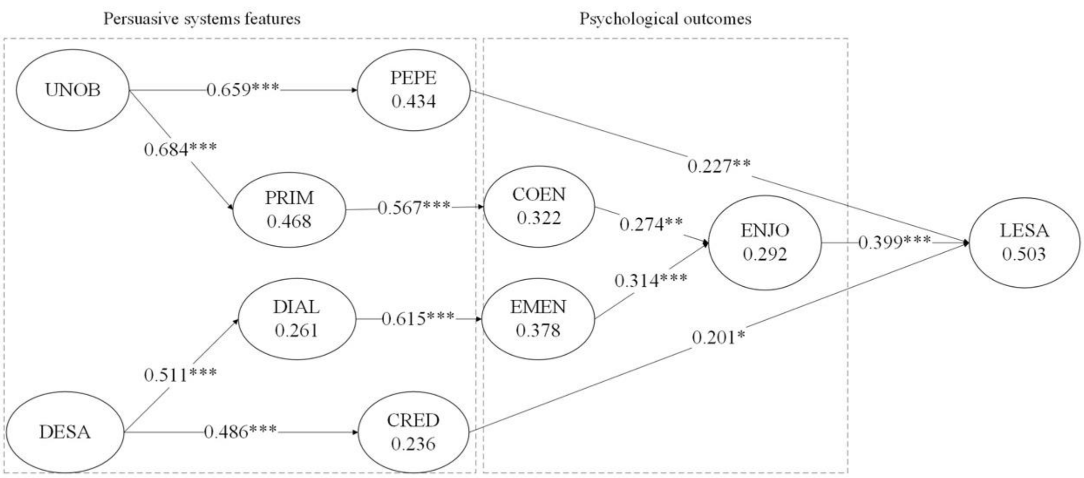

Figure 5: Structural model full path analysis (path significance: *p < 0.05; **p< 0.01; ***p < 0.001)

The model's explanatory power was evaluated by analyzing the R^2 values of the endogenous constructs. We followed the guidelines of Hair et al.(2022), R^2 values of 0.75, 0.50, and 0.25 were classified as substantial, moderate, and weak, respectively. As shown in Figure 5, the R^2 value of the endogenous outcome construct (i.e., learning satisfaction) is moderate. That is, over 50% of the variance in learning satisfaction was jointly explained by perceived persuasiveness, perceived enjoyment, and credibility support. This result suggests that developers and educators should focus on enhancing these features as a means of improving students' learning satisfaction.

Considering that all the constructs' measurement models achieved the specified threshold standards regarding reliability, convergent validity, and discriminant validity, the final stage in the assessment of the structural model was the evaluation of its predictive power. The PLS prediction procedure by Shmueli et al. (2016, 2019) was used to evaluate the predictive relevance of the model. A model's predictive capability for a construct is classified as high, moderate, weak, or none based on the PLS-SEM results. If the PLS-SEM results show a lower root mean square error (RMSE) or mean absolute error (MAE) for all constructs in the model, the model's predictive capabilities are said to be high; if the results show a lower RMSE or MAE for the majority of the constructs in the model, the model's predictive capabilities are said to be moderate; if the results show a lower RMSE or MAE for the minority of the constructs in the model, the model's predictive capabilities are said to be weak; and if the results show a lower RMSE or MAE for none of the constructs in the model, the model is said to have no predictive capabilities (Shmueli et al., 2019).

The PLS prediction algorithm was run with k-folds (10-folds) and (r = 1) repetitions using the direct antecedent (DA) approach. RMSE is preferred to MAE if the prediction errors are symmetrically distributed. Figure 6 shows that although the three plots representing the indicators of the dependent construct (learning satisfaction) have a left tail and are skewed to the right, the prediction error distributions are symmetric. Thus, the RMSE was used to assess the prediction errors.

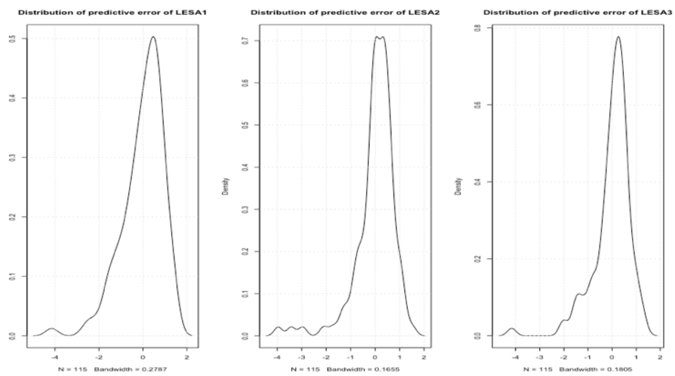

Figure 6: Distribution of prediction error for indicators of learning satisfaction (LESA1, LESA2, AND LESA3)

The final step is to compare the differences in errors for the out-of-sample based on the RMSE values. Table 6 shows the differences in prediction errors between the PLS-SEM path model and naïve linear regression model (LM). The results show negative values for the RMSE of the dependent variable (learning satisfaction), and this was observed for all constructs in the model (see Appendix A for full results). Since the PLS-SEM results have a lower RMSE for all constructs in the model, this indicates that the model used in this study has high predictive power and has the capacity to predict future results.

Table 6: Prediction metrics for selected construct items and the outcome construct items

PLS out-of-sample metrics												
PEPE 1	PEPE 2	PEPE 3	CRED 1	CRED 2	CRED 3	CRED 4	ENJO 1	ENJO 2	ENJO 3	LESA 1	LESA 2	LESA 3
0.778	0.735	0.722	0.847	0.819	0.901	0.825	0.932	0.911	0.830	0.934	0.829	0.767
LM out-of-sample metrics												

0.837	0.845	0.792	0.897	0.937	1.104	0.952	0.975	0.952	0.881	1.232	0.956	0.890
PLS out-of-sample metrics values minus LM out-of-sample metrics												
-0.059	-0.110	-0.070	-0.050	-0.118	-0.203	-0.127	-0.043	-0.041	-0.051	-0.298	-0.127	-0.123

5 Discussion and Implication of Findings

This study examined factors that influence learning satisfaction in an immersive virtual reality learning environment (IVRLE). Building on the persuasive systems design (PSD) model, this study integrated psychological outcomes into the model and examined the extent to which persuasive features (unobtrusiveness, design aesthetics, primary task support, credibility support, dialogue support, and perceived persuasiveness) and psychological outcomes (cognitive engagement, emotional engagement, and perceived enjoyment) impacted students' learning satisfaction. The model showed good explanatory power and high predictive power and provided support for all hypothesized relationships. Based on the high predictive power of the structural model, researchers and practitioners can rely on it to design effective educational interventions aimed at enhancing learning satisfaction and overall learning outcomes for students in tertiary institutions. This study contributes to the practice and theory of persuasive systems and IVRLE.

5.1 Theoretical implications

The primary contribution of this study is the theorizing and validation of a structural model based on persuasive system features to understand learning satisfaction within an IVRLE. Whereas extant literature has predominately used persuasive features in health behavior change support systems and focused on their impact on health behavior change, this study has shown the potential of leveraging persuasive system features and immersive virtual reality technology to improve students' learning satisfaction.

This study found that unobtrusiveness is a strong predictor of perceived persuasiveness and primary task support in an IVRLE. While prior research (e.g., (Lehto et al., 2012)) has confirmed these relationships on behavior change support systems, this study specifically establishes unobtrusiveness as a relevant construct in IVRLEs. This finding suggests that when an IVRLE is designed in a way that does not disturb or interrupt students when they are carrying out their primary task (i.e., learning), it will increase their favorable impression of the influence of the learning environment and enhance their performance of the primary task. For instance, an environment that guides students towards a desired learning behavior or outcome without being intrusive can be perceived as being effective in reducing complex learning tasks into simpler ones as well as persuading students compared to overt methods of persuasion.

Previous research (Lehto et al., 2012) has reported support for the hypotheses that design aesthetics influences dialogue support. This study further corroborates these findings by demonstrating a significant and positive impact of design on dialogue support. Although previous research has focused on web-based systems promoting healthy eating habits, this study extends knowledge to IVRLE. The findings suggest that when students find a learning environment to be visually appealing, they find the dialogue mechanisms to be effective and supportive in aiding their learning tasks. A well-designed virtual reality learning environment with clear and visually appealing virtual characters and elements, such as avatars with realistic body language and facial expressions, can create a more immersive and engaging dialogue experience. Thus, facilitating students' motivation to engage in positive learning behavior. Although findings from this study show that design aesthetics impacts dialogue support, Koranteng et al. (2021) argue that dialogue support impacts design aesthetics. Despite this discrepancy, these findings collectively indicate that there is a positive relationship between design aesthetics and dialogue support within environments that afford learning.

Additionally, this study confirmed that design aesthetics have a significant impact on credibility support. This finding has also been confirmed in previous studies (Chaouali et al., 2019; Koranteng et al., 2021; Lehto et al., 2012), although not in virtual reality. Findings from this study suggest that design aesthetics in virtual reality learning environments play a crucial role in shaping users' perception of credibility by enhancing the realism, authenticity, and trustworthiness of the content, computer-human interactions, and virtual characters. When students find a learning environment visually appealing, they evaluate the lessons taught in the environment as credible. Designing a learning environment with high-quality graphics, immersive audio, and a realistic avatar (in the form of a lecturer) can enhance students' sense of presence and realism, thus increasing the credibility of the information provided by the environment. Students are more likely to perceive the content as credible if they feel that they truly have a real-world experience in the virtual reality learning environment. In this study, the lifelike movements of the virtual teacher (which was a replication of a real-world lecturer), realistic facial expressions, and gestures may have provided a sense of expertise, authority, and credibility.

Virtual reality has been shown to significantly impact students' engagement in learning, particularly in cognitive engagement (Chen et al., 2023). This study showed that primary task support significantly influences cognitive engagement within an IVRLE. This indicates that when an environment provides students with the means to perform the learning task within the environment, it positively affects their level of immersion in the task, making them think actively and make connections between new and existing knowledge. While Makransky et al. (2019) argue that learning in an immersive VR learning environment leads to cognitive overload (i.e., more effort and increased frustration) and consequently poor learning outcomes, findings from this study posit that an IVRLE that affords primary task support features such as reduction, simulation, and tunneling can enable students to focus on the learning task without being overwhelmed by cognitive demands. Primary task support features reduce the cognitive load associated with using a system and help students overcome perceived burdens, efforts, and frustrations in engaging in learning tasks and positive learning behaviors. Reduction streamlines the learning experience, simulation provides a close to real-world realistic context while maintaining learning goals, and tunneling guides students through increasingly complex or challenging tasks. These features of primary task support collectively enhance cognitive engagement by directing students' attention to relevant content and activities within the virtual reality learning environment.

Virtual reality (VR) learning environments provide presence and immersion that can trigger emotionally engaging learning situations (Vesisenaho et al.2019). In this study, dialogue support was found to significantly impact emotional engagement within IVRLE. These results indicate that, to get students fully invested, motivated, and connected to a learning task within an IVRLE, the learning environment should not only afford presence or immersion, but also be brought to life with relatable characters/elements that enhance computer-human interaction. This is because the appearance and motion of virtual characters have a significant effect on emotional engagement (Mousas et al., 2018). The present IVRLE afforded several relatable characters and elements such as a classroom that imitates a real-world classroom that the study participants were familiar with (similarity) as well as a virtual coach (social role) with realistic voice, gestures, and facial expressions of the lecturer. These dialogue support features make the computer-human interaction more engaging and help students connect with the task emotionally.

Cognitive engagement and emotional engagement were confirmed to conjointly influence perceived enjoyment. These findings are consistent with those of previous research (Moreira et al., 2022). This indicates that a highly emotional and cognitively engaging virtual reality learning environment will increase students' perceptions of the fun and pleasure derived from learning activities within the environment. It is important to note that emotional engagement was found to be a stronger predictor of perceived enjoyment than cognitive engagement. This suggests that emotional engagement is more closely related to perceived enjoyment than other forms of learning engagement, and it plays a more important role in how much students enjoy the VR learning experience. Interestingly, this has also been confirmed in physical classrooms (Reeve et al., 2020). When IVRLE fosters positive emotions, such as excitement and joy, and uses emotional responses to reinforce positive learning behaviors (e.g., celebrating successes (praise) through positive feedback and suggestions, or providing real and engaging interactions), which are features provided by dialogue support, students are more likely to find the learning process enjoyable. By fostering positive emotions and creating close to real-life experiences, VR can transform learning from a passive activity into an enjoyable and engaging experience. Nevertheless, the positive impact of cognitive engagement on perceived enjoyment should not be overlooked. By reducing distractions (unobtrusiveness) and providing clear goals (primary task support) within the IVRE, VR affords students the opportunity to focus on the primary task, which leads to an enjoyable learning experience. Subsequently, there were high levels of learning satisfaction.

Among the direct determinants of learning satisfaction, perceived enjoyment was the strongest predictor of learning satisfaction. This is consistent with previous studies (Makransky & Lilleholt, 2018), indicating that perceived enjoyment is relevant for predicting learning satisfaction. Based on self-determination theory (Ryan & Deci, 2000), when students perceive learning to be enjoyable, it becomes intrinsically motivating rather than extrinsic. That is, students are more driven by their interest in the primary task, a desire to learn more, and the satisfaction derived from accomplishing the task and not extrinsic motivators such as rewards, good grades, or avoidance of negative learning outcomes. In addition to perceived enjoyment, perceived persuasiveness and credibility support also significantly influenced students' learning satisfaction. This indicates that students' affective response to the learning activity, favorable influence of the learning environment, and trust in the information provided by the environment lead to positive feelings of learning satisfaction.

This study also contributes to the understanding of the indirect determinants of learning satisfaction within IVRLE. Prior studies (Almulla, 2024; Chen et al., 2023; Salimon et al., 2021; Yin et al., 2024) suggest that technology acceptance features influence learning satisfaction via constructs such as emotional engagement, cognitive presence, higher-order thinking, and learning motivation. In this study, the results of the total effect (see Appendix) show that unobtrusiveness and design aesthetics indirectly contribute to learning satisfaction. Particularly, the significant total effect of unobtrusiveness on learning satisfaction suggests that unobtrusiveness in an IVRLE indirectly contributes to learning satisfaction through primary task support, perceived persuasiveness, cognitive engagement, and perceived enjoyment. Similarly, the significant total effect of design aesthetics on learning satisfaction suggests that design aesthetics indirectly contribute to learning satisfaction through dialogue support, credibility support, emotional engagement, and perceived enjoyment.

The findings from this study challenge existing studies that focus on technology acceptance. It expands the understanding of how persuasive system features in virtual reality can drive learning satisfaction. The findings suggest that persuasive features are not merely superficial aspects of the IVRLE but are intertwined with the cognitive and emotional processes that herness learning satisfaction.

5.2 Practical Implications

This study provides a better understanding of how and to what extent leveraging persuasive system features can influence psychological outcomes and how these relationships predict learning satisfaction within virtual reality learning environments. Findings from this study suggest that educators can leverage the full potential of persuasive system features when designing virtual reality learning environments. By prioritizing the integration of persuasive features (such as unobtrusiveness, design aesthetics, primary task support, credibility support, dialogue support, and perceived persuasiveness), educators can create immersive learning experiences that effectively engage students cognitively and emotionally, and subsequently, learning satisfaction.

The results of this study draw attention to two relevant means of impacting students' learning satisfaction within an IVRLE. The first is to design persuasive VR learning environments. That is, it is capable of changing students' learning behavior without force or deception. Second, it provides an enabling environment that affords a high level of learning engagement and intrinsic motivation. That is, to enable high levels of cognitive engagement, the learning environment must be unobtrusive and capable of reducing cognitive load. It should also be aesthetically appealing and capable of providing realistic computer-human interaction to afford emotional engagement.

However, the weak effect of credibility support and perceived persuasiveness on learning satisfaction, and cognitive engagement and emotional engagement on perceived enjoyment, suggests that better implementation of these features are needed to enhance their strength. In the current implementation, there was no feedback or direct interaction between the lecturer and students. Feedback in any form motivates students to engage more in the primary task (i.e., learning), and this enhances perceptions of the credibility of the environment and the information provided (Lehto & Oinas-Kukkonen, 2015). Lecturer-student interaction is also crucial for improving students' emotional well-being and affective responses (Xiao et al., 2023). Apart from listening to and watching the lecture, the students were not tasked with performing any other activities. Hence, although the lecture content was created with clear learning objectives, there was no form of assessment to determine the outcome of the lecture based on the cognitive levels of application, knowledge, and understanding. Since the students could not apply the lessons learned in the lecture to problem solving, this may have resulted in lower perceptions of cognitive enjoyment and a weak impact on perceived enjoyment. Therefore, a balanced approach is necessary for the implementation and utilization of virtual reality learning environments. While virtual reality learning environments are often designed to resemble real classrooms, they currently offer limited opportunities to create genuinely innovative and interactive pedagogical environments (Fowler, 2015).

6 Conclusion

This study examined factors that promote learning satisfaction within Immersive Virtual Reality Learning Environments (IVRLEs) using a structural equation model. The findings highlight the importance of unobtrusiveness, design aesthetics, primary task support, credibility support, dialogue support, and perceived persuasiveness in enhancing learning satisfaction within tailored IVRLE. Unobtrusiveness emerged as a strong predictor of perceived persuasiveness and primary task support; this demonstrates the potential of IVRLEs that are designed to be less obtrusive to influence students' impressions of the learning environment and promote performance of the primary task. The findings also emphasize the significant impact of design aesthetics, dialogue support, and primary task support on cognitive and emotional engagement.

However, while the findings provide valuable insights into the relationships between persuasive features, psychological outcomes, and learning satisfaction in IVRLEs, further studies are needed to explore the nuances of these relationships across different educational contexts and learner demographics. Also, this study primarily focused on the perceptions of students within IVRLEs without paying attention to the potential differences that may arise due to individual learning styles or preferences. Thus, further studies should be conducted to investigate how individual differences moderate the relationship between persuasive features and learning satisfaction.

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Appendix A: Prediction metrics for all construct items and the outcome construct items

PLS in-sample metrics

	COEN1	COEN2	EMEN1	EMEN2	EMEN3	EMEN4	CRED1	CRED2	CRED3	CRED4	DIAL1	DIAL2	DIAL3	DIAL4	PEPE1	PEPE2	PEPE3	PRIM1	PRIM2	PRIM3	LEEN1	LEEN2	LEEN3	LESA1	LESA2	LESA3
RMSE	0.649	0.698	0.645	0.666	0.758	0.708	0.827	0.799	0.884	0.801	0.795	1.05	0.888	0.862	0.755	0.715	0.697	0.722	0.74	0.755	0.91	0.895	0.802	0.907	0.81	0.74
MAE	0.505	0.532	0.488	0.514	0.619	0.54	0.659	0.6	0.698	0.612	0.605	0.853	0.707	0.682	0.58	0.557	0.555	0.53	0.574	0.582	0.671	0.66	0.609	0.695	0.534	0.521

PLS out-sample metrics

	COEN1	COEN2	EMEN1	EMEN2	EMEN3	EMEN4	CRED1	CRED2	CRED3	CRED4	DIAL1	DIAL2	DIAL3	DIAL4	PEPE1	PEPE2	PEPE3	PRIM1	PRIM2	PRIM3	LEEN1	LEEN2	LEEN3	LESA1	LESA2	LESA3
RMSE	0.665	0.716	0.657	0.688	0.772	0.73	0.847	0.819	0.901	0.825	0.816	1.063	0.9	0.876	0.778	0.735	0.722	0.736	0.762	0.772	0.932	0.911	0.83	0.934	0.829	0.767
MAE	0.516	0.546	0.495	0.531	0.631	0.557	0.673	0.612	0.707	0.63	0.619	0.864	0.717	0.691	0.597	0.568	0.572	0.534	0.586	0.592	0.69	0.673	0.633	0.715	0.549	0.537

LM in-sample metrics

	COEN1	COEN2	EMEN1	EMEN2	EMEN3	EMEN4	CRED1	CRED2	CRED3	CRED4	DIAL1	DIAL2	DIAL3	DIAL4	PEPE1	PEPE2	PEPE3	PRIM1	PRIM2	PRIM3	LEEN1	LEEN2	LEEN3	LESA1	LESA2	LESA3
RMSE	0.512	0.514	0.473	0.491	0.607	0.569	0.59	0.611	0.689	0.623	0.558	0.759	0.693	0.587	0.578	0.493	0.493	0.488	0.481	0.56	0.66	0.607	0.563	0.782	0.716	0.601
MAE	0.402	0.404	0.364	0.383	0.484	0.449	0.492	0.469	0.546	0.5	0.423	0.604	0.57	0.477	0.455	0.378	0.39	0.389	0.363	0.435	0.508	0.475	0.428	0.573	0.505	0.407

LM out-sample metrics

	COEN1	COEN2	EMEN1	EMEN2	EMEN3	EMEN4	CRED1	CRED2	CRED3	CRED4	DIAL1	DIAL2	DIAL3	DIAL4	PEPE1	PEPE2	PEPE3	PRIM1	PRIM2	PRIM3	LEEN1	LEEN2	LEEN3	LESA1	LESA2	LESA3
RMSE	0.752	0.799	0.708	0.695	0.961	0.894	0.911	0.935	1.119	0.968	0.835	1.101	1.054	0.935	0.848	0.79	0.804	0.703	0.741	0.82	0.981	0.976	0.881	1.234	0.963	0.906
MAE	0.593	0.628	0.526	0.539	0.736	0.703	0.711	0.707	0.816	0.748	0.632	0.856	0.83	0.728	0.659	0.573	0.606	0.55	0.556	0.635	0.744	0.738	0.655	0.922	0.713	0.647

Appendix B: Total Effects

The total effects provide an overview of the impact of the two exogenous constructs (UNOB and DESA) on the outcome constructs (LESA). All the paths were statistically significant.

Total Path	Path coefficients (β)	Bootstrap mean	Bootstrap SD	T Stat	2.5% C.I	97.5% C.I
PRIM→COEN	0.567	0.566	0.084	6.752	0.387	0.714
PRIM→LEEN	0.156	0.156	0.063	2.496	0.047	0.292
PRIM→LESA	0.062	0.062	0.029	2.155	0.017	0.128
DIAL→EMEN	0.613	0.62	0.057	10.797	0.505	0.726
DIAL→LEEN	0.192	0.202	0.069	2.762	0.074	0.348
DIAL→LESA	0.077	0.081	0.035	2.208	0.025	0.161
DESA→DIAL	0.484	0.483	0.097	4.98	0.277	0.656
DESA→EMEN	0.297	0.3	0.07	4.256	0.161	0.437
DESA→LEEN	0.093	0.098	0.041	2.264	0.028	0.189
DESA→CRED	0.486	0.49	0.088	5.541	0.31	0.651
DESA→LESA	0.135	0.142	0.048	2.837	0.054	0.24
UNOB→PRIM	0.684	0.69	0.075	9.178	0.533	0.816
UNOB→COEN	0.388	0.392	0.079	4.93	0.239	0.547
UNOB→LEEN	0.107	0.109	0.048	2.239	0.029	0.215
UNOB→PEPE	0.659	0.666	0.086	7.677	0.488	0.81
UNOB→LESA	0.192	0.196	0.065	2.937	0.068	0.325
COEN→LEEN	0.275	0.273	0.092	3.007	0.092	0.458
COEN→LESA	0.11	0.108	0.043	2.551	0.035	0.202
EMEN→LEEN	0.313	0.322	0.098	3.184	0.128	0.515
EMEN→LESA	0.125	0.129	0.051	2.459	0.042	0.241
LEEN→LESA	0.399	0.399	0.082	4.845	0.234	0.555
PEPE→LESA	0.227	0.23	0.091	2.48	0.045	0.397
CRED→LESA	0.201	0.21	0.09	2.238	0.032	0.385
PRIM=primary task support, DIAL=dialogue support, CRED=credibility support, UNOB=unobtrusiveness, PEPE=perceived persuasiveness, DESA=design aesthetics, COEN=cognitive engagement, EMEN=emotional engagement, PECO=perceived enjoyment, LESA=learning satisfaction						

Authors Bio

1. Isaac Wiafe is an Associate Professor of Information Technology at the University of Ghana. He is currently serving as the head of the Human-Computer Interaction research lab and has been researching human-computer behavior and persuasive technologies for over 15years.
2. Akon Obu Ekpezu is a doctoral researcher at the University of Oulu, Department of Information Processing Science. She is currently researching persuasive systems design and its impact on users' compliance, competence, and continuance intention in persuasive systems(including health and fitness apps and virtual reality fitness environments) that promote physical activity.
3. Dr. Gifty Oforiwaa Gyamera holds a PhD in Education Studies and serves as the official partner of the UNESCO Chair in Equity, Social Justice, and Higher Education. With extensive research and teaching expertise in Policy Studies and International Education, Dr. Gyamera has actively contributed to a wide range of national and international initiatives and programs.
4. Winful Fiifi Baffoe Payin holds a BSc. in Computer Science from the University of Ghana. He is currently a research assistant in the Human-Computer Interaction research lab of the same department. His research interest focuses on persuasive technology, virtual reality, and natural language processing.
5. Elikem Doe Atsakpo is an MPhil graduate of Computer Science from the University of Ghana. He is currently in the initial stages of pursuing a PhD in Computer Science. His research interest focuses on computers and human behavior, and how to visualize and communicate data from non-destructive testing using immersive technology for civil infrastructure and environmental asset monitoring.
6. Charles Nutrokpor is a Ghanaian researcher pursuing a PhD in Informatics and System Science at the University of Reading, UK. He has authored and co-authored publications on human-computer interactions (HCI), behaviour change, and persuasive technology. His current research focuses on artificial technology's impact on changing human behaviour within virtual reality.
7. Dr. Stephen R. Gulliver (PhD, DBA) is an Associate Professor (in Pervasive Informatics) at Henley Business School, University of Reading, UK. Stephen has published extensively in the fields of multimedia, human factors, human and business solutions development, information assimilation, education and learning, and systems acceptance.