Redefining the Digital Paradigm for Virtual Museums
Towards Interactive and Engaging Experiences in the Post-pandemic Era

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Abstract. The COVID-19 pandemic has greatly accelerated the digitization of services. As physical spaces become harder to access, there is a growing shift towards the use of virtual spaces for remote work, education and entertainment. In 2020, brick-and-mortar spaces like museums, art exhibits and galleries were especially affected by a lack of visitors. Shifting to a virtual medium would allow these entities to reach out and retain visitors more effectively. However, the use of virtual spaces to support these kinds of services is still quite under-explored. Presence, engagement and a real connection are difficult to establish through virtual exhibits. To explore these challenges, we partnered with the Liberation War Museum in Bangladesh and created a web-based 3D virtual museum to represent three of their historical galleries. Each virtual gallery has a different presentation modality - "self-guided", "avatar-guided" and "game-based". We sought to explain which of these artifact presentation modes led to the best performance in learnability, usability and engagement by conducting a user study. Our findings and user feedback are presented in this paper. We hope that these findings will be useful for designing virtual experiences that can allow users to learn and engage with virtual artifacts as effectively as they would with real-world ones.

Keywords: Virtual museum · Web-based museum · 3-D Virtual Museum · Post-pandemic · Digital paradigm · Digital age · Learning · Engagement · COVID-19 · Avatar-guided museum · Game-based museum

1 Introduction

Museums are an essential part of preserving and defining the history, culture, technology and identity of people. They offer an immersive and well-curated learning experience that helps visitors develop a better understanding of their

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history through the exhibition of artifacts. Museums are a predominantly 'brick-and-mortar' presence that preserve, create and disperse knowledge. However, the COVID-19 pandemic has created an unforeseen barrier for in-person interactions. Physical distancing measures have led to an unprecedented downturn in tourism and hospitality [3]. As a result, museums have been getting fewer visitors. If this trend continues, some museums might have to close permanently. This should be a wake-up call to the need for having a well-defined digital paradigm for museums [13]:

> *"The transformation won't mean that museums lose what they have to offer as physical sites conveying knowledge through the medium of material objects. It means that the museum will get another dimension, a digital one."*

Digitizing museums democratizes access and education for people regardless of location, resources, and age. The digital medium can be a powerful agent for learning, but it is significantly underutilized by museums. Some popular museums, such as the Smithsonian National Museum of History, offer a virtual self-guided experience but lack in interactive experiences. Whereas, Swartout et al. [23] specifically emphasize on designing interactive methods for facilitating engagement and learning in museum visitors who sometimes ignore the exhibits. Current practices of developing virtual museums can be categorized as brochure museums and content museums [22]. They are mostly limited to a digital collection of images, A/V files and text documents which scarcely inspire learning. However, the development and analysis of interactive methods for facilitating engagement and learning in museum visitors is a novel paradigm to explore. Our study focuses on the unique potential of the digital medium in developing interactive and engaging learning experiences. We aim to examine and evaluate three modes of virtual education through museums - a free roam self-paced experience, a guided experience led by an instructor (authority) and a puzzle-based experience, all to assess the users' engagement, motivation and knowledge retention in the virtual experience.

To explore these three modalities, we partnered with the Liberation War Museum (LWM) of Bangladesh and created a web-based virtual museum for them. The LWM has a strong presence and a rich history of research into museology. Therefore they were an ideal group for us to collaborate with. We conducted multiple rounds of focus group meetings with the members of the board of trustees of the LWM to better understand their requirements. We compared three methods—"self-guided", "avatar-guided", and "game-based" experiences using this virtual museum. The "self-guided" experience facilitates visualization of virtual exhibitions in the form of 3D galleries and lets the virtual visitor walk around at their own pace and explore the artifacts. The "avatar-guided" experience is created by developing a virtual museum guide that uses narrations to explain the 3D virtual artifacts [9]. The "game-based" experience utilizes the gamification technique for making the artifacts interactive and part of a puzzle game/scavenger hunt for conveying a story. We use learning, engagement

and usability as metrics for evaluating and comparing the three methods by conducting a user study.

Overall, the aim of this research is to reexamine the digital paradigm for museums and identify best practices for curating virtual museums in the post-pandemic world. Hopefully our findings will be useful for designing similar virtual experiences that inspire curiosity and the desire to learn more in museum visitors.

2 Related Work

Virtual museums have been researched for decades but the current digital approaches still do not offer a quality of experience comparable to their physical counterparts [15]. The COVID-19 pandemic has expedited the need for people to embrace virtual environments. There are different methods of engagement that museums can adopt to shift over to the virtual paradigm which include free-roam, guide-based, and game-based museums [8]. Museums in different countries have been implementing 3D virtual web-based museums using VR technology. A virtual environment can also be setup in a stereoscopic view. It gives the visitors illusion of being in the real place instead of visiting an exhibit [21]. Such museums include the Smithsonian Natural Museum of History and the British Museum. These museums also provide information about specific artifacts through different mediums like image and audio transcripts [11].

Another method of learning is through gamification techniques. Some video games provide historical simulations giving players the opportunity to learn, such as "The Civil War – a Nation Divided" [17]. Gamers can interact with each other synchronously within the simulated historical era. There are vast amounts of virtual exhibits and museums, such as the Mayan recreation made through "Second Life";

Embracing virtual reality environments can help improve learning and education. Such works include a "Hidden Waterfall City", an underwater archaeology virtual reality (VR) experience, and a digital Malaysian cultural heritage compendium. The "Hidden Waterfall City", presented a mystical place in the virtual environment [8]. Meanwhile, the underwater VR experience, introduced people to underwater archaeological overview of Iceland and the country's underwater life [18]. The Malaysian compendium aims to preserve the Malaysian culture [24]. Mixed-Reality is also seeing increased application as a digital medium for educational experiences [10]. However, the exact contribution of these mediums to enhancing engagement and learning needs to be further explored.

When focusing on curated experiences in museums in a virtual setting, there are factors to consider in terms of information being conveyed. For instance, acceptance of the use of a tour guide versus a self-guided experience. In terms of learning, the guide serves as a medium to fully convey information, preventing information from being overlooked. The appearance of avatars as guides in virtual museums need to be relevant to the information that they present. Their assumed specialization affects the way that they are perceived, since people tend to ignore elements that are diverging from their perceived experience [20]. In a

virtual game-like setting, interacting with digital avatars enhance user's engagement and presence [7].

Our idea of incorporating new technology with learning derives from the technology-mediated learning (TML) approach introduced by Alavi and Leidner [2]. The technologies described in their work have advanced and have become more accessible to the average user in web browsers, allowing new levels and modes of education to be implemented in online educational services.

Hou et al. investigated and compared three approaches to museum learning for university students—a traditional museum experience, a paper-based supplement, and a mobile device supplement [12]. Results from their pre and post-test examinations found that participants in the mobile device learning group received the highest average scores and had the largest overall increase in their post-test scores. Collected data also showed that the mobile device group paid more attention to exhibits than the other two groups. Klopfer et al. found game-based learning in museums to be an effective mode of learning for both children and their parents [14]. Feedback from their study indicates increased user engagement, with several participants claiming to have learned materials they had not learned before, whereas in some cases the user had visited the museum before on multiple occasions. We hope to find similar results and compare user feedback between modes of learning in our museum. Yiannoutsou et al. examined the incorporation of mobile devices with educational games used in a museum education for junior-high school children [25]. They noted that participants developed a task oriented approach of searching for clues and answers in the games, and results indicated that this approach helped students develop a clear understanding of each exhibit's main ideas. Their study also found that some exhibits were better suited for game-based education than others.

3 Problem Definition

The current era is termed as the "digital age". The widespread use of the internet and personal computers have dramatically established the digital world as being almost as important as the physical world. Hence digitization has become an inevitable trend for any service, be it education, museums, galleries, retail etc. Because of COVID-19, museums around the world were forced to close off for the general public. This event has intensified the need for a virtual presence.

Museums are an agent for learning and the preservation of history and culture. The trend of digitization has already begun in the museum sector. But one persistent problem in this domain is that until now, the primary focus of research in this space has been in digitization of the artifacts [15] rather than focusing on users' virtual experience for enhancing learning, engagement and presence. The term "brochure museums" is used for most virtual museums, because of their brochure-like approach for developing a website. The problem with this approach is that flat, 2D images of artifacts cannot fully capture users' attention and encourage learning. More recently researchers have started exploring informal learning through museums using web-based stereoscopic views, virtual

museum guides in physical museums, and virtual reality (VR) experiences. But a lot of these approaches are not readily available for the average user, for example, VR solutions are not remotely accessible to the general population. On the other hand, the stereoscopic view-based approach lacks the interactive component. Moreover this approach focuses more on creating an illusion of being in the real-life museum using images rather than focusing on the artifacts themselves.

However, we focus on creating an interactive experience that will enhance learning through an user-centered perspective. We examine different approaches to retain visitor's attention through providing 3D interactable artifacts, audio-visual media and game-like 3D walkable space design. Web-based services are also more accessible to the underprivileged population and can bridge the gap in resource availability for students. We feel that the current pandemic makes this a timely and relevant topic to explore. As mentioned by Pallud, the primary two components of a visitor's experience are education and entertainment [19]. Designing a museum requires both aspects to be implemented appropriately. Hence we examine and report our findings of using three approaches—a self-guided experience, a guided experience using virtual avatar and a puzzle-type game based approach. We hope that our exploration of the three modalities will help redefine the digital paradigm for museums.

4 Approach

In this section, we describe our approach for comparing the three modalities and reasons for choosing them to create an engaging, interactive and immersive virtual experience. The three modalities are "self-guided", "avatar-guided" and "game-based" experiences. The "self-guided" 3D walk through experience is currently the most prevalent format in web-based virtual museums. For example, the web-based Smithsonian National Museum of History provides one type of free-roam experience to the visitors.

Current avatar-guided museum experiences, such as the Ada and Grace experience [23], dictate to visitors virtually, but are in a physical museum. We aim to integrate this into the virtual museum experience using a digital animated avatar narrating descriptions to the visitors.

Finally, game experience for virtual museums is a growing body of research, which integrates content into game-based learning due to the proven positive effects of games on learning [5]. However, learning by gaming is not presently recognized by formal educational systems, primarily in low and middle-income countries, and games for museums are a relatively new concept. They require mechanics in the design where the experience is not only stimulating, by presenting a challenge, but also provide an educational experience for the user.

To compare the learnability, engagement and usability aspects of these three approaches, we developed a web-based 3D virtual museum [6] and conducted a user study. The website was created in collaboration with the LWM to present the journey of Bangladesh towards becoming a sovereign nation.

The LWM collaborators conducted the survey-based user study to evaluate the museum. The survey responses (without identifiers, such as email address,

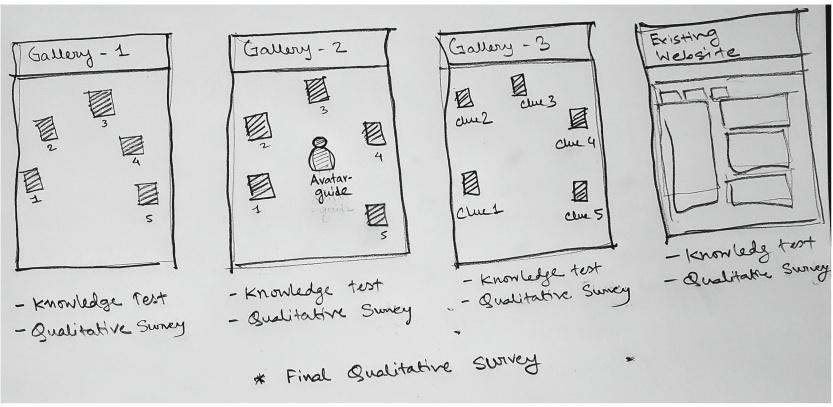

Fig. 1. User study: concept sketch of three galleries. Gallery 1: self-guided. Gallery 2: avatar-guided. Gallery 3: game-based.

IP address, name, phone number, etc.) were shared with Virginia Tech students for evaluation and analysis. The study was conducted with 22 participants. We used Mozilla Hub, Unity Game Engine, Web3D, and Google Tour Creator for developing the three experiences of the museum.

The virtual museum consists of three galleries, with five different artifacts in each gallery (Fig. 1). The three galleries are designed using the three approaches for an one-hour study. Participants explore each gallery for 10 min and then complete a knowledge-based test and a qualitative survey. First, in the self-guided experience, participants walk around exploring the different artifacts. The second gallery has a avatar-guide that leads the visitor to artifacts and conveys information about them. Finally, the third gallery has participants solve a puzzle by investigating artifacts to find information.

After participants finish experiencing the three galleries, they take an overall qualitative survey to determine which experience was the most educational and enjoyable. We analyze the knowledge-based tests, qualitative surveys, and the final survey to compare the learnability, usability and engagement of each approach.

4.1 Focus Group Discussions

The board of trustees of the LWM is the focus group for the purposes of this study. We chose them as a focus group because of their decades-long experience and expertise in the domain of museology.

The museum was established in 1996 by this board of trustees with the vision to commemorate the heroic struggle of the Bengali nation for their democratic and national rights. Prior to the pandemic, school students (high school) from all over Bangladesh, would participate in extra-curricular activities organized by the LWM. However, due to lockdowns and safety measures, the museum had to close

Fig. 2. Top left: Gallery 1 (self-guided). Top right: Gallery 2 (avatar-guided). Bottom: Gallery 3 (game-based).

its galleries for visitation, requiring the museum to adapt to the transitions of the digital age and the new normal. One of the members of the board of trustees said, *"...it is the responsibility of the current generation to preserve history for their future generations."*.

We curated the virtual museum based on the focus group discussions with the board members of the LWM. The meetings were conducted virtually and the goal was to create an interactive virtual museum experience to enhance learning. We discussed the other museums, like the Topography of Terror museum in Berlin, Germany, that provide different types of choices (text, audio and video narration) in addition to the physical artifacts to engage visitors. Therefore, our virtual museum has been developed with each gallery highlighting a different method of engagement to understand its effect on learning.

4.2 Design Development

The galleries are designed as hexagonal rooms where five walls are used as a backdrop for five sets of artifacts. The first gallery is self-guided, second gallery is avatar-guided and third one is game-based (Fig. 2).

We designed the artifacts for each gallery in the following manner:

1. Image-based artifacts: A combination of 2D images and 3D models. Textual description appears once the visitor interacts with the artifacts.
2. Video artifacts: A combination of 2D images/3D models and a video clip. The video clip appears once the visitor interacts with the artifact.

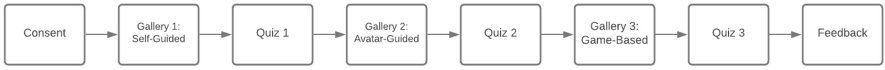

Fig. 3. User study flow diagram: data collection process.

3. Text with narration: A combination of 2D images/3D models/video clip and narration from the avatar-guide.

For the second gallery, we chose an avatar-guide which was a symbolic reference to the nation of Bangladesh, the Royal Bengal Tiger. For the third gallery, we chose a puzzle-type game where hints are provided to the visitors that leads to different artifacts.

4.3 Application Development

The virtual museum is developed using Unity3D, a 3D game development engine with C# back-end. Artifacts are mostly provided by the LWM, while some of them are collected from publicly available sources [1,16]. Utilizing open source software and servers, we host the work on GitHub pages with "000Webhost" to contain diagnostic user interaction data. WebGL, a JavaScript API that supports rendering 3D objects and environments, is used to provide intuitive interaction.

Gallery 2 contains an avatar-guide, a 3D tiger model with nine animations of walking, conversing, and referring to artifacts. Standard artifacts allow the visitor to rotate the artifact by holding and moving the left mouse button, a brief description is shown on the bottom of the screen while interacting. An exit button is enabled only after a period of five seconds to ensure that the participants engage with the artifacts.

Diagnostic data is collected internally to be cross-examined with the qualitative feedback and knowledge-test scores of each user. We use Unity RayCast to determine whether an user is looking at an artifact from within a certain distance. Once the user completes visiting a gallery, the color of an "exit door" changes from black to green prompting the user to leave through the door. Once the user collides with the door, a post request with diagnostic data is sent to the database hosting site.

5 User Study Description

In this section, we describe the user study as a step by step process (Fig. 3). The following brief instructions are communicated virtually and through e-mail.

1. The participants are provided a consent form and information sheet to explain that their personal identifiable information (email address, name, IP Address, contact number) will be kept confidential and solely accessible by the principal investigator from the LWM. The consent form also includes sections for collecting demographic information.

2. The User is then provided with the URL [6] of the virtual museum through which they generate their unique identification number (user ID).
3. From the home page, they are prompted to enter the first gallery by clicking a link. They are redirected to the web page of the first gallery. This page remains open for the entire duration of the experience.
4. Upon completing each gallery, a new tab opens with a link to the survey for the corresponding gallery. The participants are instructed to disable their pop-up blocker to have an uninterrupted participation. The surveys include knowledge tests and qualitative questions.
5. After the completion of the survey of the third gallery, the user is provided with a URL of the overall survey by the principal investigator. This final survey seeks feedback based on the overall experience of the museum in terms of user friendly interface, comfort in using the interface, impact on learning through the curated instructiveness etc.

Demographic Information

We conducted the user study with 22 participants. The selected participants were chosen on the basis of their age. All participants were at least 18 years old. Table 1 depicts the demographic information of the participants. Seven of the participants are private service holders, four students, three interns, three lawyers, two engineers, one entrepreneur, one homemaker and one volunteer at the LWM. All of the participants are Bangladeshi citizens.

Table 1. Demographic information: 22 participants.

Gender	Age (median)	Education	Visited the LWM In-person Before (%)	Visited Any Virtual Museum Before (%)	Experience with Digital Systems (%)
Male: 6 Female: 16	27	PhD: 2 Masters: 11 Undergrad: 9	Yes: 68.18 No: 31.82	Yes: 36.16 No: 63.64	Beginner: 36.36 Intermediate: 45.45 Advanced: 18.18

6 Results

In this section, we analyze the usability, engagement and the effectiveness of the three approaches as learning media. We also explore the engagement aspects of the artifacts. The avatar guide, an animated 3D model of the Royal Bengal Tiger, is the unique feature of the second gallery. The game-based puzzle-solving approach is the unique characteristic of the third gallery.

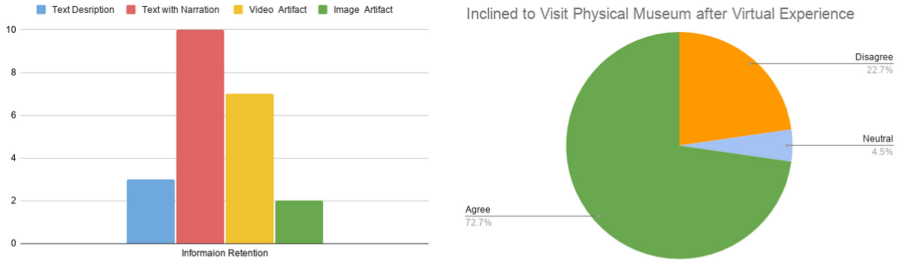

Fig. 4. Left: artifact type vs. number of participants—most effective artifact for information retention. Right: inclination to visit physical museum after virtual museum experience.

6.1 Learnability

Qualitative Results: Artifacts in each gallery are designed as either video artifacts, image-based artifacts, textual description with narration or only textual description focused artifacts. Based on the responses from the final survey, the artifacts consisting of textual description with narration were the most effective for information retention (Fig. 4(Left)). Participants were enthusiastic about the avatar-guide, as it was fun and interactive: *"Of course the guide itself! Brilliant idea and execution."* The second most preferred artifacts were the video artifacts. One of the participants mentioned, *"The Concert for Bangladesh was engaging, as it was informative and music always helps."*

72.7% of the participants expressed interest in visiting the physical museum after the virtual museum experience (Fig. 4(Right)). Which means the virtual experience was able to encourage learning within the visitors.

Quantitative Results: Participants took a knowledge test after completing each gallery. These scores might reflect a possible bias arising from the varying level of difficulty for the questions in each gallery. Moreover, the participants are Bangladeshi nationals, so there can be a possible bias arising from pre-existing knowledge. However, these scores help us understand the effectiveness of the three design approaches as learning media. For gallery 1 (self-guided), participants scored an average of 98.4% in the knowledge-based test. In case of gallery 2 (avatar-guided), the score was 93.91% on avergae. For gallery 3 (game-based), the average score was 91.44%. We conclude that all three galleries performed well on the learnability aspect as the average scores were above 90%. As a future work, we are curious to explore the results by conducting an user study with non-Bangladeshi participants to see how these scores vary.

While discussing the gallery 3, one user said, *"(I found) the scavenger hunt (engaging) as it helped me remember the learnings. However, I think it should end with some reward, for example, a badge that can be shared on Social Media."* Another user responded, *"The quiz made me look through the gallery with more details."*

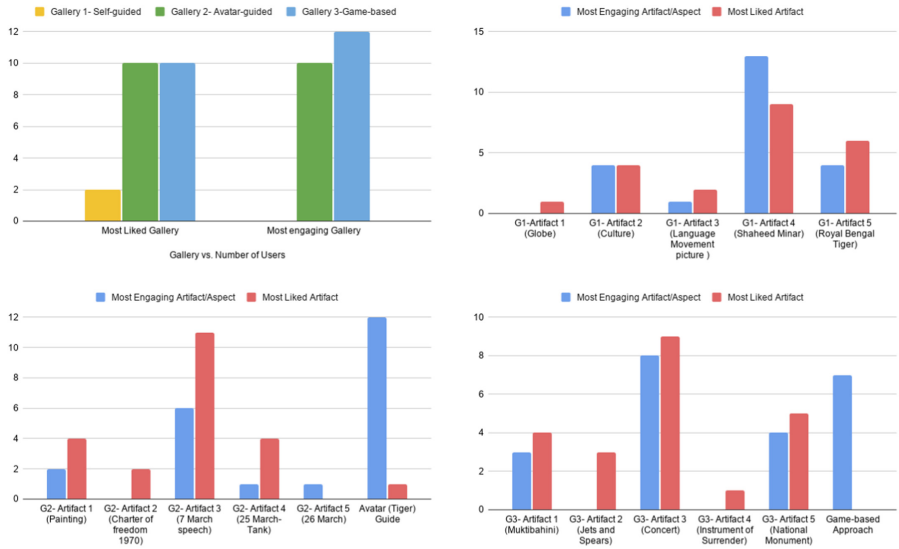

Fig. 5. Gallery/artifacts vs number of participants—most liked and most engaging. Top left: most liked/engaging gallery. Top right: Gallery 1. Bottom left: Gallery 2. Bottom right: Gallery 3.

6.2 Engagement

Qualitative Results: Most liked gallery and most engaging gallery: As evident from Fig. 5, Gallery 2 and 3 were the most liked galleries because of the avatar-guide and game based approach. On the other hand, the third gallery was found to be the most engaging because of its puzzle-solving, game-based approach. This gallery was well-liked also because of its interactive nature—*"...the game based version. The clues were nice and interactive."*

Most Engaging and Liked Artifact/Aspect: The most engaging artifact in gallery 1 was the "Shaheed Minar" replica and the audio and visual display that was associated with it. This was also the most liked artifact in this gallery. Followed closely by the 3D model of the tiger.

One of the participants mentioned, *"Shaheed Minar model was engaging and pretty, the 3d nature allowed me to walk around and see it from multiple angles."*

For gallery 2, the most engaging aspect was the animated, 3D avatar-guide. The participants really enjoyed the avatar and its narrations as a unique mode of learning.

To quote a participant, *"The guide, audio visual aspect gives an immersing story telling which is beautiful."* Another participant had some suggestions about the text description and the narration, *"(The most engaging aspect was) the talking tiger as he acted as a guide. However, the mismatch between the voice and the writing was a bit distracting for me as I was not being able to concentrate on either of them."*

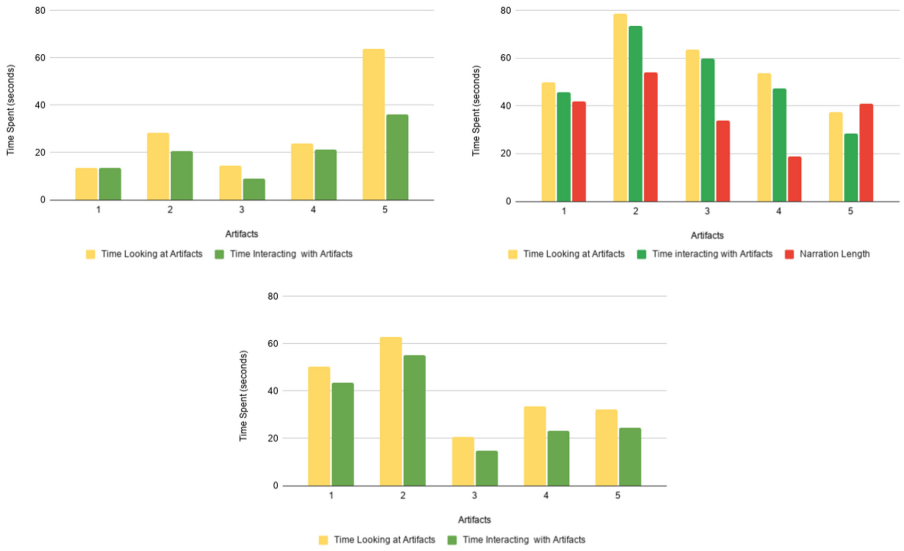

Fig. 6. Artifacts vs time looking and time interacting. Top left: Gallery 1. Top right: Gallery 2. Bottom: Gallery 3.

The second most engaging aspect/artifact was the video artifact (7 March speech). It was also the most liked artifact. To quote a user, *"The 7th March speech. Visually more stimulating than still artifacts."* The second most liked artifact was the 3D model of a tank. To quote a user, *"The 3-D model of the tank, as it felt alive."*

For gallery 3, the most engaging aspect was the video artifact depicting the concert. One user said, *"The Concert for Bangladesh (was the most engaging), due to it being audiovisual."* The approach of puzzle solving scored a close second place as a unique mode of learning. To quote a participant: *"Game based Gallery is very interactive, fun and gives a different experience to museum visits."* The most liked artifact in this gallery was the video artifact. The 3D model of the freedom fighters was also appreciated because of its details. One user mentioned that, *"(I liked) the weapons of the freedom fighters. That the freedom fighters started engaging the war by traditional weapons, it gives the visitors a proper idea of the level of dedication and love of the martyrs."*

Overall, we can see that participants overwhelmingly preferred the video artifacts. They also thoroughly enjoyed an animated guide who would walk them through history in a chronological order. The game-based approach was also very engaging for the participants as they were working toward a goal and the reward of completing the tasks. participants said that, *"...this would be amazing for children"* and *"The experience is not monotonous"*. So, a combination of these approaches could be considered while designing a virtual museum.

Quantitative Results: We collected three data points from each user—the total time they spent in each gallery, the total time they spent looking at each artifact, the total time they spent interacting with each artifact (Fig. 6). The "time looking" at an artifact was the amount of time the user spent looking at the artifact from a certain distance. "Time interacting" with an artifact was the amount of time the user spent after clicking the artifact until the time they exited. It is important to note that the user interacts and looks at an artifact simultaneously.

In the first gallery, the artifact that was both looked at and interacted with for the longest amount of time was artifact 5, the model of the Royal Bengal Tiger. Artifact 5 was likely examined for a longer period of time due to the complexity of the 3D model compared to other artifacts in the first gallery. The qualitative data (Fig. 5) also suggests that artifact 5 was the second most liked/engaging artifact.

For the second gallery, it is worth noting that the participants were required to interact with the artifact throughout the length of the narration given by the avatar-guide. Participants could exit only after the narration ended. The qualitative data (Fig. 5) suggest that the avatar-guide was the most engaging aspect of this gallery. It also appears that participants spent additional time examining and interacting with artifacts before or after the narration (Fig. 6). According to the collected diagnostic data, approximately 86% of the participants appeared to follow the guide's directed order for visiting the artifacts.

In the third gallery, the riddles provide hints to lead towards a specific artifact and the answer to the riddle can be found by exploring the artifact's description or video. Participants appeared to be the most engaged with the first two artifacts. However, qualitative data (Fig. 5) suggest that artifacts 3 and 5 were the most liked/engaging. One probable explanation could be that, after the first two riddles, participants got the hang of the game, hence required less time for the later ones. In this gallery, solving the puzzle was likely a bigger motivation for participants rather than visiting the artifacts which is also supported by qualitative data.

6.3 Usability

At the end of the study, participants were asked to fill out a survey which contained a modified version of the System Usability Scale (SUS) [4]. The SUS is a simple tool for measuring the usability of an application. It consists of a 10-item questionnaire with five response choices ranging from "strongly disagree" to "strongly agree". Each of these responses are given a numeric value on a scale of 1–5 (strongly agree (5), strongly disagree (1)). These scores are summed up and scaled to 100 to get a representative measure of each user's usability score for their experience with the museum. The questions used for the SUS questionnaire are provided below.

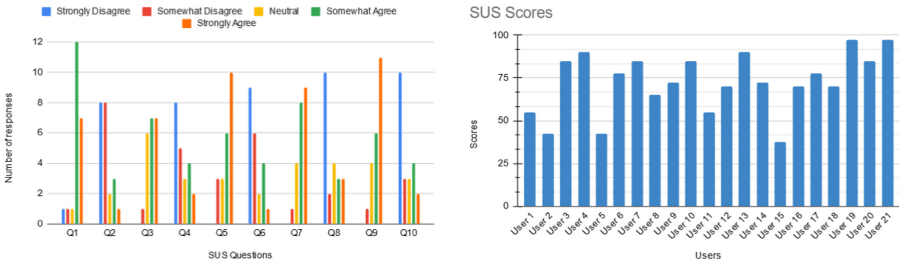

Fig. 7. Usability evaluation. Left: SUS responses per question. Right: SUS scores per user.

1. I think that I would like to revisit the virtual museum.
2. I found this virtual museum experience unnecessarily complex.
3. I thought this museum was easy to navigate.
4. I think I would need assistance to be able to use this virtual museum.
5. I found the various functions in this virtual museum were well-integrated.
6. I thought there was too much inconsistency in this virtual museum.
7. I would imagine that most people would learn to use this virtual museum very quickly.
8. I found this virtual museum very cumbersome/awkward to use.
9. I felt very confident using this virtual museum.
10. I needed to learn a lot of things before I could get going with this virtual museum.

A total of 22 participants provided their responses to these SUS prompts. However, one user's data contained missing entries and had to be discarded. The responses of these participants can be seen in Fig. 7(Left). The prompts that received the highest scores from the participants were numbers 5, 7, and 9. Figure 7(Right) depicts the final SUS scores per user, scored out of 100 points. The average score per user was 72.5 and the median score was also 72.5. According to [4], a score of above 68 classifies as above average. This finding suggests that the majority of our participants considered the virtual museum to be usable as a more accessible online extension of the LWT.

7 Discussion and Conclusion

In this research, we provide a comparative analysis between three different modalities for developing web-based 3D virtual museums towards achieving interactive and engaging learning experiences. Whereas other related efforts have mostly focused on mimicking the physical museums in the virtual world, we have focused on enhancing the visitor's experience by utilizing the unique capabilities of the digital medium. As evident from our user study, the novelty of the application was received with enthusiasm by the participants.

Fig. 8. Word-cloud from participants' final comments.

While testing the three modalities for virtual museums—self-guided, avatar-guided and game-based experiences, we received useful feedback from the participants. A word-cloud (Fig. 8) generated from the qualitative feedback represents overall user enthusiasm about the novel approaches like 3D walkable environment, learning through narration and interactive artifact design, engaging game-experience.

Our collected diagnostic data and qualitative feedback align closely. To summarize, our user study results show that the avatar-guided and game-based galleries received the highest scores from the participants based on interest and engagement.

Participants were the most enthusiastic, and spent the most amount of time while interacting with video artifacts and 3D models. Collected data also suggest that the narration from the animated avatar-guide increased the participants' attention towards the artifacts.

We also find that game-based learning is an effective mode of learning as it offers a reward-model which increases engagement and satisfaction. 72% of the participants expressed interest in visiting the physical museum after visiting the web-based version which represents the effectiveness in encouraging learning. The SUS score also suggests that the 3D virtual experience was usable and an welcome experience for the visitors.

One user commented, *"The overall experience was very good. I liked both the avatar-guided and the game-based versions and I think they can be mixed to keep both the flavours alive."* We conclude that a multi-modal approach is best suited for encouraging learning and engagement in visitors.

For designing the individual artifacts, participants suggest that providing all three options of audio-visual, narration and text-description for each artifact will engage people more with the topics. Having the galleries designed with bright colors will also make it visually attractive to children. Also having an artifact list in each gallery can be an useful reference for visitors. One participant mentioned that, *"However, I wish that I could see the actual artifacts, articles*

and pictures from the museum better and more clearly instead of just having a text that describes it." That means, providing the functionality to select and read/look at the artifacts closely as a digital asset will prove useful.

Some of the participants suggested that the narration by the avatar-guide could be clearer and if the text descriptions matched the narration, it would have been a better experience. This comment provides us with an interesting future study topic. We are curious to explore the effect of having the narration in user's native language or having the voice-over done by a speaker of the same nationality as the user.

Few of the participants complained about the cumbersome navigation and implementation flaws where the program becomes unresponsive. We presume that participants without previous gaming or 3D virtual environment navigating experience have a learning curve to use this sort of experience. But overall majority of the participants who experienced a virtual museum for the first time were excited and enthusiastic about the unique experience.

Extensive research in the domain of web-based virtual museums is required as the creation and demonstration of virtual architectural, cultural and historical reconstructions make it possible to transfer the cultural heritage to the newer generation. This digitization will help facilitate remote learning and democratize access to information and education. Another important aspect is providing continued accessibility in case of pandemic-like emergencies or other natural disasters. We hope educators and researchers of museuology will find our results valuable to identify best practices and develop effective educational strategies through virtual museums.

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