Inclusive and Engaging Virtual Museum Experience for Children: A Usability Evaluation

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Abstract: This study explores inclusive and educational museum experiences in virtual environments for children. Virtual Reality (VR) enables adaptable scenarios tailored to users' needs, addressing cultural differences and sensory disabilities. Moreover, it encourages the creation of interactive activities, such as simulating object manipulation, enhancing immersion and engagement, as well as supporting the understanding of artistic concepts and history. In particular, this work presents the design and development of a virtual museum application, consisting of two phases: exploration and game. The virtual environment is customized based on the single user preferences and capabilities to ensure accessibility for diverse groups of children, facilitate an engaging and playful acquisition of information, and enhance interest in cultural heritage. A preliminary study on usability and engagement is also conducted.

1 INTRODUCTION

In recent years, advances in networking, graphics, and affordable acquisition devices have made Virtual Reality (VR) a powerful tool for education and cultural heritage experiences, revolutionizing how knowledge can be acquired in an enjoyable manner.

For instance, VR allows museum visitors to immerse themselves in digitally reconstructed environments, interacting with historical artifacts and cultural sites engagingly. Indeed, visitors are not passive; they have the freedom to explore and be active participants as they can create their own virtual tour and paths (Styliani et al., 2009), without the limits of time and space. In this way, the educational mean provided by museum can be fully exploited. Moreover, virtual exhibitions can display assets that are normally not visible in the physical museum, stored in deposits due to space limitations or fragility, or artifacts from different museums can be collocated together. The exclusive interaction with virtual assets enhances presence and engagement, fostering deeper emotional and cognitive connections. VR is especially valuable for school visits, making cultural heritage more interesting and engaging. By merging gaming with interactive learning, it transforms education into a dynamic, playful experience that sparks curiosity and creativity (Bossavit et al., 2018).

A key aspect of the success of VR visits, particularly for children and schools, is the possibility of adapting the experience to meet the diverse needs of users. Social inclusion plays a crucial role in this context, as accessibility to technology and content must be ensured for everyone, regardless of physical or language abilities especially in multiethnic environments characterized by strongly different cultural backgrounds. Adaptive technologies, such as the ability to customize navigation or include visual and auditory aids, are essential to ensure that every child can actively participate and enjoy the experience. By incorporating playful features or quiz games, virtual exhibitions can attract a wider audience and cater to various learning preferences, strengthening the connection between cultural heritage, schools, and entertainment (Bossavit et al., 2018).

The work presented here exploits works carried out within the House of Emerging Technologies Genoa "Digital Factory for Culture" project and extended within the PNRR RAISE Project (Robotics and AI for Socio-Economic Empowerment), Spoke 1 (Urban Technologies for Inclusive Engagement), which focuses on developing inclusive tools to enhance the quality of life of citizens through technology and AI. In this context, an immersive virtual mu-

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seum visit experience followed by a mini-game centered on the explored cultural assets is being developed to support primary school students, aged 8 to 11 years, in complementing history learning. The work addresses the main research question: how to create inclusive and educational museums in VR? Therefore it has two primary objectives: inclusion and engagement. Inclusion and accessibility are tackled by developing methods to adapt the virtual environment and information presentation to meet the diverse capabilities and preferences of users. To improve engagement, a short game and the possibility to interact with artifacts are included. While accessibility is needed to allow a complete experience to a wider range of users to overcome physical and cultural barriers, engagement is crucial for increasing interest in cultural heritage and improving learning outcomes.
To ensure an experience that tackles as much as possible the major difficulties in an educational context, the application is developed with the collaboration of a primary school characterized by a hight percentage of children of diverse nationalities, where varying language and physical abilities are present. The educational personnel highlighted how virtual experience like this can play a crucial role in promoting integration and providing access to cultural experiences that may otherwise be out of reach for some students. Before introducing the tool into education settings, we conducted a preliminary evaluation of the application's usability, that represents the contribution of this work. The evaluation focuses on the ease and intuitiveness of setting up the scene prior to the exploration and game phases, the naturalness of interaction with the virtual world, and the overall engagement of the visit.

The paper is organized as follows: Section 2 overviews most pertinent efforts in accessible and inclusive VR and educational gaming. Section 3 describes the proposed virtual museum experience, while its main features for inclusion and engagement are outlined in Section 4. The experiments for the system usability evaluation are discussed in Section 5. Conclusions are provided in Section 6.

2 RELATED WORKS

To provide an enjoyable entertainment and learning experience for all visitors, including people with disabilities, virtual museums must not only be accessible, but also inclusive: they must provide greater equality and cultural and learning opportunities for all social groups (Caldarelli et al., 2022). In this perspective, several works have addressed various aspects related to accessibility for VR applications (Dudley et al., 2023) in general, and to virtual museums and cultural heritage, in particular.

While some guidelines exist for physical museums and web applications considering universal design principles since several years, only recently guidelines emerged for VR applications, such as those indicated by the W3C consortium (W3C, 2021) and by the XR association (XRA, 2020). Principles of universal design have been reviewed against VR technologies for game development by Dombrowski et al. (Dombrowski et al., 2019). Rojas et al. (Rojas et al., 2020) consider Web Content Accessibility Guidelines 2.1 for the development of a web virtual museum. Several works have been devoted to provide VR access to people with vision problems, generally creating non visual VR with audio and haptic feedback or providing visual and audio augmentations (Picinali et al., 2014; Zaal et al., 2022; Zhao et al., 2019). Additional efforts have been made to address children disabilities or special educational needs (Carreon et al., 2022; Campitiello et al., 2022; Chițu et al., 2023) with main emphasis on autism spectrum disorder, but no real effort has been devoted to adapt the virtual environment to children needs in virtual museum exhibition context to effectively make information and data easy accessible.

From the engagement and educational point of view, to reach a broader audience and involve young people more effectively, making them active participants and more motivated to acquire information, activities such as educational games are often proposed (Theodoropoulos and Antoniou, 2022; Mortara et al., 2014). Different interactive games have been presented in the last years (Liu et al., 2021; Shackelford et al., 2018), as well as guidelines for designing educational games to support the learning of abstract artistic concepts have been outlined (Bossavit et al., 2018; Tsita et al., 2023).

However, the intersection of cultural diversity, physical impairments, and digital games, considered collectively, remains largely unexplored in this area of research, with only a few studies addressing these aspects (Lee et al., 2020; Tillem and Gün, 2023).

The work here presented aims to address this intersection while focusing on the ability of systems to adapt to individual user needs and preferences. In fact, the development of customized interaction methods to enhance user engagement is crucial (Bekele and Champion, 2019). This perspective aligns with the various research outcomes and the XR and accessibility challenges indicated by W3C (W3C, 2021) and the innovative "design-for-one" philosophy, which prioritizes creating personalized experi-

(a) Exploration phase.

(b) Game phase.

Figure 1: 3D reconstruction of the Oriental Art Museum E. Chiossone where the two phases of the application take place.

ences tailored to each user's specific requirements, rather than adopting a universal design approach.
Therefore, in our virtual museum application, we are considering various settings, interactions and rendering capabilities adjustable according to the user characteristics and preferences. In particular, we focus on some criteria that have been indicated to be fundamental to satisfy the accessibility needs of various disabilities and user characteristics. They include: easy to read and understand information, use of audio/video in addition to text, different and easy navigation methods, easy reachable interactable elements.

3 APPLICATION OVERVIEW

In this section, we provide a general overview of the system, highlighting how it has been developed for educational purposes, structured into two distinct phases, namely *exploration* and *game*, and how the virtual environment has been designed to offer an inclusive and engaging experience.

The environment features digital copies of rooms and artifacts from the Oriental Art Museum E. Chiossone in Genoa. Specifically, the real artifacts have been acquired using photogrammetry and 3D processing software, resulting in the 3D models incorporated into the scene. Most of the artifacts are remains located in the Museum deposit, usually not exhibited due to their fragility of even for space limitation.
Both the exploration and game phases take place within a simplified 3D reconstruction of the museum (Figure 1), specifically the BIM model of the building created from a laser scanner survey.

3.1 Exploration Phase

When the application starts, the user is immersed in the virtual museum. Before the scene is fully rendered, certain variables must be initialized, which will be discussed in detail in the next section (see Section 4). Inside the first-floor room, six pedestals hold artifacts from Japanese history. Each pedestal is equipped with two interactive buttons: one for displaying text and another for playing audio information about the artifact (Figure 1a).

The user can freely navigate the virtual space, observing and examining the artifacts in any order and manner he/she prefers. However, he/she must explore all displayed objects by either reading or listening to the provided information, clicking at least one of the buttons. This step is essential for acquiring knowledge about the objects, their functions, usage, and historical significance, preparing the user for the subsequent game phase where comprehension will be tested. There is no time limit, allowing children to interact with the objects freely, fostering engagement and enjoyment while learning. Throughout the visit, users can grasp and scale the artifacts for closer inspection, enabling them to examine fine details that might be overlooked at their original size. This interaction not only enhances engagement but also deepens understanding.

Once all objects have been examined, the option to proceed to the game phase is unlocked. A colored cube with a question mark appears at the empty side of the room, where the user must go to enter into the new scene.

3.2 Game Phase

The game phase is designed to evaluate the effects of using VR visit on the comprehension of the concepts acquired during the exploration phase.

At the start of this phase, a new scene is loaded. The scene variables are inherited from the exploration phase, ensuring consistency and eliminating the need for reconfiguration. The user finds himself/herself in the previous museum room, where pedestals and artifacts have been rearranged. All previously encountered artifacts, along with additional objects featuring similar functions but differing in characteristics and historical periods, are randomly placed on tables in front of the user. Three empty pedestals are presented, each equipped with an already visible text panel and an audio button (Figure 1b). Instead of the previous descriptions, the text now presents riddles that hint at the functionality or unique details of the associated object. The user must match the correct artifact from the tables to its corresponding pedestal based on these clues. If the user correctly places an object, the pedestal changes to the pre-selected color for correct answers, indicating that the object is properly positioned and can no longer be moved. If the placement is incorrect, the pedestal changes to the designated incorrect answer color, the object remains interactable, and the user is prompted to try again.

Once all objects are placed correctly, the game ends and a final panel appears displaying the total number of attempts made.

4 FEATURES FOR INCLUSION AND ENGAGEMENT

In this section we deeply discuss the variables and the features that characterize the provided system in terms of inclusion and engagement for a heterogeneous group of users.

In this regard, the scene setup depends on some variables that are initialized based on user-specific parameters, which may be cultural or physical.

Currently, some information is directly requested from the user before populating the museum scene through intuitive questions. Among these, the language preferred and presence of color blindness. Other data, such as the user's height, is automatically detected via headset positional data. As for engagement, natural interactions are provided to deal with virtual objects.

4.1 Scene Customization

In the following the scene variables and their initialization according to user-specific parameters are described in detail.

Language. The language barrier can significantly impact the understanding of the exhibited artifact with its cultural, historical and artistic value, thus limiting both the didactical and the enjoyment values. Information is typically presented in the local language, often with only an English translation available. This can be especially challenging for children, who may struggle to follow explanations or understand displayed text, leading to frustration and reduced engagement. To enhance inclusion and integration, our VR system offers a multilingual option, including less common languages, ensuring a more accessible and personalized experience. Language selection is the user's first action, as it defines the format of all communicative content (text and audio) within the scene. This process is designed to be intuitive and text-free. When the application starts, a central panel displays a world map divided by continents, each with an interactive button (Figure 2a). After selecting a continent, a second panel appears, showing country flags labeled with their official language (Figure 2b). This dual-reference system, using both images and text, prevents confusion, particularly for users with color blindness. Once a flag is chosen, all text and audio are automatically provided in the selected language.

The multilingual translation and text-to-speech conversion is managed by an asynchronous translation tool we have developed in Python that leverages two key APIs: Google Translate and Google Text-to-Speech.

This approach is crucial for improving understanding, especially considering the subsequent game phase, where initial comprehension is fundamental to foster engagement and learning.

Color. Despite the significance of color blindness issue, it is often overlooked in the design of VR experiences. It becomes particularly problematic in games that rely heavily on color to convey important information or differentiate between game elements. VR, however, offers the potential to overcome this limitation by enabling the customization of color schemes, making the experience more inclusive and accessible to a wider range of users. For instance, in many VR applications, buttons and user interfaces change color to provide feedback on activation or deactivation, with green and red commonly used for this purpose. However, this color combination poses a challenge for individuals with color blindness. To address this, after language selection, we provide users with an interactive panel where they can choose a distinguishable color pair (Figure 2c). The first color represents positive feedback (e.g., object activation, correct answer), while the second indicates negative feedback (e.g., object deactivation, wrong answer). The panel presents primary complementary color pairs, along with options that incorporate different textures, selected based on an analysis of studies on color blindness (Tillem and Gün, 2023). The inclusion of textures further increases the likelihood that every user can identify at least one suitable pair, ensuring a more accessible and inclusive experience.

Objects Positioning. The need to adapt the height of objects and ensure they are comfortably reachable emerged during the testing of an earlier application. In that initial version, the tailoring of the virtual environment was not yet implemented, which resulted in usability challenges, particularly for children. These

(a) Continent selection. (b) Language selection. (c) Colors selection.

Figure 2: Panels for language and colors selection for the scene customization.

findings highlight the importance of dynamic scene customization to enhance accessibility and provide a more inclusive and enjoyable experience for all users. In the here proposed application, this operation is carried out automatically at the start of the game. It is done taking into account the environmental mapping characteristics of Meta Quest and the standard human body proportions. The idea is to set the top of the pedestals at the height of the user's elbows to make the objects well visible and graspable and the buttons easy to press. According to human body proportions, the total height of a person is 8 times the head, and elbows are at a height of 5 heads from the ground. We estimate the player's height by measuring the height of his eyes thanks to the Meta Quest camera features and we compute the elbows positions according to the above proportions.

4.2 Interactions and Content Fruition

Currently the above information are all those requested by the user to customize the experience. In addition to those characteristics, various methods are offered to perform specific operations in a natural, inclusive, and engaging way. For example, various locomotion techniques are provided, along with the possibility to naturally interact with virtual objects, and the option to either read or listen to the provided information content.

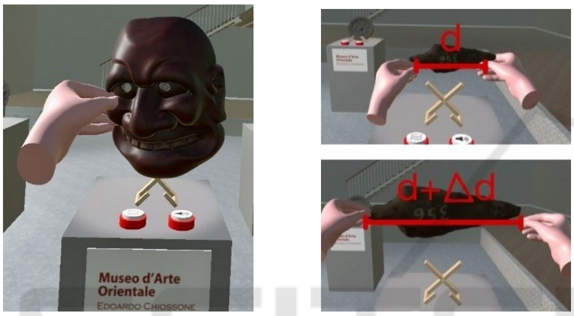
Locomotion Techniques. Navigating a virtual environment is crucial for immersion in VR, but poor implementation can lead to discomfort or motion sickness. This study presents a methodology that adapts to user preferences, reduces stress, and ensures accessibility for individuals with varying physical capabilities, including those with limited mobility. The application features two validated locomotion techniques: natural and semi-natural (Bonino et al., 2024). The first technique emulates the user's natural walking motion, which is mirrored in the virtual environment using VR headsets equipped with "room-scale" tracking technology that tracks the user's position in space. The second technique uses a pointing gesture, enabling users to navigate the virtual space without moving physically. This method allows users to remain stationary in their real environment while still interacting with the virtual one via an HMD.

Both techniques are inspired by real-world movements to create a natural and intuitive experience in the metaverse and to foster the sense of presence and engagement (Mott et al., 2020). Also, the elimination of intermediary devices, enhance immersion. Natural and semi-natural methods can be used independently or together, offering flexibility based on user preference, needs, and how they perceive the experience, such as in cases of cybersicknes.

Interaction. A key feature of the application designed to enhance the virtual experience compared to the physical one is the possibility to interact with historical assets. This functionality is intended to improve entertainment value, promote playful engagement, and support understanding by enabling users to explore artifacts in ways that are not possible in a traditional museum setting, without the risk of breaking or damaging objects. In this regard, the provided application not only allows users to grab objects for a closer look, but also enables them to scale the artifacts, making small details more visible than they would be at their real size. To make these operations as natural and intuitive as possible, while avoiding the need for external tools (e. g., joysticks) or additional commands, the system incorporates free-hand gesture recognition.

Specifically, to handle an artifact, the user must perform a grab gesture when his/her hand (either left or right) is in contact with the object (Figure 3a). Once grasped, the object follows the movement of the hand, allowing it to be manipulated as it would be in real life. To uniformly scale the artifact, the user has to keep the hands with the thumb and the index pinched, then moves the hands closer or farther apart (Figure 3b). The object zooms in or out in proportion to the variation in distance between the fingers. When the object is brought back into contact with its support on the pedestal and the grab is released, it automatically returns to its original size and position.

Text and Audio. To enhance the visitor experience by providing context and information about the exhibited objects in an accessible and engaging manner, the proposed virtual museum exhibition offers the possibility to both read and listen to the description of each artifact in an interactive and immersive way. As described in Section 3, on each pedestal two buttons are arranged that the user can push to respectively show a text panel and play an audio. The panel is designed to be highly visible and easy to read. It utilizes a font specifically created for individuals with dyslexia (OpenDyslexic, 2024) to enhance readability. Additionally, the panel's position automatically adjusts to the user's height, ensuring it appears at eye level for optimal accessibility. To further accommodate users with reading difficulties, such as dyslexia or visual impairments, the audio can be played at any time, facilitating reading by combining both options.



(a) Handling. (b) Scaling.

Figure 3: Examples of interactions with artifacts.

5 THE EXPERIMENT

In this initial phase, before introducing the application in schools, we test its usability with adults using the System Usability Scale (SUS) (Brooke, 1996). The evaluation covers language and color selection, objects manipulation (grasping, rotation), objects scaling, information acquisition, virtual museum visit, and the description-object association game. We assess ease of scene setup, interaction naturalness, and information accessibility. Additionally, user engagement is measured through the User Engagement Scale Short Form (UES-SF) (O'Brien et al., 2018), which evaluates perceived usability (PU), aesthetic appeal (AE), focused attention (FA), and reward (RW).

5.1 System and Protocol

The system is developed using Unity 2022.3.20f1 with the OpenXR Plugin 1.10.0 for rendering and interaction management. The application runs on Meta Quest 3, which uses inside-out tracking to detect hand and finger movements as well as spatial positioning.

The experiment involves 10 participants (5 men, 5 women), mainly aged 25-34 and 45-60. Most were native speakers of Italian, English, or French. Two participants reported accessibility needs: one with walking impairments and another with low vision. In conformity with the request made to the ethical committee, before the experiment, participants were informed about personal data management, research objectives and instructions on interactions. They completed the full experience before filling out the anonymous SUS and UES-SF questionnaires. Suggestions were provided during the experience to ensure all system functionalities were explored and tested.

5.2 Results

The System Usability Scale (SUS) score is calculated based on a questionnaire with ten items, each rated on a 5-point Likert scale (from 1 = strongly disagree to 5 = strongly agree). To compute the total SUS score, responses to the odd-numbered questions (1, 3, 5, 7, 9) are adjusted by subtracting 1 from each response value. Responses to the even-numbered questions (2, 4, 6, 8, 10) are adjusted by subtracting each response from 5. This transforms all scores into a 0–4 scale. The adjusted scores are then summed and multiplied by 2.5 to normalize the total to a 0–100 scale. The final SUS score represents an overall measure of usability. Generally, a SUS score above 68 is considered above average, while scores above 80 suggest excellent usability (Bangor et al., 2009).

The results of this evaluation are summarized in Table 1. The evaluations for Getting **Information** (96), Virtual Museum **Visit** (87.5), Description-Object Association **Game** (87), and **Color** Selection (86.25) all scored well above 80, indicating a highly usable and user-friendly experience in these aspects. A very positive aspect is how the getting of information is evaluated, which is crucial for the educational impact and the understanding of content. **Manipulation** (84.5) also falls within the excellent range, that is promising in terms of the engagement and the interactivity of the system. Conversely, **Language** Selection (79) and Object **Scaling** (78) are slightly below the 80 threshold but still above average, suggesting they are usable but may benefit from minor improvements. Overall, all categories scored above 68, demonstrating a good level of usability, with certain areas performing exceptionally well while others could be refined for an even better user experience.

The results of this usability evaluation are highly encouraging, as they indicate a generally positive user experience across all categories, with several aspects scoring in the excellent usability range. Given that

Table 1: SUS Scores for Different Categories.

SUS Categories	1	2	3	4	5	6	7	8	9	10	Total
Language Selection	2.6	3.4	3.0	3.1	2.3	4.4	2.8	3.9	2.3	3.8	79
Color Selection	1.8	4.3	3.2	4.1	2.6	4.1	3.0	4.4	2.8	4.2	86.25
Object Manipulation	3.0	3.8	2.7	3.3	3.0	3.7	2.7	4.4	3.0	4.2	84.5
Object Scaling	2.4	3.8	2.5	3.2	2.9	3.9	2.4	3.8	2.5	3.8	78
Getting information	2.8	4.5	3.3	4.5	3.5	4.4	3.0	4.5	3.4	4.5	96
VR Museum Visit	2.9	4.4	3.0	3.4	3.0	4.2	3.1	4.1	3.1	3.8	87.5
Association Game	2.1	4.2	2.9	3.6	3.0	4.4	3.0	4.2	3.2	4.2	87

these scores were obtained from typical users, the next phase is to extend the validation process to a more diverse audience. This includes involving students and individuals with various impairments (e.g., motor, visual, and auditory disabilities) to assess the application's level of inclusion and accessibility in greater detail. By conducting targeted testing with these user groups, it will be possible to identify potential barriers and refine the system to ensure a truly accessible and user-friendly experience for all.

The UES-SF questionnaire results indicate an overall positive user experience. They are summarized in Table 2 where the mean scores on a 5-point Likert scale (from 1 = strongly disagree to 5 = strongly agree) are reported. The highest score was for Perceived Usability (4.42), suggesting that users found the interface and interactions accessible and functional. The scores for Aesthetic Appeal (3.90) and Reward Factor (3.97) also indicate that the application is visually appealing and provides a satisfying experience. However, Focused Attention (3.43) received the lowest score, implying that some users might have struggled to maintain full engagement throughout the experience.

Finally, since the variance among the involved groups did not reveal significant differences, we did not perform an ANOVA or t-test analysis.

Table 2: Mean scores for UES-SF dimensions.

Engagement Dimension	Mean Score
Focused Attention (FA)	3.43
Perceived Usability (PU)	4.42
Aesthetic Appeal (AE)	3.90
Reward Factor (RW)	3.97

6 CONCLUSIONS

Immersive VR applications are increasingly used for educational and entertainment purposes. Among them, virtual museums and, in general, cultural heritage exhibitions stand out for their significant educational, democratizing, and inclusive value, of particular importance also for schools.

In this work, we present the development of a virtual experience, the final application of which is addressed to primary schools, consisting of an exploration phase and a game phase. The main goals are two: first, to design a virtual environment that is inclusive and accessible to diverse groups of users, considering cultural differences and mild physical disabilities. Second, to create an engaging experience that supports and enhances the understanding of artistic concepts or cultural heritage assets. Also, a preliminary evaluation of the system's usability is conducted with adults to validate the implemented functionalities and refine them to optimize the experience for its final use with children. The results are promising and interesting feedback has been provided, which deserves further discussion in collaboration with schools and teachers. For example, the language selection process is not as intuitive as it could be. We plan to address this by adding sound feedback, such as a double-tap on the flag that will allow users to hear the name of the language in that language.

As future work, we are managing to evaluate the system in schools with a broader group of users of different ethnic backgrounds and with various disabilities. In this context, we will also assess the learning effects by comparing the virtual experience with traditional methods.

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