UNIVQUAKE: SERIOUS VIRTUAL REALITY GAME ABOUT EARTHQUAKES IN UNIVERSITY SCENARIOS

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ABSTRACT. Conventional earthquake drills often fail to provide safe, realistic, and repeatable training for procedural knowledge. This limitation is particularly critical in high-density settings, such as university environments, where it is vital to be prepared in the event of such disasters. Virtual reality (VR) combined with serious games (SGs) provides an opportunity for users to experience and practice responses to such events within a controlled environment. This research describes the design, development, and validation of VR-based SG for earthquake preparedness. The primary objective was to assess the effectiveness of the SG in improving university students' knowledge of the measures to be taken in the event of earthquakes. The secondary objective was to analyze the correlation between the level of presence experienced in the SG and the knowledge gain. A pre-post study was conducted using a questionnaire validated by expert judgment to measure knowledge acquisition. The results demonstrated a statistically significant increase in participants' average knowledge scores after using the VR-based SG. Additionally, a noteworthy finding was that no direct correlation could be confirmed between the level of presence reported by the participants and the knowledge they acquired. This research concludes that VR-based SG are an effective technological tool for improving procedural knowledge in earthquake preparedness in university settings, even when subjective presence is not a significant factor in the learning process.

KEYWORDS: earthquake, virtual reality, presence, serious game, undergraduate

UNIVQUAKE: JUEGO SERIO DE REALIDAD VIRTUAL SOBRE TERREMOTOS EN ESCENARIOS UNIVERSITARIOS

RESUMEN. Los simulacros de terremotos convencionales a menudo no proporcionan una formación segura, realista y repetible sobre los procedimientos a seguir. Esta deficiencia es especialmente grave en entornos de alta densidad, como los universitarios, donde la preparación ante este tipo de desastres resulta fundamental. La realidad virtual (RV), combinada con los juegos serios (JS), ofrece la oportunidad de «vivir» y practicar las respuestas a estos eventos en un entorno controlado. Esta investigación describe el diseño, desarrollo y validación de un JS basado en RV para la preparación ante terremotos. El objetivo principal era medir la eficacia del JS para mejorar los conocimientos de los estudiantes universitarios sobre las medidas que deben tomarse en caso de terremoto. El objetivo secundario era analizar la correlación entre el nivel de presencia experimentado en el JS y la adquisición de conocimientos. Se llevó a cabo un estudio pre-post utilizando un cuestionario validado por expertos para medir la adquisición de conocimientos. Los resultados demostraron un aumento estadísticamente significativo en las puntuaciones medias de conocimientos de los participantes después de utilizar el JS de RV. Además, un hallazgo notable fue que no se pudo confirmar una correlación directa entre el nivel de presencia reportado por los participantes y los conocimientos que obtuvieron. Este estudio concluye que los JS de RV son una herramienta tecnológica eficaz para mejorar los conocimientos procedimentales en materia de preparación para terremotos en entornos universitarios, incluso cuando la presencia subjetiva no es un factor significativo en el proceso de aprendizaje.

Palabras clave: realidad virtual, terremotos, juego serio, presencia, universitarios

INTRODUCTION

Peru is part of the so-called Pacific Ring of Fire (Guardia & Tavera, 2012, p. 1), which means that the possibility of an earthquake is a constant risk in the country. This vulnerability is shared by other countries, such as Japan, which is considered an international reference in disaster risk reduction due to its effective strategies for managing such disasters (Pastrana-Huguet et al., 2022). In contrast, Peru faces challenges in fostering an effective culture of prevention and safety, as only approximately 55% of the population participated in drills during 2019 (Instituto Nacional de Defensa Civil [INDECI], 2020).

This vulnerability presents a critical risk for high-density populations. In 2023, Peruvian private universities had combined a total of over 1.5 million enrolled students (National Institute of Statistics and Informatics [INEI], 2023). Given the unpredictability of earthquakes, they can occur at any time, including during class hours. Therefore, this research focuses on undergraduate students, as preparedness on university campuses is a key factor in mitigating risks.

Currently, the primary preparedness tool used in this context is national drills. However, most earthquake drills lack sufficient effectiveness and realism. Consequently, students and administrators do not gain a truly realistic experience during these activities (Gong et al., 2015, p. 2242).

Given the need for simulated environments that provide a realistic experience of these events, a number of studies have proposed the use of new technologies, including VR, to recreate disaster-training scenarios at a lower cost and with significantly reduced risk compared to real-world exercises. This approach has proved to be useful in both educational and training contexts (Lu et al., 2020). Additionally, users must be able to learn from the simulation in an interactive and engaging way. According to Checa and Bustillo (2020), serious games (SGs) offer a student-centered educational approach with specific, well-defined tasks that enhance learning. Through this approach, students engage in an interactive and motivating process that will improve their overall, active, and critical learning. Therefore, the objective of this study is to design, develop, and validate a VR-based SG for earthquake preparedness in a university scenario.

The article is organized into three main parts. First, it introduces a review of the relevant literature from the last seven years related to the research proposal. Next, it describes the methodology proposed for this research. Finally, it addresses the experimentation conducted.

STATE OF THE ART

This section provides a compilation of articles on VR-based SG for emergencies, VR-based SG focused on earthquakes, and VR-based earthquake simulators. It also summarizes recent advances and identifies existing research gaps.

Serious Immersive and Non-Immersive Games for Emergencies

VR-based SG can support training for emergency scenarios and enhance individuals' chances of survival in highly hazardous situations (Irshad et al., 2021). Furthermore, VR technology offers an innovative approach to delivering this training in a scalable and resource-efficient manner (Rickenbacher-Frey et al., 2023). Table 1 presents a compilation of articles on the design, development, and implementation of VR-based SG for emergency situations.

Table 1

VR-based SG for Emergency Situations

Emergency	Subjects	I or N	Type of navigation	Scenario	Origin	Authors	Contribution / Gap
Rescue in confined spaces	20 regular workers and 20 special-ized workers	I	Limited to decisions	Inci-dent in Foshan, China	China	Lu et al. (2020)	Gap: Partici-pant cannot control movement
Flooding	55 volunteers	N	Open navigation via key-board and mouse	Urban buildings in Italy	Italy	D'Ami-co et al. (2023)	Contribution: Focus on safe routes and object interaction
Terrorist strike	32 volunteers	I	Teleporta-tion	University building	New Zealand	Lovreg-lio et al. (2022)	Contribution: University scenario
Fire	30 people aged 60 to 80	I	Teleporta-tion	Realistic residenc-es	China	Fu & Li (2023)	Contribution: Dynamic events
Fire	140 junior students	I	-	High-rise building	Taiwan	Chen & Chien (2022)	Contribution: Teaching situations based on levels
Fire	78 hospital staff mem-bers	N	Open navigation via key-board and mouse	Vincent Van Gogh Hospital	Belgium	Rahouti et al. (2021)	Contribution: Immersive experience positively affects "Presence"

Note. I = immersive, N = non-immersive.

VR-BASED SG FOR EARTHQUAKE TRAINING

Serious games in VR about earthquakes

Table 2 presents a compilation of articles that address the design, development, and implementation of immersive VR-based SG focused on earthquake preparedness training.

Table 2

Immersive VR-based SG for Earthquakes

Subjects	Type of navigation	Scenario	Origin	Authors	Contribution / Gap
91	Predefined	High school and office building	-	Feng, González, Mutch et al. (2020)	Contribution: 6-framework for customizable learning
93	Predefined	Fifth floor of Auckland City Hospital	New Zealand	Feng, González, Amor et al. (2020)	Contribution: Qualitative strategy for damages
147	Open using remote control	Shopping mall	-	Ahmadi et al. (2023)	Gap: No object interaction
42	Teleportation	Juvenile room	Greece	Maragkou et al. (2023)	Contribution: Interactive mechanics

The literature reveals a lack of studies that integrate natural locomotion systems with object interaction across different scenarios.

VR Simulators for Earthquakes

During this section, the reviewed literature uses VR to measure and observe participant behavior. For example. Zhang et al. (2021) developed a VR simulator to evaluate the safe actions people take during an earthquake in an office and in a room, aiming to understand people's behavior during an earthquake. Similarly, Mitsuhara et al. (2021) created a system to observe behaviors during the evacuation of people, highlighting the differences between a single-person and a two-person simulation. Their primary goal is to understand what people do in these types of emergencies.

On the other hand, the literature also focuses on the environmental replication of real scenarios. Xu et al. (2023) implemented a method using mixed reality where they scanned the simulation area and showed safe and dangerous zones where the participant should be located, highlighting the ability to represent an environment in VR. Also, Suzuki et al.

(2018) conceived an earthquake simulator that generates a copy of the indoor environment using artificial intelligence (AI) technologies and allows it to be projected into the VR world.

Meanwhile, other literature validates the educational impact. Rajabi et al. (2022) decided to evaluate the effect of VR education on decisions during an earthquake, using a classroom in Tehran as a case study. Liuwandy et al. (2020) explored an affordable way to conduct earthquake simulations in VR, creating an earthquake simulator that can be run on cell phones. Finally, Shu et al (2019) compared the presence and effectiveness of an earthquake simulator viewed on a computer screen with that of a VR headset. They concluded that VR simulators help people become familiar with earthquake simulations.

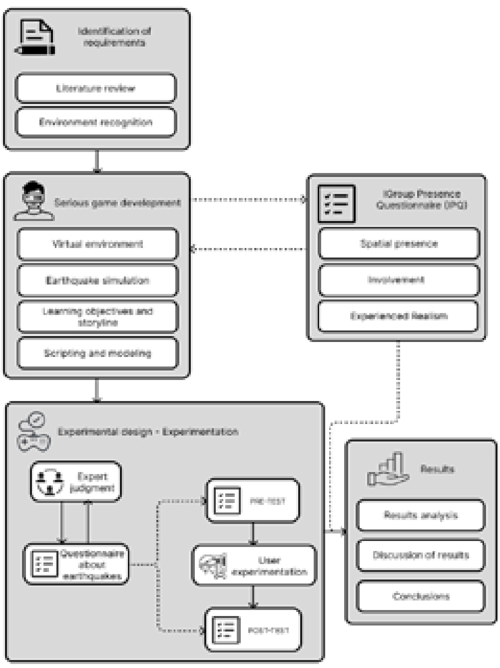
A review of the literature reveals significant deficiencies. We identified a short-coming in locomotion and navigation, with most applications opting for restrictive navigation methods. Secondly, physical interactivity is clearly limited. Current applications focus on decision-making rather than on interactions with the environment. Finally, reviewed simulators are primarily used for behavioral observation. This suggests an opportunity to gamify these simulations, transforming them into effective training tools.

3. MATERIALS AND METHODS

The methodology proposed for this research can be seen in Figure 1.

Figure 1

Methodological Scheme



Identification of Requirements

During the requirements identification process, the material provided by INDECI was reviewed, from which the relevant recommendations and instructions for these disaster scenarios were extracted. This information is essential for defining the learning objectives and developing the game's storyline.

As shown in Table 3, the learning objectives incorporate INDECI's recommendations for actions to be taken before, during, and after an earthquake.

Table 3

Learning Objectives During the Stages of an Earthquake

Stage	Learning objectives
Before an earthquake	• Identify safe areas • Prepare an emergency backpack • Keep exits clear of obstacles
During an earthquake	• Remain calm • Avoid falling objects • Stay away from windows • Go to safe areas or perform the "drop, cover, and hold on" procedure
After an earthquake	• Check your health and others' health • Do not use elevators • Cover your head during evacuation • Avoid returning to the building • Evacuate in an orderly and safe manner • Call emergency numbers, if necessary

Note. Learning objectives based on interviews and a review of official guidelines (INDECI, 2024).

Additionally, the learning objectives address other preparedness activities, such as identifying the essential items that should be included in an emergency kit: (i) water, (ii) canned food, (iii) coats, (iv) a flashlight, (v) a battery-powered radio, (vi) a whistle, and (vii) a first-aid kit. Furthermore, the objectives include identifying safe areas inside buildings in the event of an earthquake, such as (i) columns, (ii) life-triangle zones, (iii) areas away from glass or falling objects, (iv) doorways, (v) locations under beams, and (vi) areas outside elevator shafts (INDECI, 2024).

Regarding the recognition of environments, the approach taken by Xiao et al. (2017) was followed, in which the author proposed a complete review of the infrastructure of the environments. Classrooms L3-402 and O2-202 at the Universidad de Lima were selected for analysis and research, along with their respective evacuation routes and points of interest, due to the availability and accessibility of infrastructure data.

SG Development

During the development of the virtual environment, basic 3D models were used to create the buildings aiming to replicate reality as closely as possible, along with textures designed to simulate the surrounding environment. Several objects within the environments were sourced from Sketchfab (https://sketchfab.com/) and Unity Asset Store (https://assetstore.unity.com/). As seen in Figure 2, these models in the virtual classroom must exhibit physics, dimensions, and behaviors consistent with their real-world counterparts (Rajabi et al., 2022).

According to Lovreglio (2018), this study will use earthquake simulation using a qualitative strategy. This approach involves simulating the damage caused by the disaster without incorporating information about the structures in the simulated environment. In addition, this strategy was used because it is more suitable for designing a SG, as it allows threats to be represented strategically to enhance training effectiveness (Lovreglio, 2018). The Modified Mercalli Intensity (MMI) scale was used to choose the earthquake magnitude, as it aligns with the qualitative approach, based on work of Feng, González, Mutch et al. (2020). The scale chosen for this research is MM9, as this causes partial damage to buildings, total breakage of glass, and cracks in walls (Dowrick et al., 2008).

Based on Lu et al. (2020) and Rahouti et al. (2021), a story for the game is proposed using the scenarios and learning objectives (see Table 3). The story, which lasts approximately 30 minutes, consists of the following elements:

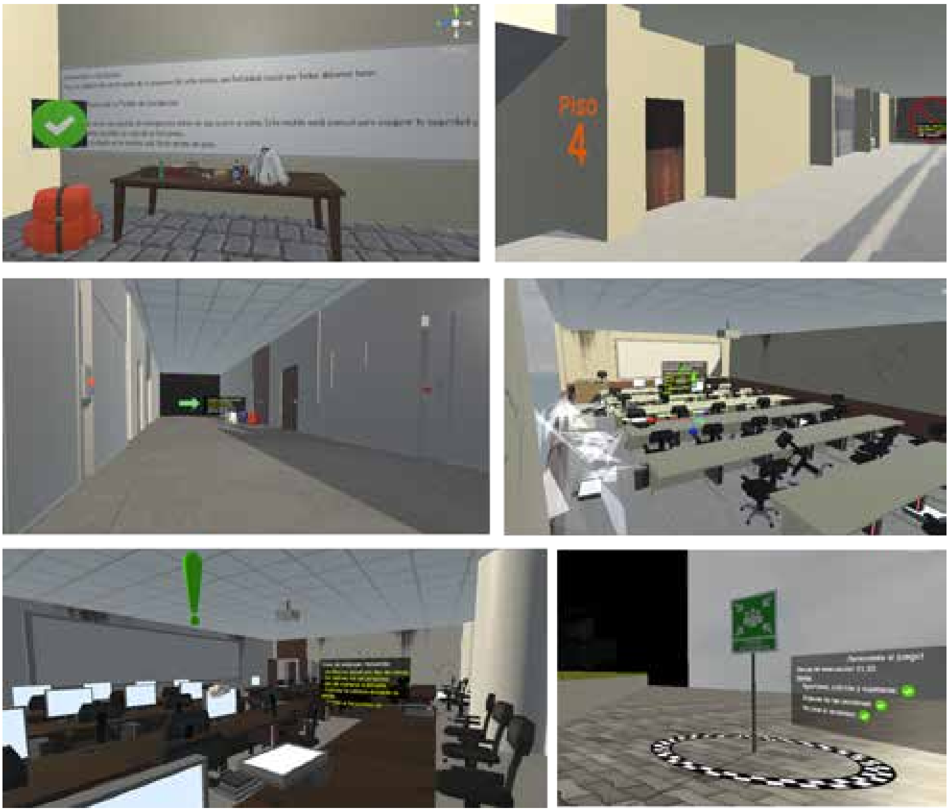
- At the beginning, participants must prepare their emergency kit before proceeding to their classroom.
- Participants begin outside their classroom building and are required to proceed toward it.
- During their journey, they must recognize safe areas and ensure that there are no obstacles along the evacuation route.
- When they arrive at their classroom and take their seats, an earthquake begins. Participants must remain calm and decide whether to take shelter under a table, move to a safe area, or evacuate as quickly as possible using the available controls. Depending on their choice, they may need to repeat this level.
- After the earthquake, participants must wait for any aftershocks or move toward the exit.
- During the evacuation, participants must avoid any objects that may fall or cause injury, while keeping their heads protected as a precaution.
- Once the evacuation is complete, participants must proceed to an emergency meeting point and call the emergency numbers, if necessary, to end the game.

They will also have the option to return to the building, in which case they will restart the level.

At the end of the game, the players will be provided with a report detailing their actions throughout the simulation, along with the total evacuation time (Figure 2).

Figure 2

Screenshots of UnivQuake



Note. UnivQuake scenes: "Emergency kit" (top left), "L3 hallway" (top right), "O2 hallway" (middle left), "L3 classroom after earthquake" (middle right), "O2 classroom after earthquake" (bottom left), and "Evacuation complete" (bottom right).

Unity Game engine was used to create the game, as this Integrated Development Environment (IDE) provides the audio, physics, and graphics tools required to create an enjoyable experience in a space in which users can freely navigate the virtual space (Ilongwe et al., 2023). Within Unity, version 2021.3.23f1 was used, along with the XR Interaction Toolkit, an interaction system for creating augmented and VR experiences through interactive objects that operate using Unity events (Unity, 2023).

Regarding the sounds implemented for the earthquake simulation, the audio files were sourced from Zapslat (https://www.zapslat.com/) and were used to illustrate the noises that occur during an earthquake.

During the development stage, a pilot test was conducted to measure the presence level of the SG using the Igroup Presence Questionnaire (IPQ), an instrument designed to assess the sense of presence experienced by users in a virtual environment. The IPQ consists of one general item and three subscales: (i) Spatial Presence, (ii) Involvement, and (iii) Experienced Realism (Igroup, 2016). This pilot test enabled adjustments to several presence-related aspects of the SG.

Questionnaire About Earthquakes

The questionnaire used in this research to measure knowledge consists of five open-ended questions related to the learning objectives, as shown in Table 4. The score for each question will be determined by the number of correct responses provided by the participants for that question. The use of this type of questionnaire is supported by De Fino et al. (2023), Feng, González, Mutch et al. (2020), and Lu et al. (2020). These studies use pre-test and post-test questionnaires, methodologically designed to measure the knowledge acquired through their respective SGs.

Table 4

Earthquake Knowledge Questionnaire

Questions	Score
What actions should you take before an earthquake?	• 3 points if you give 3 answers similar to the following options: (i) Pack your emergency kit, (ii) Identify safe areas in the building, and (iii) Ensure that there are no obstructions along the exit route. • 2 points for 2 similar answers out of the 3 options. • 1 point for 1 similar answer out of the 3 options. • 0 points if participants provide no correct answers.
What to do during an earthquake?	• 4 points if you give 4 answers similar to the following options: (i) Avoid falling objects or broken glass, (ii) Use the triangle of life, (iii) Stay calm, (iv) Go to the safe area inside. • 3 points for 3 similar answers out of the 4 options. • 2 points for 2 similar answers out of the 4 options. • 1 point for 1 similar answer out of the 4 options. • 0 points if participants provide no correct answers.

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Questions	Score
What to do after an earthquake?	• 8 points if you give 8 answers similar to the following options: (i) Check your health and/or that of others, (ii) Do not use elevators; use stairs, (iii) Leave in an orderly and safe manner without running, (iv) Cover your head while leaving, (v) Do not return to the building, (vi) Go to the meeting points, (vii) Follow INDECI information/stay informed, and (viii) Call emergency numbers, if necessary. • 7 points for 7 similar answers out of the 8 options. • 6 points for 6 similar answers out of the 8 options. • 5 points for 5 similar answers out of the 8 options. • 4 points for 4 similar answers out of the 8 options. • 3 points for 3 similar answers out of the 8 options. • 2 points for 2 similar answers out of the 8 options. • 1 point for 1 similar answer out of the 8 options. • 0 points if participants provide no correct answers.
What items should be included in an emergency kit?	• 7 points if you give 7 answers similar to the following options: (i) Water, (ii) Canned food, (iii) Warm clothing, (iv) Flashlight, (v) Battery-powered radio, (vi) Whistle, and (vii) First aid kit. • 6 points for 6 similar answers out of the 7 options. • 5 points for 5 similar answers out of the 7 options. • 4 points for 4 similar answers out of the 7 options. • 3 points for 3 similar answers out of the 7 options. • 2 points for 2 similar answers out of the 7 options. • 1 point for 1 similar answer out of the 7 options. • 0 points if participants provide no correct answers.
What are the safe areas inside a building in the event of an earth-quake?	• 6 points if you give 6 similar answers to the following options: (i) Columns, (ii) Life triangle, (iii) Away from glass or falling objects, (iv) Doorways, (v) Under beams, and (vi) Outside elevators. • 5 points for 5 similar answers out of the 6 options. • 4 points for 4 similar answers out of the 6 options. • 3 points for 3 similar answers out of the 6 options. • 2 points for 2 similar answers out of the 6 options. • 1 point for 1 similar answer out of the 6 options. • 0 points if participants provide no correct answers.

The questionnaire was validated by expert judgment. The scale used was the Content Validity Ratio (CVR) proposed by Lawshe (1975). The five questions were evaluated by twelve INDECI members, each receiving a CVR value of 0.80. Therefore, these questions are essential and were included in the questionnaire.

Participants

The target population consisted of undergraduate students who attended computer-equipped classrooms during 2024. The sample included 30 undergraduate students (25 male, 5 female), aged 20 to 25 years. All participants reported prior experience in computer-equipped classrooms. Consistent with Tavares (2022), the sample was familiar with digital interaction, as most participants are young individuals who frequently engage with digital technologies such as video games. Regarding the technology used in the study, only four participants reported prior experience with VR headsets.

Experimentation

To assess the knowledge of the measures to be taken during earthquakes, a quasi-experimental repeated-measures design was implemented. A pre-test using the proposed questionnaire was conducted to determine the participants' initial knowledge level. Subsequently, a post-test was conducted after participants completed the SG in VR.

To evaluate the presence experienced in the SG, the IPQ was used, as in the pilot test, since this instrument allows effective measurement of participants' sense of presence in virtual environments.

Additionally, the study aims to analyze the relationship between the level of presence experienced by the test participants and the improvement in knowledge of earthquake safety measures. To this end, a correlation analysis will be conducted between the IPQ scores and the differences between pre-test and post-test results.

The different hypotheses proposed are described below:

- Null hypothesis 1 ($H0_1$): There is no significant difference between the participants' knowledge before and after the SG test.
- Alternative hypothesis 1 ($H1_1$): There is a significant improvement in the participants' knowledge after participating in the SG.
- Null hypothesis 2 ($H0_2$): No significant correlation was found between the level of presence experienced in the SG and the improvement in knowledge of earthquake safety measures.
- Alternative hypothesis 2 ($H1_2$): A significant positive correlation was found between the level of presence experienced in the SG and the improvement in knowledge of earthquake safety measures.

To participate in the game, a device enabling immersive visualization of the virtual environment is required. Therefore, Meta Quest 2 headsets were used in the research, allowing for tracking of both head and hand movements.

For interaction with the virtual environment and free movement, the Touch controllers included with the headsets were used. Regarding sound stimuli, Logitech Astro A10 headphones were used during the experiment.

RESULTS

This section presents knowledge assessment results corresponding to Hypothesis 1. As shown in Table 5, the Shapiro-Wilk test was first applied to data to determine their normal distribution. The resulting *p* value for this test is reported in the "Normality" column. If the normality value was less than 0.05, the non-parametric Wilcoxon test was applied; if it was greater than 0.05, the paired t-test was used. Subsequently, the selected test was used to validate the existence of an improvement. The table compares these pre-test and post-test scores, where *M* is the mean score and *SD* is the standard deviation

Table 5

Earthquake Knowledge Questionnaire Results

Learning objectives	Pre-test	Post-test	Normality	*p* value	T- values/ W values	Statistical test
Before the earthquake	M = 1.53 SD = 0.68	M = 2.26 SD = 0.73	0.0003974	0.00005912	*W* = 9	Wilcoxon
During the earthquake	M = 1.86 SD = .77	M = 2.36 SD = .96	.0346	.009472	*W* = 39	Wilcoxon
After the earthquake	M = 1.53 SD = .77	M = 2.63 SD = 1.21	.04416	.0005698	*W* = 32.5	Wilcoxon
Emergency kit	M = 3.50 SD = 1.63	M = 5.36 SD = 1.09	.08104	.000001844	*T* = 5.6951	Paired t-test
Indoor safe zones in case of earthquakes	M = 1.23 SD = .77	M = 2.43 SD = 1.19	.02167	.0001014	*T* = 5.1739	Paired t-test
Total	M = 9.66 SD = 2.68	M = 15.06 SD = 3.12	0.2961	9.61E-10	*T* = 8.5727	Paired t-test

An improvement in knowledge was observed across all evaluated areas. In the assessment of knowledge prior to the earthquake, the mean score increased from 1.53 to 2.26, with a $p < .05$, indicating a significant improvement in knowledge levels. This effect may be attributed to the fact that this stage involved the greatest level of participant interaction with objects within the game.

During the earthquake knowledge assessment, this item showed the smallest increase, with the mean score rising from 1.86 to 2.36 and a $p < .05$. This could be caused by the fact that during this stage, participants were in distress due to the earthquake, which led them to focus on escaping the environment rather than performing the recommended actions. In the post-earthquake knowledge assessment, the mean score increased from 1.53 to 2.63, with a $p < .05$, which suggested a significant improvement.

The question related to the emergency kit showed the greatest increase in the mean score compared to the other questions. This effect may be attributed to participants' engagement with the activity of preparing the emergency kit. Finally, the assessment related to indoor safe zones during earthquakes showed an increase in the mean score from 1.23 to 2.43, with a $p < .05$, which suggested a significant improvement, even though the activity related to this assessment was addressed superficially. Our findings on knowledge improvement are consistent with those reported by Feng, González, Mutch et al. (2020) and Lu et al. (2020). However, these findings contrast with those reported by Ahmadi et al. (2023), who indicated that their post-game assessment did not show a significant increase in safety knowledge.

Hypothesis 2 proposes a significant correlation between the perceived level of presence and improved knowledge of earthquake preparedness measures. Spearman's correlation test was applied, given that the data from the knowledge questionnaire did not show a normal distribution across all objectives. These results did not show significant evidence between the two variables, with a correlation coefficient $\rho = 0.236$ and a coefficient of determination $r^2 = 0.0557$, implying that only 5.5% of the variability in knowledge can be explained by the overall level of presence. Therefore, Hypothesis 2 is not supported by the findings of this study.

CONCLUSIONS

The purpose of this research was to design, develop, and validate a VR-based SG for earthquake preparedness in university scenarios. The primary objective was to assess participants' knowledge, and the secondary objective was to analyze the correlation between the level of presence experienced in the SG and improved knowledge.

To this aim, two simulated environments were created in which participants could experience an earthquake and complete tasks before, during, and after the earthquake. The pre-post study used a questionnaire validated by expert judgment to measure knowledge.

A statistically significant increase in participants' average knowledge scores was observed after testing the SG. In addition, an important finding was that a direct correlation between the level of presence and the knowledge gain.

The importance of this work lies in the provision of a technological solution for earthquake risk management education in university settings and emphasizes the scientific value of VR SG in as an effective tool for disaster preparedness training.

One of the main limitations is the hardware processing capacity, which restricts the generation of more realistic scenarios and the inclusion of non-player characters.

These limitations provide directions for future research. Additionally, the implementation of immediate feedback is proposed to enable participants to identify and correct their mistakes in real time. It is suggested to include more activities that reinforce knowledge in stages and investigate which factors directly influence learning within VR.

In conclusion, this research validates VR SGs as a practical and effective tool for building procedural knowledge in disaster preparedness within university settings.

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