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RESEARCH ARTICLE

Evaluating the Impact of Presentation on Learning and Narrative in AR of Cultural Heritage

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ABSTRACT Cultural heritage exhibits an inherent relationship among various historical concepts and events. Previous studies that integrate augmented reality with cultural heritage have recognized AR as an effective tool for experiencing and learning about cultural heritage. In relation to cultural heritage AR, many researchers use presentations to provide users with diverse historical information and stories. However, too few cases have evaluated the influence of the use of presentations in cultural heritage AR on users' learning and narratives. Therefore, our study aimed to investigate the impact of presentation methods on users' learning achievements and narrative formation outcomes in the context of cultural heritage AR. To conduct this study, we divided users into three groups and presented them with AR experiences specifically designed with different types of presentations. We conducted uniform user evaluations, assessments of learning abilities, and in-depth interviews across all three groups, comparing the results. Ultimately, the method that had the most significant impact on both user learning and the narrative involved placing key cultural heritage information within virtual environments and repeatedly utilizing visual presentations. In conclusion, the group that adopted this approach exhibited significantly better results in terms of the evaluation of learning effectiveness and learning achievements compared to the other methods. Furthermore, it demonstrated a clear difference in visual graph representations for confirming narratives and word usage frequency, establishing it as a superior presentation method compared to the alternatives. Based on these findings, we offer practical guidelines for enhancing the use of presentations in cultural heritage AR experiences.

INDEX TERMS Augmented reality, presentation, cultural heritage, narrative, user experience, user tasting.

I. INTRODUCTION

Cultural heritage (CH) comprises historical significance related to human existence in specific regions and encompasses intricate concepts like past values, traditions, and important events [1]. Numerous researchers have employed AR as a means to enhance accessibility and provide the general public with historical insights and immersive experiences related to CH [2].

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Merging the virtual world with reality, like augmented reality, can be used to reenact or explain past events when visiting cultural heritage sites [3], [4]. When visiting museums, interactive exhibits and multimedia displays enhance our understanding of the stories related to historical artifacts [5], [6]. Even when in-person visits to museums or heritage sites are not possible, historical information can still be observed and experienced through the use of readily available tools and image-based resources [7], [8]. These virtual encounters can be just as effective in fostering a deeper understanding of cultural heritage. Studies on the application of augmented reality in cultural heritage education highlight the potential of such methods to enhance learning outcomes [9], [10].

Researchers advocate for the use of augmented reality in cultural heritage (CH) learning to promote a deeper understanding of artifacts [11], [12] and to enable users to delve into specific historical narratives [13], [14]. The effectiveness of CH AR applications is often assessed through multiple-choice questions centered on CH. However, there is a dearth of research exploring how users construct CH narratives following their engagement with CH learning experiences.

CH is predominantly intertwined with complex historical contexts [15]. It is challenging to convey the entirety of such subjects through a single artifact, as doing so must encompass historical eras, individuals, and events. Hence, most CH AR applications incorporate historical stories and narratives [16].

In an effort to deliver CH effectively given the wealth of information and intricate narratives, Cameron et al. [17] proposed what is known as the VIP (Visualization, Interaction, Presentation) approach to provide virtual CH experiences. Visualization involves digitally representing physical objects and incorporating processes such as 3D scanning, 3D modeling, and artifact reconstruction. Interaction with virtual objects must be enabled to provide key elements. Finally, presentation involves supplementing CH information with additional data. This method provides historical information and storytelling to users by incorporating audio, video, text, and image components. It is commonly used in CH AR research and aims to provide users with better educational experiences [18], [19]. As an example, a study focusing on the creation of court paintings AR, among Korea's documentary CH, utilized the presentation method to design visitor experiences and provide information [20]. However, there is a lack of research on the effects of different presentation approaches in relation to CH AR on visitor learning achievements and narrative variations.

Here, we provide users with three systems with different presentation designs while keeping the amount of information in the court paintings (CP) AR consistent with that in a previous study [20]. Subsequently, we investigated the impact of these different presentation approaches on user learning achievements and narrative variations. The specific contributions of this research are as follows:

- The provision of an in-depth understanding of the differences in user learning achievements and narrative variations resulting from the use of different presentation methods to provide historical information and storytelling in relation to CH AR
- An exploration of the relationship between CH learning achievements and narrative variations
- A discussion of practical guidelines when using presentation in CH AR

To confirm these research contributions, we conducted experiments involving CH learning evaluations, user studies, and in-depth interviews for each case.

The experiments demonstrated that integrating CH 3D objects and the visual presentation method significantly improved user learning achievements by providing key information. Additionally, it was observed that this method facilitated the proper use of the necessary vocabulary by users when describing related CH after their AR experience.

II. BACKGROUND

A. NARRATIVE IN CH AR

A story refers to a series of events or narratives that form an overall plot or storyline [21]. Stories are composed of events that take place at a specific location and time.

On the other hand, a narrative can be explained as the structural representation of events, experiences, or stories such that the development of events is organized [22]. Additionally, a narrative has been defined as a tool that includes meaningful events such as stories, characters, and timelines and that reconstructs various narratives for communication and understanding [23].

These characteristics of a narrative can be integrated with the interactivity of AR. While AR is not the only medium that combines a narrative with other media, the interactivity in AR allows for a departure from the passive experience of a narrative [24]. Additionally, AR can seamlessly create a narrative between real and virtual worlds by complementing omitted parts of multiple information sources in a digital format without replacing or disrupting the real world [25], [26], [27].

The digital narrative theory in Ryan et al. [28] distinguishes between the outer layer, which provides exploration without user participation, and the inner layer, which involves user engagement. The outer layer of interaction only affects the expression of the story, as the story itself is already predetermined. In contrast, the inner layer allows user interactions to shape and generate new story aspects.

In the context of CH AR, allowing interaction in the outer layer is common. Modifying the CH narrative can undermine its meaning, as the narrative holds significant value in the learning process. Furthermore, combining AR with a narrative provides a visually engaging storytelling environment for CH, stimulating the imaginations of users [29].

We can find various examples of providing narratives in CH AR. Geigel et al. [5] delivered narratives to users using 3D audio guides to convey unique historical stories within the context of museums. In a study implementing AR location simulation to recreate historical events on site [30], narratives of historical events were provided to users. A project implementing AR for modern history events in the Philippines [31] confirmed the effectiveness of narrative delivery through user evaluations. A study examining user storytelling and narratives through AR centered on CH sites [13], [14] contextualized spatiotemporal assistance for the narrative structure. Additionally, to assess the impact of outdoor environment AR storytelling on the space and narrative connection, the study observed the significant locations (Points of interest) chosen by users and the spatial trajectories of the corresponding generated narratives. However, these studies did not consider the presentation method. Furthermore, it is challenging to find discussions on the differences in CH narratives generated by users based on variations of these methods.

B. LEARNING IN CH AR

Various studies have demonstrated that AR can improve learning outcomes by spatially anchoring virtual content to physical locations and objects [32]. Particularly, research suggests that memory encoding is context-dependent and that memory retrieval and learning are enhanced when related information is associated with physical locations [33]. This type of learning can provide support for the pedagogical value of mobile AR based on the integration of real objects and physical cues [16].

AR environments have been widely applied to museums and CH in an effort to enhance the experience and learning by the user through increased interactivity [9]. Li et al. [10] presented a smartphone-based AR application that relies on low-cost markers in the form of cubes. Through an implemented AR prototype of museum collections, users were able to interact with high-quality 3D models outside the museum space. Furthermore, a museum of African art utilized AR to provide audio and visual information about artifacts to facilitate learning about the museum collections [34]. This enables users to explore and learn about artifacts in their digital form both inside and outside the museum [11]. Moreover, AR is used in schools and public institutions to teach CH history. The use of AR in educational settings has been found to increase student engagement [35] and improve learning outcomes when teaching complex historical events [36]. Mobile AR for teaching Greek mythology has also shown high utility in educational contexts [37].

In this study, we will evaluate the learning of specific historical stories, costumes, and artifacts represented in CPs. Additionally, we will assess the relationship between CH learning achievements and narrative formation based on different presentation techniques.

III. RESEARCH METHOD

In order to evaluate learning and narratives in CH AR based on different presentation methods, we divided the methods into three categories. Our goal is to answer the following research questions:

RQ1: How does the choice of presentation method within the system affect learning effectiveness? Which presentation method is preferred? Presentation design choices are widely used not only in CH AR but also in various AR applications. We anticipate that there will be differences in users' learning gains depending on the presentation methods they select (H1). Additionally, we expect that combining visual presentations with augmented reality 3D objects to yield better learning outcomes, such as improved understanding of historical context and enhanced recall of specific details (H2).

RQ2: How does the choice of presentation method within the system shape users' CH narratives? We anticipate that different presentation methods for each user group will have a significant impact on the structure and content of their CH narratives (H3). Furthermore, we expect that the presentation methods will also influence the linguistic choices users make as they construct their narratives (H4).

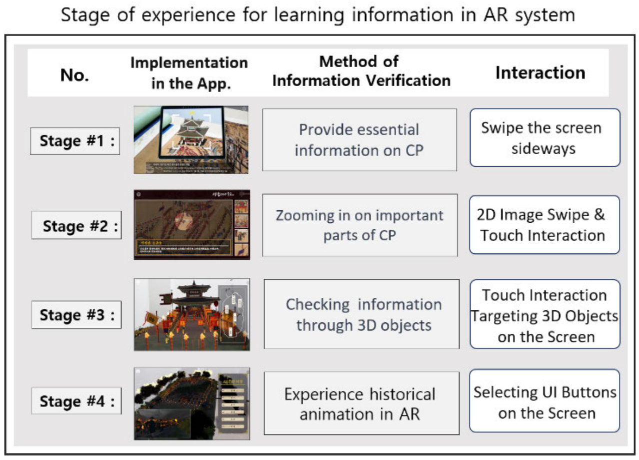

FIGURE 1. This figure illustrates the stages of the learning experience in the AR system. Stage #1: Overview of the target court paintings. Stage #2: Detailed examination of court paintings. Stage #3: Information retrieval based on the appearance of court paintings reproduced as 3D virtual objects (individual information retrieval of 3D objects). Stage #4: Experiencing historical events through animations.

A. SYSTEM DESIGN

We created an AR system that enhances the appreciation and learning of CPs depicting historical events in Korea that occurred in 1795. This system was developed as a mobile application using Unity 3D. Their paper aimed to provide users with an experiential understanding of CPs to enhance their learning of historical information. The AR system presented four stages of experience. Additionally, it incorporated a 2D-based pre-learning phase before the AR experience. The following Figure 1 illustrates the four stages of experience for learning information within the AR system.

Stages 1 and 2 were designed in a 2D format, with Stage 1 explaining the historical significance of the CPs and introducing the system through images, text, and voice-over events. Stage 2 allowed the users to examine the original images, enabling them to zoom in and select specific areas of interest for additional learning. Stages 3 and 4 were created as augmented 3D models based on physical models. In Stage 3, users could interactively access information about various characters and objects in the paintings through touch interactions on the screen. Stage 4 allowed users to experience an animated representation of military training actions depicted in CPs. The training stages were indicated by buttons, and users could observe and learn about five distinct historical military training actions.

This experiential approach received positive feedback in user evaluations, indicating its immersive and effective learning outcomes. However, the specific effects of differentiating the presentation in 2D and 3D stages, as well as the inclusion

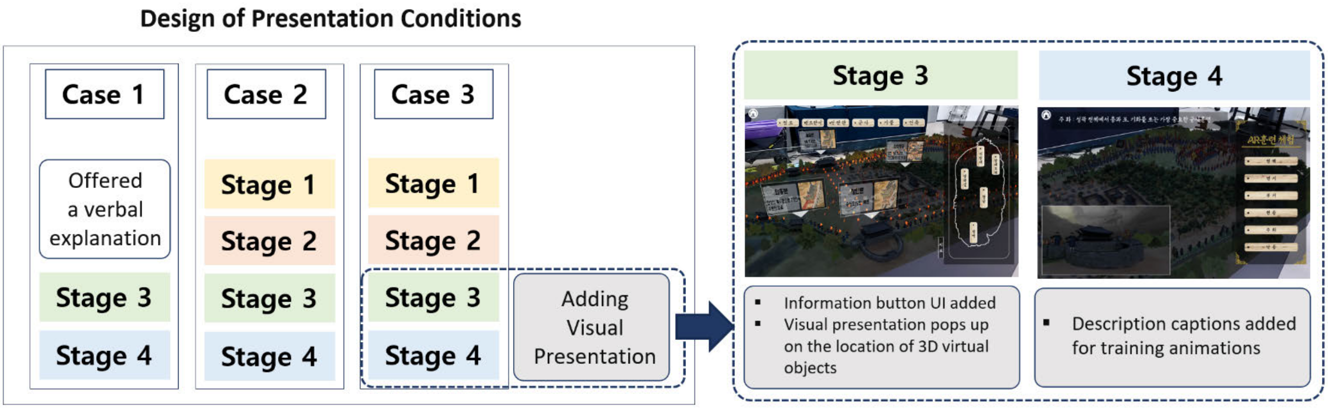

FIGURE 2. This figure illustrates the stages of the learning experience in the AR system. Stage #1: Overview of the target court paintings. Stage #2: Detailed examination of court paintings. Stage #3: Information retrieval based on the appearance of court paintings reproduced as 3D virtual objects (individual information retrieval of 3D objects using on-screen button UI touch interaction). Stage #4: Experiencing historical events through animations.

TABLE 1. Presentation methods are provided for each case. (a): audio guide. (b): sound effects. (c): 2D image pre-knowledge. (d): 2D image exploration and information images. (e): 3D object + critical information. (f): 3D animation + button. (g): 3D animation + summary text.

	(a)	(b)	(c)	(d)	(e)	(f)	(g)
Case 1	○	×	×	×	×	○	×
Case 2	×	○	○	○	×	○	×
Case 3	×	○	○	○	○	○	○

of the voice-over feature, on users' learning and narratives were not examined.

B. STUDY CONDITIONS

The presentation aspect of VIP [17] is a method that enhances the provision of information about virtual objects (3D objects) by providing additional data. It typically combines auditory presentation methods (such as audio and sound effects) with visual presentation methods (such as text, 2D images, and video clips) to convey the story, metadata, and impact of CH more effectively. Previous studies utilized various presentation techniques, including 2D images, text labels, audio guides, videos, and sound effects [4], [5], [6], [7], [8], [9], [10], [11], [34], [37] to deliver CH information in AR systems.

To address our research objectives, we designed three systems with different presentation conditions. The three study conditions are illustrated in table 1 and figure 2.

Case 1 limited the effects of the presentation by excluding visual and sound effects. In this case, we provided users with the AR experience and voice explanations, excluding the 2D pre-learning information (Stages 1 and 2). The voice explanations were identical to those provided in Stages 1 and 2, and an experimenter read them aloud before the users experienced the system. Users were not given any written information and had to rely solely on the experimenter's auditory explanations to acquire knowledge. Users in Case 1 had access to Stages 3 and 4, which were consistent across all cases. However, they were unable to hear the voices of the characters or sound effects during the animation in Stage 4.

In Case 2, we added visual presentations to the Case 1 scenario. These additional presentations are not integrated into augmented reality but are separately accessible on different pages before the user encountered augmented reality. These take the form of 2D images that contain historical information and detailed illustrations.

Case 3 adds a visual presentation combined with augmented reality. In Stage 3, users could select the labels of key information in CPs using buttons on the AR screen. When a user selects one of the buttons displayed on the screen, an image and text describing the selected 3D virtual object are provided at the location of that object on the virtual terrain. This information was identical to what was provided in Stage 2, connecting key information depicted in CPs with augmented 3D objects. Additionally, a summarized text of the training information was displayed at the top of the screen during Stage 4.

C. PARTICIPANTS

We initiated the study with a total of 51 participants recruited from students studying traditional culture. These participants had a background in fields related to CH as their major. The varying levels of basic knowledge among the participants could potentially result in significant differences in the experimental outcomes. Therefore, we specifically assessed the participants' knowledge levels regarding the CP "*SeojangdaeyaJodo*." Participants who indicated no knowledge of the painting (23 participants) or those that only knew the name of the painting (18 participants) were selected as candidate subjects for the experiment. Furthermore, participants who claimed some familiarity with the painting but scored below 33% on pre-test questions administered prior to the

FIGURE 3. Types of Presentation methods presented in the experiment. (a): 2D images with audio guide - Providing an overview of the system and historical background knowledge. (b): 2D images - Exploring court painting in detail and providing essential information,(c): Augmented Reality (AR) with 3D objects and critical information combined. (d): Individual information presentation of selected 3D objects. (e): Button to confirm military training sequence (animation). (f): Summary text of military training animation.

AR system experience were also included in the sample (4 participants).

In the end, the final sample consisted of 45 participants aged between 19 and 35 years (M = 25, SD = 3.22). Among them, 9 were male and 36 were female. The allocation of participants to each case as defined above was 15, without considering the gender ratio or age distribution. Furthermore, because more than half of the participants had either never used AR (11 participants, approximately 24%) or had only used it once or twice (19 participants, approximately 42%), we provided an explanation of basic AR usage and an overview of the entire system experience before conducting the experiment.

D. EXPERIMENT

This study was conducted in accordance with the research ethics guidelines of the Korean Traditional Culture University. Before the experiment, participants were given an explanation of the experimental procedure and provided their consent.

Our experiment consisted of two sessions per participant. The first session included two learning evaluations and one user evaluation, while the second session included one learning evaluation and one interview.

1) DEPENDENT VARIABLES

To test our research questions, we compiled data through surveys, learning assessments, and interviews to measure the impact of participants' AR experiences. The study selected AR usability, the usefulness of information for learning, and changes in learning outcomes and narratives as dependent variables. The independent variable was the type of presentation method used in the AR system.

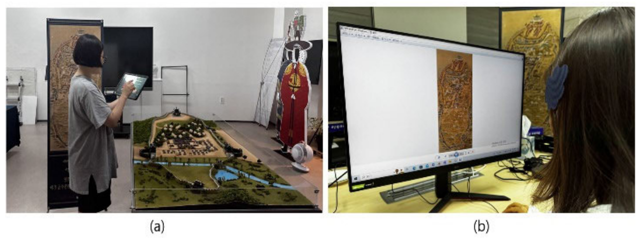

FIGURE 4. The pictures above depict participants involved in the experiment. (a): A participant experiencing augmented reality. (b): A participant participating in an interview after experiencing augmented reality, explaining the paintings.

To assess participants' satisfaction with AR usability and the usefulness of information and learning, we used a seven-point Likert scale with 19 items. The evaluated questionnaire was developed by selecting items from three scales commonly used in evaluations of AR experiences designed in a game-like format: the Post Study System Usability Questionnaire (PSSUQ) [39], the Game Experience Questionnaire [38], and the NASA-TLX tool [40].

Additionally, we created a separate assessment to measure the learning outcomes after the users experienced the AR system. Lastly, we conducted interviews to investigate narrative changes in more detail.

2) LEARNING EVALUATION TESTS

We evaluated the participants' learning abilities through a pre-test, an immediate recall test, and a delayed recall test. All three tests consisted of the same questions presented to every participant. This evaluation approach was designed based on previous studies [10], [41], [42] that utilized AR systems to assess learning abilities.

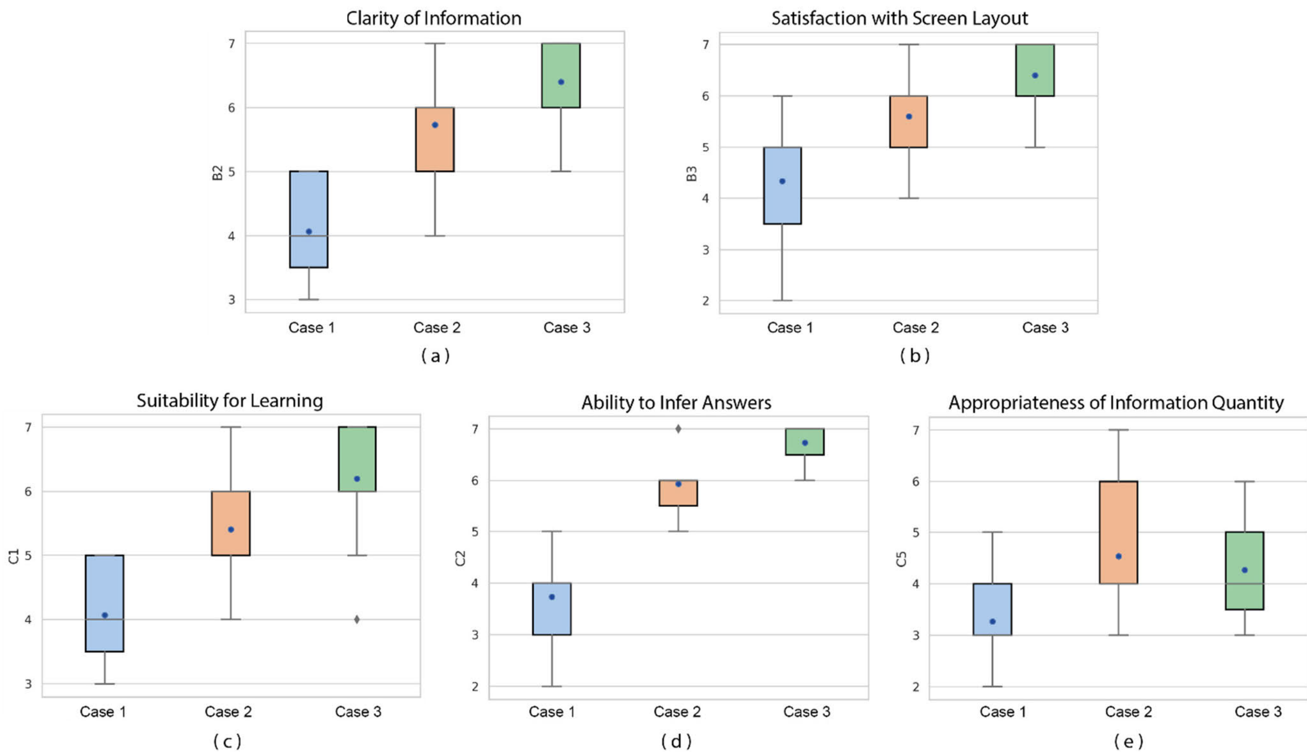

FIGURE 5. The following figures visually present the results of statistically significant usability evaluations. (a): Clarity of Information. (b): Satisfaction with Screen Layout. (c): Suitability for Learning. (d): Ability to Infer Answers. (e): Appropriateness of Information Quantity.

The learning assessment questionnaire consisted of a total of 12 questions. Questions 1 to 3 assessed basic facts about the CPs, while questions 4 to 6 presented problems requiring knowledge of the CP's storyline. Questions 7 to 10 asked for interpretations of important elements in the paintings. Finally, questions 11 and 12 required the participants to provide specific descriptions of the historical events in the CPs.

The questionnaire was designed to be solvable with sufficient observation of and experience with the AR system in our study. However, due to varying difficulty levels among the questions, careful observation and thorough experience with AR were necessary to answer them correctly.

3) INTERVIEWS

The interviews consisted of a total of seven questions. Participants were asked about the usefulness of the learning approach, notable aspects of the system, their recall of the historical narratives in the CPs, and their suggestions for system improvements. All interview content was recorded after obtaining consent to do so from the participants beforehand.

Previous studies used interviews as a supplementary tool, and there are limited cases in which interviews have been used to assess narratives. In a study investigating narratives associated with spatial locations [14], user-selected points of interest were used to construct stories about CH. We drew inspiration from this approach when designing our interview method.

Participants were shown the CPs on a computer monitor during the interviews. These paintings served as a visual aid to help the participants recall their experience with the AR system. They also facilitated discussions about the historical events depicted in the CPs and the information learned.

When answering questions related to historical narratives, participants pointed to specific elements within the paintings while providing their responses.

We recorded the mouse movements of all participants and analyzed these data as log data. Additionally, we transcribed the interview responses into written documents. We conducted a frequency analysis of word usage using text mining based on these transcriptions. This method is one of several analytical techniques used in text mining and helps to analyze descriptive data and quickly understand key information within data [43], [44].

E. PROCEDURES

In the first experiment, participants completed one AR system experience, two learning assessments, and one user evaluation.

In the initial phase of the first experiment, participants were given an explanation of the experimental procedure specific to their assigned case and then took the pre-test. Completing this test initially sparked interest in the AR system for participants who lacked prior knowledge of the CPs. After completing the test, participants experienced the AR system according to their assigned case.

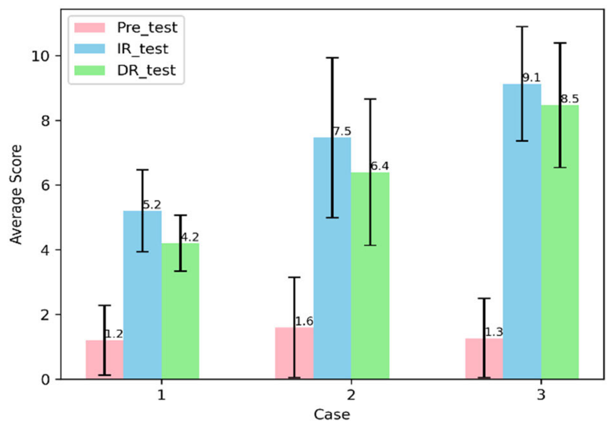

FIGURE 6. Displays the means and standard deviations of the three cases for the pre-test (Pre_test), immediate recall (IR_test), and delayed recall tests (DR_test).

Participants in Case 1 were given voice explanations by the experimenter before experiencing the AR system. The participants in the other cases experienced the AR system without any historical descriptions. The AR experience lasted for approximately 10 to 15 minutes, with some variation among participants.

After the AR experience, participants took the immediate recall test again and completed the user evaluation questionnaire. The second experiment occurred 2-3 days after the first experiment. Participants took the delayed recall test without re-experiencing the AR system and then participated in an interview. The entire process of the two sessions took approximately 40 to 50 minutes per participant.

F. ENVIRONMENT AND EQUIPMENT

The experiment took place in a space that included replicated CPs measuring 140cm × 60cm in actual size and three-dimensional models (diorama) of the same paintings measuring 182cm × 92cm × 90cm. The overall space is estimated to be 2.8m × 3m × 2.5m, providing sufficient room for participants to move around the models and engage in AR experiences. Interviews were conducted at a desk (180cm × 60cm × 85cm) adjacent to the AR experience area, where a computer and a 32-inch monitor were set up. The AR experience was conducted only in the first experiment, and scheduling was adjusted to avoid overlap with the second interview, ensuring that participants from both spaces did not encounter each other.

Based on findings from prior research [45], [46], [47], tablet PCs and mobile augmented reality are acknowledged for their ability to provide users with an engaging experience due to their user-friendly operation and accessibility. Therefore, in environments such as museums, the use of tablet PCs with high accessibility is considered more advantageous. Consequently, participants in this study engaged in augmented reality experiences using tablet PCs (Galaxy Tab S7+), equipped with the exact specifications employed in the previously mentioned study [20]. The tablet screen measured 285.0 × 185.0mm, and participants held the tablets themselves during the experiment (Figure 4).

IV. RESULTS

We conducted various analyses using the data collected during the study to test our hypotheses.

To assess usability, we used Cronbach's alpha test to determine the internal consistency reliability of the survey items. Although our questionnaire consisted of 17 items, we could not obtain reliability on two items. Therefore, we obtained reliability from the remaining 15 items after excluding the two items ($\alpha = 0.73$). We achieved relatively high reliability with a Cronbach's alpha value exceeding 0.60.

To assess the fulfillment of the assumption of homogeneity of the variance, crucial for our study, we conducted Levene's variance analysis. The results confirmed that the assumption was valid, enabling us to proceed with a one-way analysis of variance (ANOVA) and subsequent post-hoc testing using the Duncan test.

The ANOVA results revealed significant differences in the evaluations of clarity of information (B2: $F = 30.882$, $p = .000^{***}$), satisfaction with the screen composition (B3: $F = 16.085$, $p = .000^{***}$), suitability of learning (C1: $F = 22.219$, $p = .000^{***}$), inference of correct answers (C2: $F = 73.096$, $p = .000^{***}$), and suitability of information quantity (C5: $F = 5.902$, $p = .006^{**}$). These results indicate that participants' evaluations of these specific aspects as measured by each item differed significantly.

A. SATISFACTION WITH SCREEN LAYOUT

Figure 5(b) illustrates the satisfaction (B3) with the screen composition among participants in each case. The precise wording of this question is "I am satisfied with the screen composition of this system (including buttons and images)". Participants in Case 1 showed the lowest satisfaction level (M = 4.33, SD = 0.347, Min = 2, Max = 6). Participants in Case 2 exhibited above-average satisfaction (M = 5.60, SD = 0.214, Min = 4, Max = 7), while participants in Case 3 demonstrated higher satisfaction than both other cases (M = 6.40, SD = 0.190, Min = 5, Max = 7).

B. QUANTITY AND ACCURACY OF INFORMATION

We asked participants about the system's ability to provide accurate information on CPs, which is the central theme of the system, and whether the amount of information provided is appropriate (C5, B2). The results are presented in Figures 5(a) and (e).

Participants in Case 1 perceived the provided information as less accurate (M = 4.07, SD = 0.206, Min = 3, Max = 5) and felt that the quantity of data was insufficient (M = 3.27, SD = 0.206, Min = 2, Max = 5). In contrast, participants in Case 2 regarded the information as reasonably accurate (M = 5.73, SD = 0.248, Min = 4, Max = 7) and felt that the amount of information supplied was appropriate (M = 4.53, SD = 0.336). However, some participants considered the information overwhelming (Min = 3, Max = 7). These

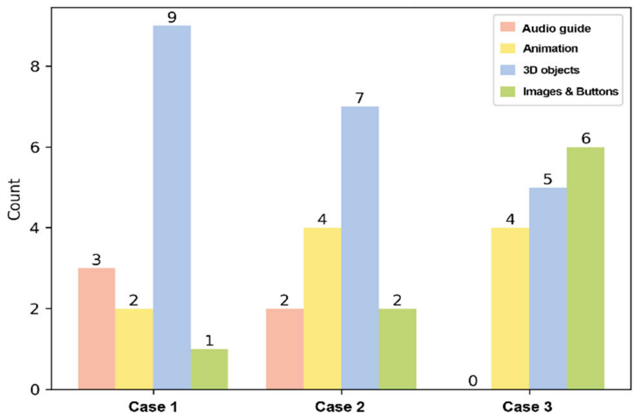

FIGURE 7. Preference for Presentation Methods chosen by participants in each case. Since visual Presentation methods were not explicitly provided to the users, they were given a choice based on four common presentation techniques as a reference.

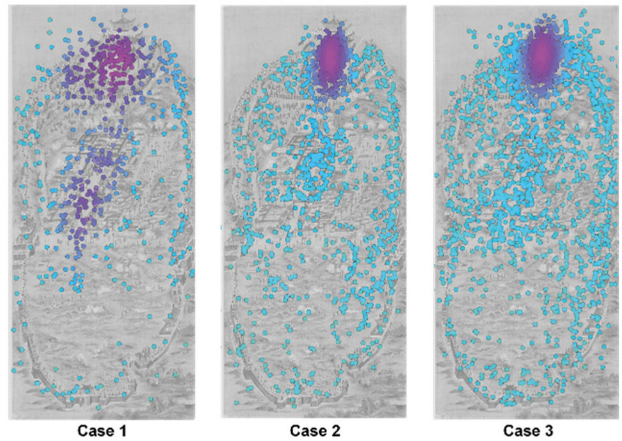

FIGURE 8. Captured the mouse pointer movements of participants while explaining everything they remembered about the paintings.

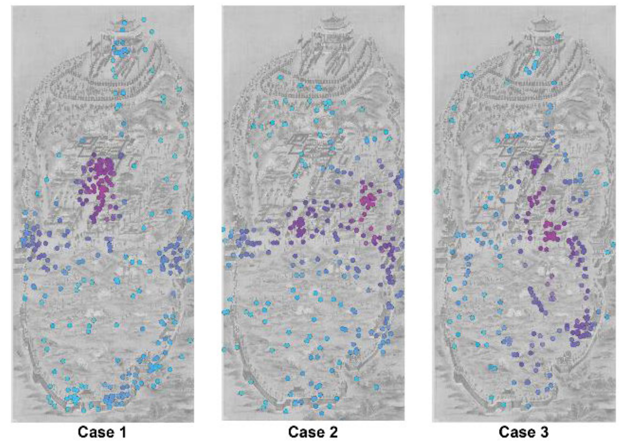

FIGURE 9. Recorded the explanations of participants who experienced the system but failed to learn certain aspects.

findings differ from the opinions of participants in Case 3. Participants in Case 3 reported that the system provided accurate information (M = 6.40, SD = 0.190, Min = 5, Max = 7) and perceived the amount of data as neither excessive nor insufficient (M = 4.27, SD = 0.267, Min = 3, Max = 6). Participants in Case 2 evaluated the quantity of information provided as higher than others.

C. USER'S INFERENCE CORRECT ANSWERS

The graph in Figure 5(d) presents the responses to the question of whether the users were able to infer the correct answers while using the system. For the Case 1 users, the general response indicated that inferring the correct answers was challenging on average (M = 3.73, SD = 0.228, Min = 2, Max = 5). However, some users indicated that they could infer the correct answers to some extent. The range of responses from Case 1 users was observed to be broader than in the other cases. In Case 2, users reported that inferring the correct answers was possible (M = 5.93, SD = 0.188, Min = 5, Max = 7). Similarly, Case 3 users also confirmed that they could infer the correct answers without much difficulty (M = 6.73, SD = 0.118, Min = 6, Max = 7).

D. SUITABILITY FOR LEARNING

To assess the suitability of learning with this system, we asked participants to answer, 'Is this system suitable for learning about CPs?' (C1 : Figure 5(c)) the necessary answers for learning (M = 3.73, SD = 0.228, Min = 1, Max = 5). Participants in Case 2 reported that learning with the system was ordinary yet optimistic (M = 5.40, SD = 0.235, Min = 4, Max = 7), and they found it easy to find the correct answers (M = 5.93, SD = 0.182, Min = 5, Max = 7). Finally, participants in Case 3 considered the system highly suitable for learning about CPs (M = 6.20, SD = 0.243, Min = 4, Max = 7) and found it very easy to find the correct answers (M = 6.73, SD = 0.118, Min = 6, Max = 7).

E. EVALUATING OF LEARNING ON CH AR

We created an evaluation questionnaire and conducted three identical tests to assess the participants' learning outcomes through our system. Subsequently, we performed Repeated Measures ANOVA to examine the validity of these results. The assumption of sphericity was violated ($p < 0.05$), so Greenhouse-Geisser correction was applied. The results of Greenhouse-Geisser indicated a significant impact ($p = 0.680$), confirming distinct differences among cases in the learning outcomes.

Figure 6 displays the means and standard deviations of the three cases for the pre-test, immediate recall, and delayed recall tests. In the pre-test, participants showed similarly low scores across all subjects (Case 1: M = 1.20, SD = 0.336, Case 2: M = 1.60, SD = 0.336, Case 3: M = 1.267, SD = 0.336) since the selected participants had minimal knowledge about CPs, which is the central theme of the system.

The results of the immediate recall test varied among the cases. Case 1 received the lowest evaluation score (M = 5.20, SD = 0.491), followed by Case 2 (M = 7.467, SD = 0.336), and Case 3 had the highest score (M = 9.133, SD = 0.336). Comparing these results with the pre-test,

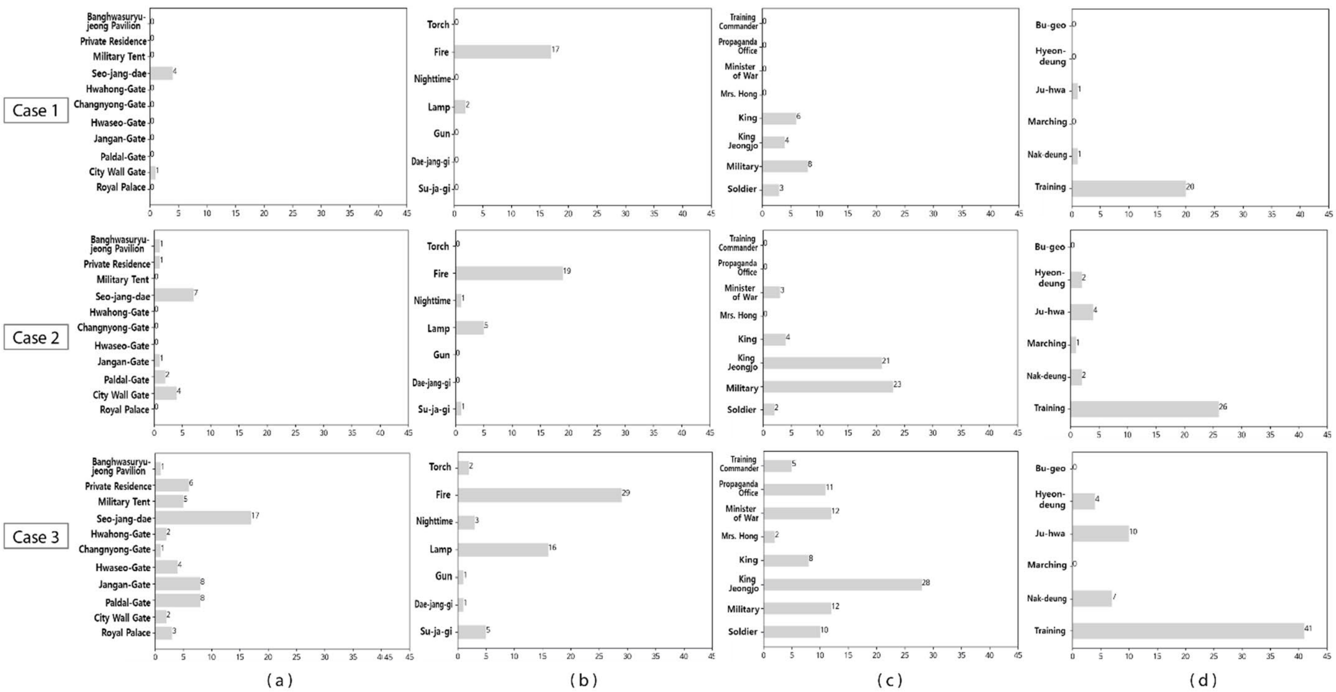

FIGURE 10. We conducted a word frequency analysis using text mining techniques based on the participants' interview content. (a): Collection of words related to the critical buildings depicted in the court paintings, (b): collection of terms associated with military training, (c): words referring to significant figures, and (d): collection of words and types of military training.

participants in Case 3 demonstrated the most significant improvement.

Overall evaluation scores in the delay recall test slightly declined (Case 1: M = 4.20, SD = 0.461, Case 2: M = 6.40, SD = 0.461, Case 3: M = 8.467, SD = 0.461). The ranking of evaluation scores remained consistent with the immediate recall test, showing a decline of approximately 0.7 to 1 point on average.

F. INTERVIEW

We conducted quantitative and qualitative analyses of the interviews to derive meaningful results to validate our research hypotheses. The interview consisted of seven questions, and we obtained significant results in three areas: participants' preferences for presentation methods, analysis of mouse movement, and word frequency analysis. We recorded mouse movements to analyze participants' narratives and performed text mining techniques for word frequency analysis on the recorded data (6 hours, 4 minutes, 36 seconds).

1) PREFERENCE FOR PRESENTATION METHODS

The investigation of participants' preference for presentation methods was conducted during the interview. We asked participants to choose their preferred method from four options, and their responses are presented in Figure 7.

In Case 1, the participants' most commonly chosen method was examining 3D objects (n = 9). This result had the highest number compared to other cases. The following preferences were audio guide (n = 3), animation (n = 2), and images with buttons (n = 1) in that order. One participant (P:5) requested, "Please explain which 3D object in AR should be viewed first next time."

In Case 2, participants preferred 3D objects the most (n = 7). However, unlike Case 1, animation (n = 4) was chosen as the next preference. Lastly, voice explanations (n = 2) and images with buttons (n = 2) received equal selections. Participant P22 mentioned, "It's good to experience the training directly, and it would be great to have summarized text displayed alongside."

In Case 3, participants preferred images with buttons (n = 6). Interestingly, no one selected voice explanations, and animation (n = 5) and 3D objects (n = 4) were chosen in that order. Participant P38 stated, "The information obtained through images and buttons combined with 3D objects made it easier to understand the information." Another participant (P42) mentioned, "A brief explanation of the animation is essential."

2) TRACKING MOUSE POINTER MOVEMENTS

To assess participants' understanding of CPs following the experiment, we asked them to provide narratives on CPs while directly viewing CPs. Participants elaborated on their understanding of CPs by pointing to specific content on the monitor using their mouse movements. We recorded these mouse movements, which were subsequently visualized as scatterplot heat maps in Figures 8 and 9.

Figure 8 captured the mouse pointer movements of participants while explaining everything they remembered about the paintings. Figure 9 recorded the explanations of participants who experienced the system but failed to learn certain aspects. The mouse movements varied slightly depending on the case.

In Figure 8, participants in Case 1 most frequently pointed to the upper part of the painting, where the "Seojangdae" (a building) and the middle "Haenggung" (a palace) are located. They also traced the perimeter of the painting, which represents the surrounding walls. In Case 2 and 3, the most frequently pointed locations were also the "Seojangdae" and "Haenggung." However, the frequency of these locations was significantly higher than in Case 1, with Case 3 ranking first and Case 2 second.

Regarding Figure 9, the heatmaps for Cases 2 and 3 showed similar patterns, making it challenging to identify significant results. In both cases, participants mentioned that they were unaware of the "Min-ga" (a residential area) next to the "Haenggung," the space at the bottom of the painting, and the road beside the walls. However, in Case 1, participants indicated that they were unaware of the specific names of certain elements, such as the gates on a section of the walls and a separate pavilion.

These results indicate that the participants' explanations were based on the locations they simply pointed to, which was insufficient to determine the specific differences in narrative outcomes. Therefore, we proceeded to analyze the participants' interview content.

3) WORD FREQUENCY ANALYSIS

To analyze the participants' interview responses, we performed word frequency analysis using text mining techniques. We examined the frequency of words used by participants in response to the interview questions and identified the underlying topics and concepts represented by those frequently used words. A total of 4,860 words were analyzed across the three cases, with Case 1 comprising 1,236 words, Case 2 comprising 1,425 words, and Case 3 comprising 2,199 words.

Figure 10(a) presents a collection of words related to the critical buildings depicted in the CPs, while Figure 10 (b) represents a collection of terms associated with military training. Figure 10 (c) includes words referring to significant figures, and Figure 10 (d) designates different parts of military training, with varying training content depending on the terms used. Analyzing the frequency of words for each case, we found that Case 3 used the most words across all collections. Notably, all the words related to the entire buildings (Figure 10 (a)) and significant figures (Figure 10 (c)) were present. Notably, the exact names of the four gates were mentioned. Additionally, words related to military training (Figure 10 (b)) and the terms of actual figures were also detected. The most frequently mentioned words in each collection were "Seojangdae" ($n = 17$), "fire" ($n = 29$), "King Jeongjo" ($n = 28$), and "training" ($n = 41$).

For Case 2, we detected words related to figures (Figure 9(b)) and the process of training (Figure 10 (d)). The most frequently seen words in each collection were "Seojangdae" ($n = 7$), "fire" ($n = 19$), "military" ($n = 23$), "King Jeongjo" ($n = 21$), and "training" ($n = 26$).

In Case 1, we found the fewest words detected across all collections. The most frequently mentioned words were "Seojangdae" ($n = 4$), "fire" ($n = 17$), "military" ($n = 8$), and "training" ($n = 20$).

Despite some similarities in the most frequently mentioned words across all cases, there are variations in their frequency of occurrence and the appropriate use of particular names based on the context.

V. DISCUSSION

A. PRESENTATION METHODS AND LEARNING ACHIEVEMENT

To investigate the relationship between presentation methods and learning outcomes, we conducted surveys and administered learning assessments. The findings corroborated our first hypothesis (H1), demonstrating that learning achievement is contingent upon the presentation design method. Furthermore, the results of our study provide evidence to support our second hypothesis (H2), which predicted that combining visual presentations with augmented reality 3D objects would result in improved learning outcomes, including enhanced understanding of historical context and recall of specific details.

Our validation of these two hypotheses yielded intriguing insights for each case. Firstly, participants consistently favored visual presentations over audio explanations, leading to enhanced learning outcomes. Secondly, participants achieved the highest level of learning when critical information was conveyed through a combination of visual presentations and 3D objects within an augmented reality (AR) environment. In this case, participants expressed the most favorable disposition towards learning CH using AR technology.

Lastly, participants perceived the amount of information provided differently depending on its accuracy. Each participant had varying perceptions of the quantity of information we provided. Participants felt the communication was limited in Case 1, which had the least utilization of Presentation methods. In Case 2, where Presentation methods were used but not combined with 3D objects, participants responded that the information was abundant. However, in Case 3, participants felt the amount of information supplied was appropriate. Therefore, it can be speculated that the perceived quantity of knowledge varies depending on the difference in Presentation methods.

B. PRESENTATION METHODS AND NARRATIVE

Participants developed different narratives based on how the information was presented, supporting our hypotheses (H3, H4). Specifically, our experiment's results allow us to conclude the following: Using heatmaps to visualize mouse pointer tracking enables us to understand the narratives participants create after experiencing augmented reality. This method helps us pinpoint the specific image areas users mention by analyzing cumulative pointer positions. In our study, we compared narrative differences between Cases 2 and 3 by analyzing point density in scatter plots.

Furthermore, we detected differences in participants' reports through word frequency analysis using text mining techniques. This suggests that how information is presented can influence how participants remember and recall specific details. While we didn't deliberately vary the amount of information during the experiment (the information remained consistent), different presentation methods led participants to use varying terminology to describe their narratives for each case. This finding strongly supports the heatmap analysis and underscores the clear distinctions observed between Case 2 and Case 3.

C. LIMITATIONS

Our study involved implementing various presentation methods for CH AR and conducting both quantitative and qualitative analyses of participants' experiences. While these analyses have provided valuable insights, there are several limitations to consider.

Firstly, the sample size is small. Although our results are statistically significant, a larger sample size could reveal more diverse cases.

Secondly, there is the issue of passive responses in interview responses. The experiment facilitators had to persuade the participants to conduct the interviews. While most participants actively engaged in the discussions, some occasionally displayed a passive attitude in their responses. Therefore, additional methods to elicit participant responses are needed during interviews.

Lastly, it is imperative to broaden the range of presentation methods. The presentation techniques we employed are currently widespread. Nevertheless, participants expressed a requirement for additional information guidance through innovative presentation methods. Additionally, it became evident that there is a demand for visual instructions on system usage, extending beyond CH-related information.

VI. CONCLUSION AND FUTURE WORK

In this study, we investigated the effects of different presentation methods on learning achievement and narrative changes in the context of mobile CH augmented reality (CP AR). To validate our hypotheses, participants experienced CP AR under three conditions and participated in two experiments. The results revealed differences in learning achievement and narrative formation among participants based on the presentation methods. Specifically, the visual presentation method combined with 3D objects in an AR environment facilitated participants' use of specific words related to CH.

Based on all these findings, we have concluded that using presentations in CH AR, which aims to provide both storytelling and information, requires appropriate design depending on the content and objectives. Therefore, our recommendations are as follows: (1) Define the core information of the CH, (2) Utilize visual Presentations iteratively, and (3) Specifically combine visual Presentations related to 3D objects in AR to deliver the content.

In the future, we plan to expand the range of presentation methods applicable to CH AR and conduct additional experiments by designing new visual guides. We also aim to investigate the differences and effects of Presentation methods between mobile devices and HMD devices. We believe such research will enhance the effectiveness and efficiency of CH AR and contribute to a more engaging CH experience for users.

REFERENCES

[1] R. L. De La Lama, S. de la Puente, J. C. Sueiro, and K. M. A. Chan, "Reconnecting with the past and anticipating the future: A review of fisheries-derived cultural ecosystem services in pre-Hispanic Peru," *People Nature*, vol. 3, no. 1, pp. 129–147, Feb. 2021.

[2] C. Pollalis, W. Fahnbulleh, J. Tynes, and O. Shaer, "HoloMuse: Enhancing engagement with archaeological artifacts through gesture-based interaction with holograms," in *Proc. 11th Int. Conf. Tangible, Embedded, Embodied Interact.*, Whitney Fahnbulleh, Jordan, Mar. 2017, pp. 565–570.

[3] N. Chung, H. Han, and Y. Joun, "Tourists' intention to visit a destination: The role of augmented reality (AR) application for a heritage site," *Comput. Hum. Behav.*, vol. 50, pp. 588–599, Sep. 2015.

[4] H. Park, E. Kim, H. Kim, J.-E. Shin, J. Kim, K. Kim, and W. Woo, "K-culture time machine: A mobile AR experience platform for Korean CH sites," in *Proc. 20th Int. Conf. Human Interface Manage. Inf., Inf. Appl. Services (HIMI)*, vol. 20, Las Vegas, NV, USA. Cham, Switzerland: Springer, Jul. 2018, pp. 167–180.

[5] J. Geigel, K. S. Shitut, J. Decker, A. Doherty, and G. Jacobs, "The digital docent: XR storytelling for a living history museum," in *Proc. 26th ACM Symp. Virtual Reality Softw. Technol.*, Nov. 2020, pp. 1–3.

[6] L. T. De Paolis, C. Gatto, L. Corchia, and V. De Luca, "Usability, user experience and mental workload in a mobile augmented reality application for digital storytelling in cultural heritage," *Virtual Reality*, vol. 27, no. 2, pp. 1117–1143, Jun. 2023.

[7] F. Bousbahi and B. Boreggah, "Mobile augmented reality adaptation through smartphone device based hybrid tracking to support cultural heritage experience," in *Proc. 2nd Int. Conf. Smart Digit. Environ.*, Oct. 2018, pp. 48–55.

[8] G. -D. Voinea, F. Girbacia, Cristian C. Postelnicu, and A. Marto, "Exploring CH using augmented reality through Google's Project Tango and ARCore," in *Proc. 1st Int. Conf. VR Technol. CH (VRTCH)*, vol. 1, Brasov, Romania. Cham, Switzerland: Springer, May 2018, pp. 93–106.

[9] N. Xu, Y. Li, X. Wei, L. Xie, L. Yu, and H.-N. Liang, "CubeMuseum AR: A tangible augmented reality interface for cultural heritage learning and museum gifting," *Int. J. Human–Comput. Interact.*, vol. 39, pp. 1–29, Feb. 2023.

[10] N. Xu, Y. Li, J. Lin, L. Yu, and H.-N. Liang, "User retention of mobile augmented reality for cultural heritage learning," in *Proc. IEEE Int. Symp. Mixed Augmented Reality Adjunct (ISMAR-Adjunct)*, Singapore, Oct. 2022, pp. 447–452, doi: 10.1109/ismar-adjunct57072.2022.00095.

[11] A. Angelopoulou, D. Economou, V. Bouki, A. Psarrou, L. Jin, C. Pritchard, and F. Kolyda, "Mobile augmented reality for cultural heritage," in *Mobile Wireless Middleware, Operating Systems, and Applications* (Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering), vol. 93. Berlin, Germany: Springer, 2012, pp. 15–22.

[12] J. Lee, H. Lee, D. Jeong, J. Lee, T. Kim, and J. Lee, "Developing museum education content: AR blended learning," *Int. J. Art Design Educ.*, vol. 40, no. 3, pp. 473–491, Aug. 2021.

[13] J.-E. Shin and W. Woo, "Design guidelines for a location-based digital heritage storytelling tool to support author intent," in *Proc. 3rd Digit. Heritage Int. Congr. (DigitalHERITAGE), 24th Int. Conf. Virtual Syst. Multimedia (VSMM)*, Oct. 2018, pp. 1–8.

[14] J.-E. Shin and W. Woo, "How space is told: Linking trajectory, narrative, and intent in augmented reality storytelling for cultural heritage sites," in *Proc. CHI Conf. Human Factors Comput. Syst.*, Apr. 2023, pp. 1–14.

[15] R. Boboc, M. Duguleană, G.-D. Voinea, C.-C. Postelnicu, D.-M. Popovici, and M. Carrozzino, "Mobile augmented reality for cultural heritage: Following the footsteps of Ovid among different locations in Europe," *Sustainability*, vol. 11, no. 4, p. 1167, Feb. 2019.

[16] Y. Georgiou and E. A. Kyza, "Bridging narrative and locality in mobile-based augmented reality educational activities: Effects of semantic coupling on students' immersion and learning gains," *Int. J. Hum.-Comput. Stud.*, vol. 145, Jan. 2021, Art. no. 102546.

[17] F. Cameron and S. Kenderdine, *Theorizing Digital Cultural Heritage: A Critical Discourse*. Cambridge, MA, USA: MIT Press, 2007.

[18] R. Stone and T. Ojika, "Virtual heritage: What next?" *IEEE MultiMedia*, vol. 7, no. 2, pp. 73–74, Apr./Jun. 2000.

[19] Y. Li and E. Ch'ng, "A framework for sharing cultural heritage objects in hybrid virtual and augmented reality environments," in *Visual Heritage: Digital Approaches in Heritage Science*. Cham, Switzerland: Springer, 2022, pp. 471–492.

[20] E. Yoo, O. Kwon, and J. Yu, "Evaluation of an augmented reality for historical context experiences of 3D restored court paintings," *IEEE Access*, vol. 11, pp. 39197–39212, 2023, doi: 10.1109/ACCESS.2023.3268528.

[21] H. P. Abbott, *The Cambridge Introduction to Narrative*. Cambridge, U.K.: Cambridge Univ. Press, 2008.

[22] M.-L. Ryan, *Avatars of Story*, vol. 17. Minneapolis, MI, USA: Univ. Minnesota Press, 2006.

[23] D. Herman, J. Manfred, and R. Marie-Laure, *Routledge Encyclopedia of Narrative Theory*. Evanston, IL, USA: Routledge, 2007.

[24] R. Shilkrot, N. Montfort, and P. Maes, "Narratives of augmented worlds," in *Proc. IEEE Int. Symp. Mixed Augmented Reality Media, Art, Social Sci., Humanities Design (ISMAR-MASH'D)*, Sep. 2014, pp. 35–42.

[25] A. J. Hunsucker, E. Baumgartner, and K. McClinton, "Evaluating an AR-based museum experience," *Interactions*, vol. 25, no. 4, pp. 66–68, Jun. 2018.

[26] F. Giariskanis, Y. Kritikos, E. Protopapadaki, A. Papanastasiou, E. Papadopoulou, and K. Mania, "The augmented museum: A multimodal, game-based, augmented reality narrative for cultural heritage," in *Proc. ACM Int. Conf. Interact. Media Exper.*, Jun. 2022, pp. 281–286.

[27] N. Lambert, M. Smith, and J. Rasool, "Designing an augmented reality exhibition: Leonardo's impossible machines," in *Proc. EVA London*, 2020, pp. 271–277.

[28] M.-L. Ryan, "The interactive onion: Layers of user participation in digital narrative texts," in *New Narratives: Stories and Storytelling in the Digital Age*. Lincoln, Nebraska: University of Nebraska Press, 2011, pp. 36–62.

[29] Y. Nam, "Designing interactive narratives for mobile augmented reality," *Cluster Comput.*, vol. 18, no. 1, pp. 309–320, Mar. 2015.

[30] G. Liestoel, "Augmented reality storytelling—Narrative design and reconstruction of a historical event in situ," *Int. J. Interact. Mobile Technol. (iJIM)*, vol. 13, no. 12, p. 196, Dec. 2019.

[31] M. B. Garcia, "Augmented reality in history education: An immersive storytelling of American colonisation period in the Philippines," *Int. J. Learn. Technol.*, vol. 15, no. 3, pp. 234–254, 2020.

[32] K. R. Bujak, I. Radu, R. Catrambone, B. MacIntyre, R. Zheng, and G. Golubski, "A psychological perspective on augmented reality in the mathematics classroom," *Comput. Educ.*, vol. 68, pp. 536–544, Oct. 2013.

[33] A. Matassa and A. Rapp, "Map: Making: Designing a mobile application for enhancing memories' retrieval," in *Proc. 17th Int. Conf. Human-Comput. Interact. Mobile Devices Services Adjunct*, Aug. 2015, pp. 994–1001.

[34] C. Pollalis, A. Gilvin, L. Westendorf, L. Futami, B. Virgilio, D. Hsiao, and O. Shaer, "ARtLens: Enhancing museum visitors' engagement with African art," in *Proc. ACM Conf. Companion Publication Designing Interact. Syst.*, May 2018, pp. 195–200.

[35] D. Rammos and T. Bratitsis, "Alternative teaching of history subject in primary school: The case of the 3D HIT playful activity," in *Proc. Int. Conf. Games Learn. Alliance*, Cham, Switzerland: Springer, 2019, pp. 457–467.

[36] J. Challenor and M. Ma, "A review of augmented reality applications for history education and heritage visualisation," *Multimodal Technol. Interact.*, vol. 3, no. 2, p. 39, May 2019.

[37] E. Ventoulis and S. Xinogalos, "'AR the gods of Olympus': Design and pilot evaluation of an augmented reality educational game for Greek mythology," *Multimodal Technol. Interact.*, vol. 7, no. 1, p. 2, Dec. 2022.

[38] W. A. IJsselsteijn, Y. A. W. de Kort, and K. Poels, *The Game Experience Questionnaire*. Eindhoven: Technische Universiteit Eindhoven, 2013, p. 9. [Online]. Available: https://research.tue.nl/en/publications/the-game-experience-questionnaire

[39] J. Lewis, "Psychometric evaluation of the PSSUQ using data from five years of usability studies," *Int. J. Human-Comput. Interact.*, vol. 14, no. 3, pp. 463–488, Sep. 2002.

[40] S. G. Hart, "NASA-task load index (NASA-TLX); 20 years later," in *Proc. Human Factors Ergonom. Soc. Annu. Meeting*, vol. 50. Los Angeles, CA, USA: Sage, 2006, pp. 904–908.

[41] F. Bermudez-Rattoni, "Studies of short-term avoidance memory," in *Neural Plasticity and Memory: From Genes to Brain Imaging*. Boca Raton, FL, USA: CRC Press, 2007.

[42] M. Weerasinghe, A. Quigley, K. C. Pucihar, A. Toniolo, A. Miguel, and M. Kljun, "Arigatō: Effects of adaptive guidance on engagement and performance in augmented reality learning environments," *IEEE Trans. Vis. Comput. Graphics*, vol. 28, no. 11, pp. 3737–3747, Nov. 2022.

[43] C. Hacking, H. Verbeek, J. P. H. Hamers, K. Sion, and S. Aarts, "Text mining in long-term care: Exploring the usefulness of artificial intelligence in a nursing home setting," *PLoS ONE*, vol. 17, no. 8, Aug. 2022, Art. no. e0268281.

[44] B. Wang, K. Ma, L. Wu, Q. Qiu, Z. Xie, and L. Tao, "Visual analytics and information extraction of geological content for text-based mineral exploration reports," *Ore Geol. Rev.*, vol. 144, no. 2022, May 2022, Art. no. 104818.

[45] C. Baker, "Virtual, artificial and mixed reality: New frontiers in performance," in *Proc. 23rd Int. Conf. Virtual Syst. Multimedia (VSMM)*, Oct. 2017, pp. 1–10.

[46] B. MacIntyre and J. D. Bolter, "Single-narrative, multiple point-of-view dramatic experiences in augmented reality," *Virtual Reality*, vol. 7, no. 1, pp. 10–16, Dec. 2003.

[47] G. Raeburn and L. Tokarchuk, "Varying user agency and interaction opportunities in a home mobile augmented virtuality story," in *Proc. IEEE Int. Symp. Mixed Augmented Reality (ISMAR)*, Oct. 2021, pp. 347–356.

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