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Improving Engagement in Museums Through Virtual Reality Educational Escape Rooms (VREER): A Framework and Usability Study

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Abstract: This paper describes a framework to support the development of VR-based Educational Escape Rooms (VREER) that are based on real-world historical locations, such as museums and cultural sites. This framework facilitates the development of single-player escape room games, with support for capturing real-world places, environments, and objects to use in virtual settings, as well as defining hand-based interactions and inventory management with the said objects. We also describe the ongoing development of a VREER game based on a Philippine museum, built entirely using this framework. A preliminary usability study is conducted on this VREER game with the said museum's personnel, hoping to gain insights on the game's effectiveness with regards to motivating players to learn about the museum's exhibits and history.

Keywords: Virtual Reality, Authoring Tools, Educational Escape Rooms, Usability Testing

1. Introduction

The primary aim of artificial immersive experiences in education is to involve and motivate learners in the context or scenario, with multisensory affordances and interactions that may not be possible or fully utilized in the real world. One such type of artificial immersive experience is the Educational Escape Room (EER), which presents players with subject-related puzzles that, when solved, lead to a successful "escape" from a locked room—the player's desire to escape serves as extrinsic motivation to solve the puzzles, urging the player to learn about the subject matter. EERs offer an entertaining experience with a well-defined learning dimension (Botturi & Babazadeh, 2020). A review of general EER experiences (Veldkamp et al., 2020) found that escape rooms' various game mechanics and goals, such as short solving times and puzzle structures, align with the pedagogical strategies of lessons.

Our study recontextualizes museum-based educational experiences as a Virtual Reality-based Educational Escape Room (VREER) game. Compared to a physical escape room, VR-based escape rooms can be deployed anywhere, and interaction modes that are not possible or practical in the real physical location become available. Delicate museum objects can be interacted with virtually and safely. Such virtual interaction can also offer a digital-learning dimension, giving players additional information to investigate as they explore.

Virtual escape rooms have been evaluated for their educational potential in various subject areas. However, many of these use the term "virtual" in "virtual escape room" to refer to other types of virtuality instead of a fully immersive virtual world. For example, Prieto et al. (2021) investigated a teleconferencing-based escape room, while Dittman et al. (2021) used multi-section Google Forms. To our knowledge, the closest related work that discusses a general framework for virtual educational escape room games was by Clarke et al. (2017),

although this still does not use virtual reality. However, some studies have successfully implemented full-VR escape rooms for subjects such as biology (Christopoulos et al., 2023) and chemistry (Elford et al., 2021), pointing to the general viability of VREERs in education.

This paper presents the development of a general framework that can facilitate the authoring of multiple VREERs. We contextualize our framework through a proof-of-concept game for the Villa Escudero Museum, located in the Quezon province of the Philippines. The said museum is both a historical and cultural establishment, housing artifacts collected by Don Arsenio Escudero and his family from the early 1900s. These include various religious and folklore artifacts, as well as natural science, money, and weapon collections dating from World War II, which makes the museum a useful resource for multiple educational disciplines.

To ensure that we can situate potential users and learners of our application in an engaging and progressively motivating manner, we conducted a preliminary usability study of our VREER game with the staff of Villa Escudero Museum. The questionnaires were focused on VR-based usability through the lens of presence, and general game usability heuristics.

Our paper is divided into two major sections: a brief discussion of our framework's important components that supported the development of our VREER game, followed by the particulars of the usability study with the Villa Escudero Museum staff.

2. Framework Components

Our VREER framework runs on top of the open-source Godot engine (version 4 at the time of this writing) and facilitates world navigation authoring as well as object authoring (along with options for interaction and inventory management). These features are discussed in depth.

2.1 World Navigation Authoring

Our Villa Escudero VREER represents the real-world museum as one giant escape room. The game design divides the open-floor area of the museum into three sections: (a) the lower floor, (b) first half of the upper floor, and (c) the rest of the upper floor. The player can only navigate the first section at the start of the game, but the second and third sections progressively unlock as the player solves puzzles (refer to Figure 1 for the overall flow of the game). This tiered structure progressively builds the player's motivation to "escape"—early "escape victories" serve as positive feedback to the player, while the lessons and trivia learned from these earlier escape puzzles actually give the player the necessary information to solve the later puzzles.

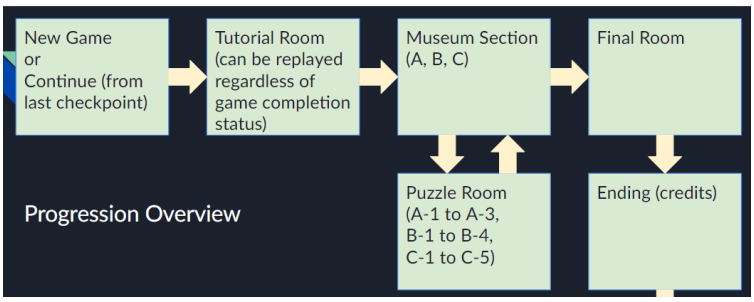

Figure 1. Progression flowchart of the Villa Escudero Museum game

While modeling every aspect of a museum environment in 3D provides the best realism, the scale of development becomes unmanageable for a small team modeling an entire museum. Thus, 360-degree photographs (such as those provided by Insta360 cameras) were used as the primary means of world representation in our framework. While this constrains the user to "static" point-of-view (POV) locations instead of six-degree-of-freedom (6DOF) movement, many VR users are nowadays accustomed and comfortable with navigating environments using simpler "teleporter"-style mechanics (Prithul et al., 2021), where "teleporter spots" are navigated to via a hand controller's trigger button (see Figure 2). Our navigation subsystem is supported by a teleport authoring tool that enables authors to specify

multiple POV locations and their graph-based connectivity (including any constraints to block the player from proceeding unless preconditions are met, e.g., possession of keys).

Figure 2. Teleporter mechanics. Left to right: normal; teleporter targeting (white line); teleporter engaged (red line, teleport will occur upon button release); teleport authoring tool

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2.2 Object Authoring and Interaction

The main highlight of our VREER game is to virtually replicate museum artifacts/objects whose public accessibility is limited, giving players the chance to examine and interact with these objects without damaging or deteriorating the actual objects on display in the real world.

The main disadvantage of using just the 360-degree photographs for this purpose is the lack of depth in the resulting photographs. To make up for this flaw, important objects at each static POV were individually captured using LiDAR scanning technology (see Figure 3). For the Villa Escudero VREER, the tour guides specified to the development team the important exhibits to highlight in the game; both LiDAR scans and reference photos were taken of these. To date, we have 19 game assets based on LiDAR scans of museum objects (with some cleanup/retouching applied based on the photos), as well as 9 manually remodeled assets that are based on but do not directly use LiDAR scans (e.g., the rightmost asset in Figure 3).

Figure 3. LiDAR scans (left) and corresponding final art assets (right).

Integral to the VREER experience is the ability to perform virtual hand-based interactions with the museum objects. The theory of Embodied Cognition suggests that bodily engagement during learning activities may significantly aid such learning (Skulmowski & Rey, 2018). Thus, our framework relies on an Object Interaction subsystem, previously described by Lee et al. (2023), where users may trigger events by orienting virtual objects with the controller, as well as perform additional or accessory actions/gestures (e.g., rotating the hand to perform a twisting motion). The three classes of actions featured in the previous work -- hit, twist, and lever – were expanded with additional interactions for wiping, connecting, and button-pressing actions (see Figure 4) to provide more interaction possibilities within the escape rooms.

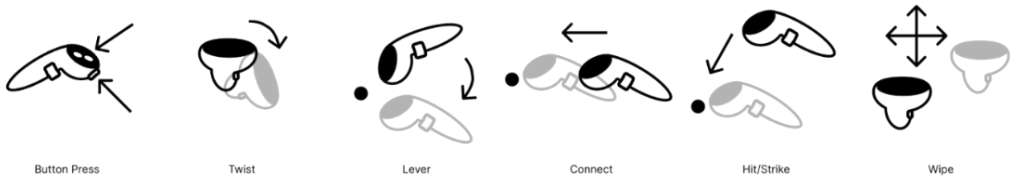

Figure 4. Interaction possibilities provided by our VREER framework.

To complement these hand interactions, a dedicated Inventory Management subsystem (Ko et al., 2023) allows players to transport items between the escape rooms. This subsystem provides five modalities that can be selected by a developer depending on the game genre or theme (see Figure 5, from left to right): Shelf (the most basic form), Magnetic Surface (items automatically “stick” to a planar surface when placed), Slots Anchored to Hand (mobile mini-

shelf that follows the user's hand), Wrist-based Stack (a more compact shelf representation), and Magic Box (a three-dimensional magnetic surface).

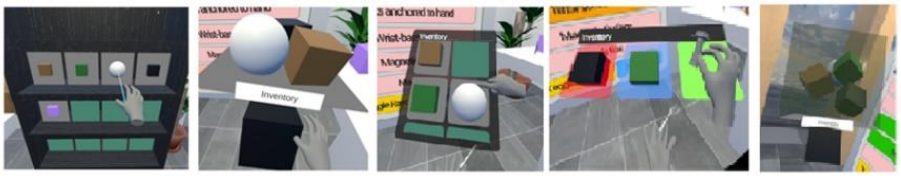

Figure 5. Five inventory system modalities available to VREER authors.

3. Usability Evaluation of the Villa Escudero Museum Game

It was decided to conduct a preliminary usability study with the museum staff of Villa Escudero so that we can obtain insight into whether the game can motivate museumgoers to learn more about the museum. This is because the museum staff inherently possess a curated, streamlined perspective of the museum exhibits. The staff are asked to fill in a self-assessment questionnaire before testing a beta version of the game. After playing, they were also asked to fill out two rating questionnaires, followed by long-form questions about their experience.

3.1 Self-Assessment

The testing involved 12 museum employees (5 female, 7 male) with an average age of 39.5 (youngest is 25, oldest is 56). Possibly due to this high average age, the average pre-existing play experience (see Table 1) is very low on a scale of 0 to 6. The questions also needed to be translated into Filipino as most of the museum employees do not speak English natively.

Table 1. Self-assessment results (answers are on a scale of 0 to 6)

Question	Ave.	Std.Dev.	Question	Ave.	Std.Dev.
Experience with VR	0.83	1.31	Experience with escape rooms	0.75	0.94
Experience with adventure games	1.58	1.91	Experience with Quest 2 VR headset	0.33	0.48

3.2 Igroup Presence Questionnaire

The Igroup presence questionnaire or IPQ (Schubert et al., 2001) determines four presence-related factors about a virtual environment: Spatial Presence, or the sense of being physically present in the Virtual Environment or VE (questions in yellow); Involvement, or the amount of attention devoted by the user to the VE (questions in blue); Experienced Realism, or the subjective experience of realism in the VE (questions in orange); and an overall General Presence rating (question in white). Table 2 reports the participants' averages.

Table 2. IPQ results (answers are on a scale of 0 to 6)

IPQ Question	Ave.	Std.Dev.
1. In the computer generated world I had a sense of "being there". (0 = not at all, 6 = very much)	4.75	2.14
2. Somehow I felt that the virtual world surrounded me. (0 = fully disagree, 6 = fully agree)	5.33	1.23
3. I felt that I was just perceiving pictures (0 = fully disagree, 6 = fully agree)	4.25	2.01
4. I did not feel present in the virtual space. (0 = did not feel, 6 = felt present)	4.83	1.80
5. I had a sense of acting in the virtual space, rather than operating something from outside. (0 = fully disagree, 6 = fully agree)	5.17	1.34
6. I felt present in the virtual space. (0 = fully disagree, 6 = fully agree)	5.25	1.22
7. How aware were you of the real world surroundings while navigating in the virtual world? (i.e. sounds, room temp., other people, etc.)? (0 = extremely aware, 6 = not aware at all)	4.33	1.50

IPQ Question	Ave.	Std.Dev.
8. I was not aware of my real environment (0 = fully disagree, 6 = fully agree)	4.17	1.90
9. I still paid attention to the real environment (0 = fully disagree, 6 = fully agree)	4.08	1.98
10. I was completely captivated by the virtual world (0 = fully disagree, 6 = fully agree)	5.64	0.81
11. How real did the virtual world seem to you? (0 = completely real, 6 = not real at all)	2.08	2.07

12. How much did your experience in the virtual environment seem consistent with your real world experience? (0 = not consistent, 6 = very consistent)	4.73	1.42
13. How real did the virtual world seem to you? (0 = about as real as an imagined world, 6 = indistinguishable from the real world)	2.75	2.05
14. The virtual world seemed more realistic than the real world. (0 = fully disagree, 6 = fully agree)	2.67	1.56

The per-question averages are subjected to the IPQ's computational guidelines, resulting in overall scores of (on a 0-to-6 scale): 4.75 for General Presence, 4.47 for Spatial Presence, 4.02 for Involvement, and 3.52 for Experienced Realism. We note the medium-to-high levels of spatial presence and involvement among the participants, which may indicate a generally positive level of player engagement. On the other hand, the mid-tier level of experienced realism deserves further investigation through the long-form question responses.

3.3 Game Usability Heuristics

A subset of the PLAY Game Usability Heuristics (Desurvire & Wiberg, 2009) was also used to determine the overall usability of the game. Selected heuristics on gameplay, immersion, and usability were asked of the participants (see Table 3). These preliminary results are subject to further analysis, but on the surface, they indicate high levels of gameplay and immersion, while the usability results had mid-tier scores with users feeling ambivalent about the unconventional VR controls and needing a manual/tutorial to play the game.

Table 3. Game usability heuristics results (answers are on a scale of 0 to 6)

Question	Ave.	Std.Dev.
Gameplay		
1. The game was fun, no repetitive and boring tasks	5.00	1.55
2. The game provided me clear goals for every task	4.67	1.87
3. The game world provides the player with a sense of control.	4.75	1.71
4. I felt safe while playing the game.	5.42	1.00
5. I felt some fatigue while playing the game	1.33	1.92
Immersion		
1. The game story is informative and encourages immersion	4.83	1.47
2. The game is educational and historically accurate.	4.92	1.31

Question	Ave.	Std.Dev.
Usability		
1. The controls are unconventional and hard to use.	2.58	2.11
2. I need to read a manual before playing the game.	3.67	2.46
3. The tutorial was necessary for me.	3.92	2.23
4. The tutorial gave me enough information.	5.08	1.24
5. The game provides me with enough help as to not get stuck in any level.	5.18	1.47
6. The screen layout is visually pleasing, the user interface is consistent, and the art is recognizable.	4.75	1.66
7. The objects in the game are recognizable and speak to their function.	4.58	1.83

3.4 Challenges and Potential

Since many of our participants are novices in VR, they did not have prior ideas of game controls and navigation, with one long-form response expressing confusion about the location of the teleporters from one room to another. However, once they were assisted in performing certain interactions, they were able to go through with the game. Also, this may have been their first time encountering the concepts of presence and immersion. Thus, the onboarding experience for forthcoming usability studies may require better tutorial examples.

Notwithstanding this observation, the IPQ results provide crucial insights into how we can develop our experience further. Realism is the most noticeable factor, and the long-form responses related this weaker score to various glitches (e.g., failure to pick up objects, objects falling off of the table). The possibility of testers immediately perceiving all things in VR as "unrealistic" cannot be ruled out, even when the scores of the other factors were higher. One interesting response from the participants noted that there should be more moving objects (e.g., trees, clouds), even if they are not necessarily interactable.

Even with these difficulties, the long-form responses revealed that the staff were still engaged with the game, citing many comments expressing amusement with the game's features. When asked regarding the educational value of the game, the participants said that

the game may be especially beneficial for the younger generation who are more familiar with immersive technologies and can, in turn, motivate them enough to visit the physical museum.

Conducting a usability study on this specific age demographic presented some advantages and disadvantages. On one hand, this study gives a good picture of the usability of the game with the general public who are still inexperienced with using VR headsets or immersive technologies; we, as developers, are still compelled to improve the features of the in-game interactions and make them more realistic. On the other hand, the results of this study may be quite different from younger participants who are not necessarily motivated to learn about the structure, contents, and significance of the museum as an educational and historical place. Thus, future usability studies should crucially include these younger participants.

4. Conclusion

Our ongoing work with VR Educational Escape Room experiences involves the creation of a flexible framework for escape room navigation and interactions. With various specialized tools, educators and developers can easily construct puzzles and educational content that can be realigned to many learning contexts and goals, with the escape room motif playing to the player's motivation to peruse and learn the content.

This initial implementation of our VREER framework and proof-of-concept game uncovered several important issues in the design of VREER experiences, such as the difficulty of capturing real-world spaces and objects to allow for their virtual representation, and the balancing act required to engage and motivate visitor demographics who are very interested in the museum itself but are not necessarily adept with new technologies, or vice versa.

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