Techno.COM, Vol. 24, No. 2, Mei 2025: 508-523

Thematic Analysis and Game-based Learning for the Development of Virtual Cultural Heritage Museums as Learning Agents

Ahmad Zainul Fanani[1], **Arry Maulana Syarif***[2], **Deddy Award Widya Laksana**[3], **Heribertus Himawan**[4], **Hanny Haryanto**[5]
The Computer Science in Arts and Culture Research Center
Universitas Dian Nuswantoro, Semarang, Indonesia
E-mail : a.zainul.fanani@dsn.dinus.ac.id[1], arry.maulana@dsn.dinus.ac.id[2], himawan26@dsn.dinus.ac.id[3], deddyaward.widyalaksana@dsn.dinus.ac.id[4], hanny.haryanto@dsn.dinus.ac.id[5]*
**Corresponding author*
Received 9 May 2025; Revised 13 May 2025; Accepted 19 May 2025

Abstract - This study aims to develop a virtual cultural heritage museum as a learning agent. Qualitative approach with thematic analysis method was applied to design a virtual museum based on the perspective of museum management as a provider of learning facilities. The opinions collected were in the form of challenges and obstacles in functioning the museum as a provider of learning facilities. Opinions were used to identify the theme of the virtual museum, and synthesized with six strategies in effective learning. The resulting synthesis was then used to develop a virtual museum model using a game-based learning approach. The Photogrammetry technique was used for 3D reconstruction of cultural heritage objects to achieve high precision results, both in terms of shape and texture. The evaluation conducted using the User Accaptence Test technique shows that the proposed model and method can actualize the characteristics of effective learning strategies.

Keywords - Thematic analysis, Game-based learning, Learning agent, Virtual museums, Photogrammetry

1. INTRODUCTION

Museums play an important role in education as a space for learning outside the formal educational environment for access to information and collections of objects of historical, cultural, scientific and other value. As a source of knowledge, museums have broad potential in developing programs that can support learning. Virtual museums are one of the museum programs that enable inclusive access and learning experiences, where everyone can have access to explore the content in virtual museums. The development of information technology enables the digitalization of museums with personalized experiences [1] with designs that can meet the needs, preferences and characteristics of users. With all the assets owned, the museum has a role as a learning agent. The design of the right virtual museum model is needed to function the museum as a learning agent. Graphic elements, aesthetics, information management, interoperability, learning models, and implementation in education are important parts in developing a virtual museum as a learning agent that is able to build new knowledge or competencies using facts and concepts learned in a virtual environment, but unpreparedness in managing these elements is a common problem encountered in designing virtual museums [2].

In this study, we develop a virtual cultural heritage museum model as a learning agent that is able to present content inclusively and support personalization of experiences to achieve effective learning strategies. The thematic analysis approach is used to develop a virtual cultural heritage museum that can act as a learning agent. We offer a search for solutions in the digitalization of effective learning strategies through the perspective of museum managers as asset

owners. Strengthening the management of elements that are important in developing a virtual museum as a learning agent is identified using a thematic analysis approach to produce a virtual museum model. Challenges and obstacles in presenting museum assets to support learning are formulated based on opinions from museum managers. Furthermore, the findings were used to develop a virtual museum models and application programs.

Museums have a strong role in education, making learning subjects easier, and supporting academic success in the development of thinking skills, curiosity, creativity and history, aesthetic perspective, reflective practice, self-awareness, and interprofessional teamwork [3-4]. Museums offer inclusion in education that can be categorized into: learning subjects, group visits, training and internships, and health therapies for people with dementia and Alzheimer's [5]. Art museum-based courses were used in integrating arts and humanities into the medical curriculum to support clinical medical students to thrive [6]. Museum digitalization encourages the development of museum-based learning that utilizes digital technology as a transferable, sustainable, and classroom-friendly learning medium [7]. Virtual museum is a modern organized informal education system [8]. Virtual museums play a role in the digital transformation of cultural heritage preservation and learning [3]. Although virtual museums cannot yet present richer experiences than visits to actual museums, they can provide more exploratory learning experiences through access to objects in a 3D visual format without distance, including immersive experiences through sound and interaction [1]. Moreover, the gamification approach in virtual museum development supports active learning and critical thinking [9]. An approach is needed that is able to combine and strengthen the role of virtual museums as preservers of cultural heritage and learners. Digitizing museum assets into virtual formats needs to be supported by effective digitalization of learning.

There are six strategies for effective learning [10]: 1) Spaced practice for planning effective and manageable work sessions, 2) Retrieval practice for getting a sense of what you already know and identifying gaps in your knowledge, 3) Elaboration for getting deeper insight on a topic, 4) Concrete examples for mastering the subject, 5) Dual coding which combines text and images, and 6) Interleaving by changing the order of topics in each learning session. These six strategies make learning more accessible and create free evidence-based resources for teachers and students [11]. Memorization strategies are part of effective learning strategies that increase the absorption of information [12]. Actualization of effective learning strategies into virtual museums is necessary to enhance the role of virtual museums as learners. Thematic analysis is appropriate for finding solutions to such problems. Thematic analysis developed for psychological research by Virginia Braun and Victoria Clarke since 2006 is a flexible method that can be adapted to various types of research [13]. Thematic analysis is commonly used in social sciences, processed using human judgment to identify explicit and latent meanings in qualitative data [14], and has been used in various studies to develop videogames and VR applications in constructing experiences, motivations, reactions, interactions, and Game Transfer phenomena [15]. This approach is popular in qualitative research involving qualitative data analysis, and is able to capture in detail various subjects and interpretations of those subjects [16] through careful examination of the data to identify common themes, topics, ideas, and patterns of meaning that recur [13]. This approach was used by [17] to identify important themes emerging in the metaverse topic. Thematic analysis that investigates qualitative data that provides broad answers to the research questions and objectives of the study [18], has complicated challenges in presenting the results as a conceptual model [19]. Therefore, practical guidance is needed to transform the themes generated from the thematic analysis process into a conceptual model. This practical guidance can be in the form of values or characteristics of the subjects being studied. In the context of developing a virtual museum as a learning agent, the values of effective learning strategies are used to transform themes into a virtual museum model.

The relationship between the theme and the virtual museum model can be built using game-based learning, an approach that utilizes game assets in the learning process. Game-based learning, which is generally in the format of serious games or educational games, is an innovative

learning approach that supports student engagement in learning, and improves learning outcomes; gamification is a learning strategy of Game-based learning that transforms the process of thinking in games into problem solving [20]. Game-based learning can increase students' motivation, emotional engagement, and enjoyment, making it suitable for educational planning [21], but the long-term consequences and impact on students of implementing game-based learning still need to be studied further [22]. However, effective learning strategies are the solution for transferring information from short-term memory to long-term memory [10]. Mobile game-based learning that utilizes Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) technology has great potential and will continue to develop as a medium used in learning about cultural heritage [23].

The development of easy-to-operate mobile device technology, such as tablets and mobile phones, has supported VR applications that can produce moving image displays in museums; this makes museum artifacts and their information more accessible to anyone via the Internet [24]. One of the challenges in developing a virtual cultural heritage museum is modeling objects into 3D format with a high level of precision, both in terms of shape and texture. Photogrammetry techniques are widely used for 3D reconstruction of this problem. Photogrammetry or aerial survey is a mapping technique through photos to take several images of objects at different angles. Photogrammetry is able to model objects in detail, and is appropriate for 3D reconstruction of cultural heritage objects [25-27].

2. METHOD

This study aims to develop a virtual museum that acts as a learning agent, and effective learning strategies are used as references in its development. There are four stages in the development of a virtual cultural heritage museum as a learning agent that is able to present content inclusively and support personalization of experiences to achieve effective learning strategies. The first stage is the thematic analysis process to produce a virtual museum design. This stage is designed based on the experience of conventional museum management which aims to identify the opinions of museum managers about the learning experience at the museum. Furthermore, the second stage is the development of a virtual museum model as a learning agent which is carried out using references from the principles of effective learning strategy to validate the suitability of the design as a learning agent. At this stage, if the virtual museum model does not meet these principles, the steps will return to the first stage. This is repeated until the virtual museum model meets the principles of effective learning strategy to continue to the third stage, namely the development of a virtual museum application. The fourth stage is an evaluation to measure the performance of the virtual cultural heritage museum design. The process and implementation at the evaluation stage are described in the Results section. Figure 1 shows an illustration of the proposed virtual cultural heritage museum development model.

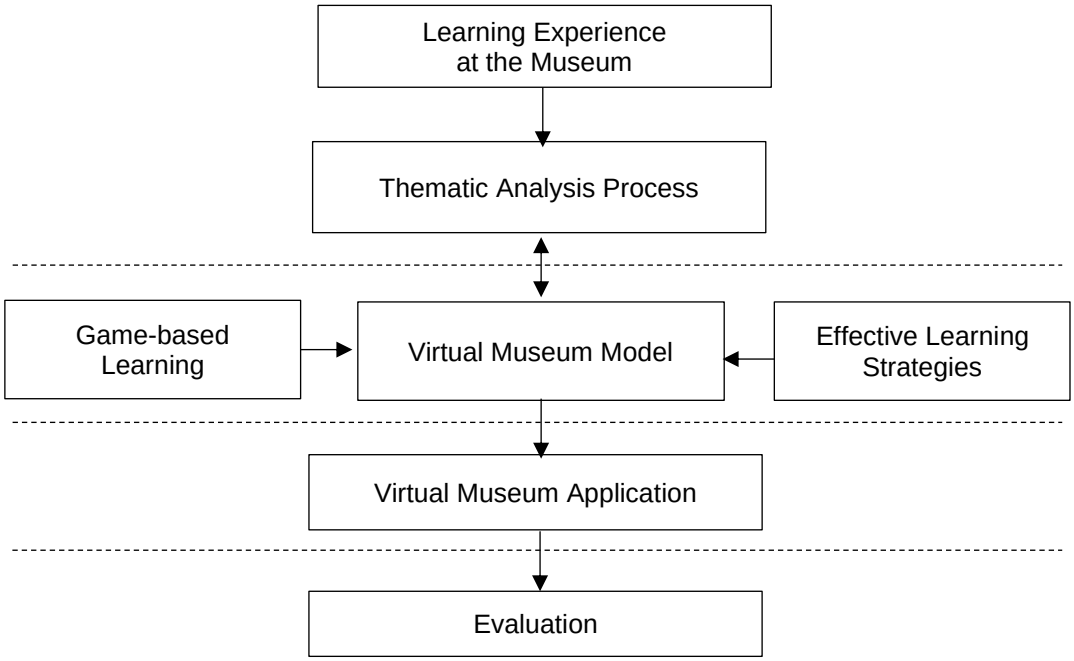

Figure 1. The proposed method of developing a virtual museum as a learning agent`

2.1. Thematic Analysis Process

The most common form of conducting thematic analysis that can prevent the analytical formulation from confirmation bias consists of six steps: 1) familiarization, 2) coding, 3) generating themes, 4) reviewing themes, 5) defining and naming themes, and 6) writing up [13]. Meanwhile, [18] proposed six steps that include conceptualization model development in qualitative research: 1) selection of quotations, 2) keywords, 3) coding, 4) themes, 5) conceptualization, 6) development of conceptual model. In this study, the method in the thematic analysis process is determined by modifying the two methods into four stages: 1) familiarization, 2) coding, 3) generating themes, 4) Conceptual model. The conceptualization and development of conceptual model stages proposed [18] are combined into the conceptual model stage. The results of the development of the conceptual model are then used to design and develop the system. At this stage, the prototyping method that actively involves clients in system development until the system is completely built is used to validate the suitability of themes to client needs.

The four stages in the proposed thematic analysis process were used to formulate research questions to analyze and identify the characteristics of the learning experience at the museum, and learning features in the virtual museum. We collaborated with the Ranggawarsita Museum which manages a collection of cultural heritage objects. The Ranggawarsita Museum is located in Semarang City, Central Java Province, Indonesia. Seven museum staffs selected by the museum management were involved as opinion providers in the implementation of thematic analysis to identify themes in the learning experience at the museum. We deliberately focused on collecting opinions about the learning experience at the museum only from the perspective of museum managers to find weaknesses in managing the museum as a learning agent. Furthermore, the results of the opinion collection were used to design the virtual museum.

2.1.1. Familiarization

The first step in this stage aims to obtain a comprehensive picture of all the data collected. Observations and interviews with the Ranggawarsita museum managers were conducted to identify the museum's organizational structure and tasks, as well as to identify the characteristics of museum visitors. Based on observations and interviews, four main points were obtained that

represent a comprehensive picture of the learning experience at the museum. Table 1 describes the four main points with the character E to symbolize the learning experience at the museum component.

Table 1. The results of the familiarization process in the learning experience at the museum

ID	Components
E1	The number of cultural heritage collections far exceeds the capacity of the museum's exhibition space.
E2	The mechanism for replacing cultural heritage objects for display is carried out periodically.
E3	The role of museum guides is to provide information to visitors about the cultural challenge objects on display.
E4	The characteristics of collective visitors are those who visit the museum in groups from an institution, and non-collective visitors are those who do not represent any institution when visiting the museum

2.1.2. Coding

The coding process was carried out by highlighting (in bold) sentences or phrases to extract respondents' opinions or answers, then the extracted data is classified or labeled to describe it. Table 2 shows an example of the results of extracting respondents' opinions about the learning experience in the museum with the Codes column including the character C to symbolize the codes.

Table 2. Example of coding process results in learning experience at the museum

Extraction of Respondent Opinions		Codes
E1	The excessive number of cultural heritage collections compared to the museum's exhibition space requires **museum managers and staff to work extra hard** (C1, C2, C3) in managing them.	(C1) Difficulties in managing cultural heritage objects due to limited space
	Currently, the Ranggawarsita Museum building has one floor, **more than 10 floors are needed** (C1) to be able to display all of its collections	(C2) Security of cultural heritage objects
E2	**The procedure for replacing cultural heritage objects for exhibition is very strict** (C1, C2) considering **the age of the cultural heritage objects** (C3).	
	There is a sense of worry if **damage occurs** (C3) when replacing cultural heritage objects for exhibition	(C3) Vulnerability of cultural heritage objects
E3	I am **not sure that all visitors listen and pay close attention to the information** (C4) given by the museum guide.	(C4) neglected information
	The large number of collections of cultural heritage objects on display makes **the information conveyed or displayed incomplete** (C5)	(C5) incomplete information
E4	Visitors, especially collective ones, can **only see the cultural heritage objects on display, and cannot make requests according to their needs** (C1, C6)	(C6) limited personalization of experience
	Museum managers **do not provide learning assignments** (C7) to visitors so that the impact of increasing knowledge can only be measured by the visitors themselves or the teachers who accompany them.	(C7) no assignment procedures in learning

2.1.3. Generating Themes

The next stage is generating themes to identify patterns in codes in Learning experience at the museum. There are four themes that are issues in the development of virtual museums, namely: Security of cultural heritage objects (security), Limited access to information (information), Limited personalization of experiences (experiences), and Limited learning processes (learning). These themes are symbolized by T1, T2, T3, and T4, respectively. Table 3 shows the results of generating themes in the learning experience at the museum component.

Table 3. Results of generating themes in the learning experience at the museum component

Codes		Themes
C1	Difficulties in managing cultural heritage objects due to limited space	(T1) Security
C2	Security of cultural heritage objects	(T1) Security
C3	Vulnerability of cultural heritage objects	(T1) Security
C4	Ignored information	(T2) Information
C5	Incomplete information	(T2) Information
C6	Limited personalization of experience	(T3) Experiences
C7	No assignment procedures in learning	(T4) Learning

2.2. Game-based Learning for Virtual Museum Model Development

Next phase is to design the virtual museum conceptual model developed based on the relationship between the four themes and the effective learning strategy principles. Effective learning strategies used by [18] were implemented in designing the conceptual model. There are six components in effective learning strategies (S): Spaced practice for planning effective and manageable work sessions (S1), Retrieval practice for getting a sense of what you already know and identifying gaps in your knowledge (S2), Elaboration for getting deeper insight on a topic (S3), Concrete examples for mastering the subject (S4), dual coding which combines text and images (S5), and interleaving by changing the order of topics in each learning session (S6).

Table 5. The results of generating themes in the learning experience at the museum component

T	S1	S2	S3	S4	S5	S6
T1	Access to the virtual museum is open 24 hours	Access to the virtual museum is open 24 hours	Access to the virtual museum is open 24 hours	Access to the virtual museum is open 24 hours	Access to the virtual museum is open 24 hours	Access to the virtual museum is open 24 hours
T2	Thematic information of cultural heritage objects	Information in image and text formats	Guides to building concepts and ideas	Thematic information of cultural heritage objects	Information in image and text format	Thematic information of cultural heritage objects
T3	Features to determine virtual visit schedules	Features to explore information on cultural heritage objects	Features for group discussions	Features for notes	Features for displaying 3D objects precisely, both in shape and texture.	Features to determine virtual visit schedules
T4	Features to create notes or recordings	Features to create and validate notes or recordings	Features to record concepts and ideas	Features for taking notes	Features for observing objects in detail	Feature to choose display theme in each virtual visit

A game-based learning approach was used to identify the game elements needed to actualize six effective learning strategies across four themes: security (T1), information (T2), experience (T3), and learning (T4). The results obtained are in the form of features and access control for virtual museum visitors as described in Table 4 with T representing Theme, and S representing effective learning strategies. Next, a gamification process was carried out on these results. The characteristics obtained in the development of virtual museums as learning agents are: online virtual museum for 24-hour access, single-player and Multiplayer game modes for individual or group virtual visits, note and recording forms for individual or group learning purposes, access control for visitors based on teacher, student, or individual roles, details of shape,

texture, and proportional scale of virtual cultural heritage objects in 3D format, information in concise and clear text. The gamification process was then applied to the form of features and access control to determine game elements that match the characteristics of the virtual museum that have been identified, and the results can be seen in Table 5.

Table 5. The results of the game elements of virtual museums as learning agents

Features and Access Control	Game Elements
Access to the virtual museum is open 24 hours	Online virtual museum
Thematic information of cultural heritage objects	Virtual rooms to display cultural heritage objects based on their theme
Features to determine virtual visit schedules	Virtual visit schedule forms
Features for group discussions	Single-player and multiplayer modes
Features to create and validate notes or recordings	Validation forms
Guides to building concepts and ideas; Features to create notes or recordings; Features to record concepts and ideas; Features for notes; Features for taking notes	Notes and recordings forms
Features for displaying 3D objects precisely, both in shape and texture; Features for observing objects in detail; Information in image and text formats; Features to explore information on cultural heritage objects	2D, 3D and text formats information

Online virtual museum for 24-hour access is implemented on a virtual cultural heritage museum model as a learning agent based on effective learning strategies with the support of features that consists of user role, game modes, discussion group, information, virtual visiting time, virtual visit tracking, virtual visit purpose, and types of virtual visit. There are five user control accesses in the virtual museum that was developed: 1) Administrator is a museum manager who is responsible for: determining the display theme, number of rooms, arranging the display of cultural heritage objects in 3D format in each room, presenting information, either in 2D image format or text, on each cultural heritage object, answering visitor questions; 2) Teachers are visitors who have access to: determine the rooms to be visited based on the assignments they make, control and validate student activities in the context of the assignment; 3) Students are visitors who have access to: visit rooms that have been determined by their teacher in the context of the assignment, or visit other rooms, form discussion groups with other students in the context of the assignment, determine the visit schedule; 4) Member guests are individual visitors who have access to visit the virtual museum and make notes for their personal needs; 5) Non-member guests are individual visitors who have access to visit the virtual museum.

Information on cultural heritage objects is presented in text and 2D images formats, including in 3D objects format, where details of shape, texture, and proportional scale of virtual cultural heritage objects can be observed precisely. Moreover, users can visit the virtual museum in single player or multiplayer game mode for individual or group virtual visits, Visitors can communicate with each other via the chat feature in text, audio, and video formats, to support discussions or questions and answers. Furthermore, the model includes provisions for virtual visiting time, virtual visit tracking, virtual visit purpose, and types of virtual visit. Figure 2 shows an illustration of a virtual cultural heritage museum model as a learning agent based on effective learning strategies.

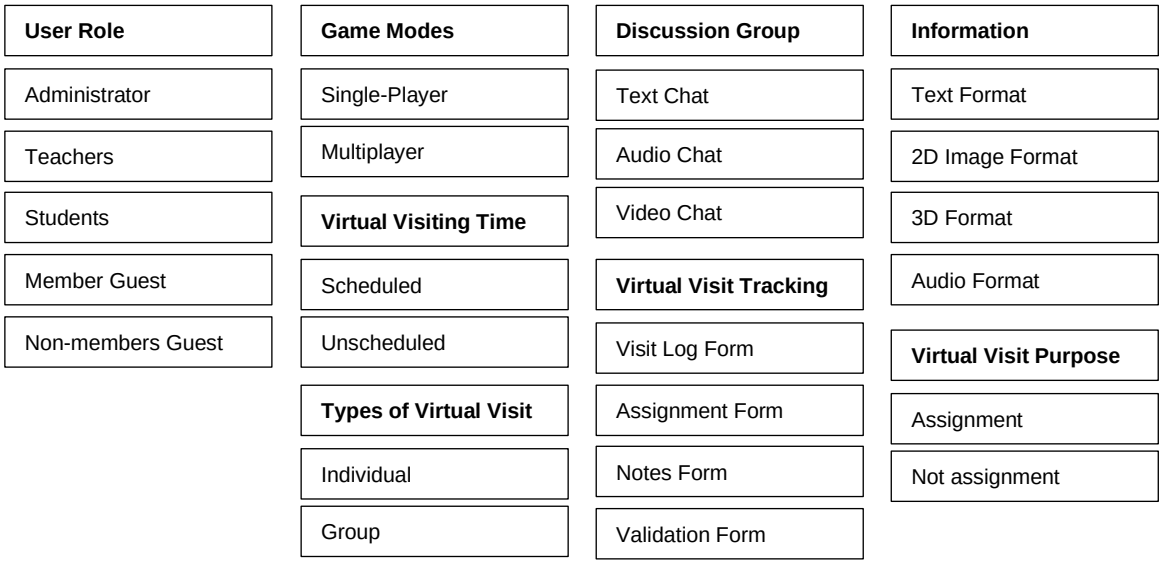

Figure 2. The proposed virtual cultural heritage museum model as a learning agent based on effective learning strategies

2.3. Virtual Museum Application Development

At this stage, the virtual museum application was developed using the proposed model. The virtual museum application was designed to run on Android and iOS mobile phone platforms, taking into account that the target users are much more likely to use mobile phone devices than Head-Mounted Displays. The application development consists of two stages: 1) data collection through photo documentation, notes containing information about cultural heritage objects, and digitization of cultural heritage objects through 3D reconstruction, and 2) virtual museum programming. Cultural heritage objects selected for display in the virtual museum prototype were determined by the museum manager based on periodization to be categorized thematically. Four themes were selected based on periodization, which were: Prehistoric period, Hindu-Buddhist period, Islamic period, Movement Period.

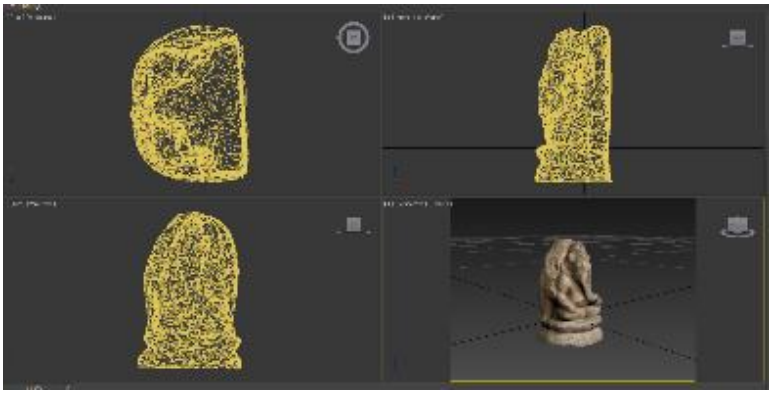

Figure 3. Illustration of the process of editing cultural heritage objects using a 3D editor

Next, the selection of cultural heritage objects was based on their themes. On average, each theme contains 25-35 cultural heritage objects. Digitization of cultural heritage objects was carried out using the Photogrammetry technique. The technique can reconstruct cultural heritage objects into 3D format with a high level of precision, both for details of the shape and texture of

the object. The 3Ds Max application program was used to edit 3D objects of cultural heritage objects while maintaining the object's dimensional scale for proportionality. Figure 3 illustrates the process of editing cultural heritage objects using a 3D editor, and Figure 4 shows an example of the results of 3D reconstruction of cultural heritage objects included in the Hindu-Buddhist period theme, which are the Durga Mahisa Suramardini (left) and Ganesha (right) statues.

Figure 4. Example of the 3D reconstruction results on cultural heritage objects, which are the Durga Mahisa Suramardini (left) and Ganesha (right) statues

3. RESULTS

This study aims to develop a virtual cultural heritage museum as a learning agent. The learning design was built based on the perspective of museum management who provides learning facilities. The development of the virtual cultural heritage museum application, including the 3D reconstruction process of cultural heritage objects, was carried out using the prototyping method. We actively communicate and discuss at every stage of development with the museum management to obtain results that are in accordance with the expectations of the museum management. Figure 5 shows the screenshots of the virtual museum application program developed in this study.

Figure 5. The screenshots of the Ranggawarsita virtual museum application displaying sign-in page (1); display room page (2), activity in group (3), display object details (4).

User acceptance testing (UAT) was conducted to test the performance of the virtual cultural heritage museum as a learning agent based on effective learning strategies. The testing involved two classes of high school, each consisting of one teacher and 36 students, and one teacher and 29 students. In addition, seven staff of the Ranggawarsita Museum were involved as museum guides. Each respondent was instructed to install the Ranggawarsita virtual museum application on their smartphone. The specified test scenario was:

1. Each teacher divided their students into groups of 4-6 students, and appointed one student as the group leader in each group. As a result, the first class consisted of six groups with each group consisting of six students. Meanwhile, the second class consisted of five groups, with four groups consisting of six students, and one group consisting of five students.
2. The teacher gives an assignment within a two-week period to conduct virtual visits and observations of cultural heritage objects exhibited in the virtual museum based on their periodization categories, and to make a report on the results of the observations.
3. Each group was free to determine the visit schedule, including the order of display rooms categorized based on periodization.
4. Each group must be accompanied by a virtual museum guide for at least three virtual visits.
5. Each student is required to make at least one virtual visit and observation to each display room individually.
6. The teacher must accompany at least one virtual visit from each group of students.

Next, a questionnaire was distributed to a total of 65 students to assess the suitability of the virtual museum as a learning agent in actualizing effective learning strategies. A Likert scale was used with a range of 1-5 representing strongly disagree - strongly agree answers to each statement in the questionnaire representing six strategies in effective learning. Table 6 shows the questionnaire and its results, with P represents effective learning strategies, and P1 to P6 containing statements for the components: spaced practice, retrieval practice, elaboration, concrete example, dual coding, and interleaving. Meanwhile, Figure 6 shows the results of the questionnaire in diagram format.

Table 6. The results of measuring the suitability of virtual museums as learning agents in actualizing effective learning strategies

P	Statements	1	2	3	4	5	Total
P1	After a virtual visit and observation to the virtual museum, I re-studied the notes that I had not understood in my free time.	0	0	3	28	34	65
P2	By using the Ranggawarsita Virtual Museum, I can memorize cultural heritage objects based on their periodization.	0	0	14	22	29	65
P3	By using the Ranggawarsita Virtual Museum, I can understand that every object is not just a display, but has more value than just a display object.	0	2	4	17	42	65
P4	By using the Ranggawarsita Virtual Museum, I can give a real example of the use of cultural heritage objects.	0	0	2	16	47	65
P5	By using the Ranggawarsita Virtual Museum, I can explain the characteristics of cultural heritage objects based on their periodization, both in the form of simple outline drawings, sentences, and verbally.	0	7	11	31	16	65
P6	By using the Ranggawarsita Virtual Museum, I can memorize more because I am free to organize virtual visits and observations to the virtual museum individually.	0	0	5	17	43	65

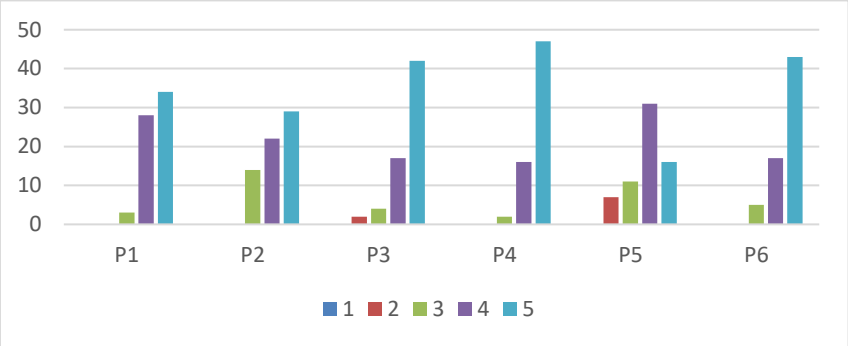

Figure 6. The diagram of the results of measuring the suitability of virtual museums as learning agents in actualizing effective learning strategies

Evaluation with the same technique was conducted to measure the performance of the Ranggawarsita virtual museum, which focused on: information access, information adequacy, learning, immersive experience, virtual visits. 65 students, two teachers, and 7 museum staff were involved as respondents. Table 7 shows the questionnaire and its results, with P1-P5 representing statements. Meanwhile, Figure 7 shows the results of the questionnaire in diagram format.

Table 7. The results of measuring the performance of the ranggawarsita virtual museum

P	Statements	1	2	3	4	5	Total
P1	The Ranggawarsita virtual museum makes it easy to find information about cultural heritage objects	0	0	2	16	59	77
P2	The Ranggawarsita virtual museum provides enough information to memorize cultural heritage objects	0	0	17	19	41	77
P3	The Ranggawarsita virtual museum provides an interesting learning experience	0	0	0	14	63	77
P4	The Ranggawarsita virtual museum provides an immersive experience	0	0	9	32	36	77
P5	The Ranggawarsita virtual museum provides a museum-like experience in a real museum	0	0	6	14	57	77

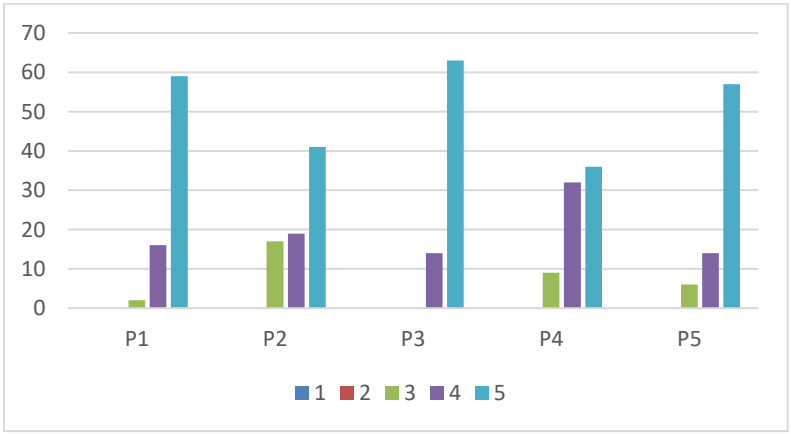

Figure 7. The diagram of the results of measuring the performance of the Ranggawarsita virtual museum

The evaluation carried out using the User Acceptance Test technique to measure the suitability of the virtual museum application as a learning agent based on effective learning strategies showed positive results. The statement that the performance of the virtual museum has been in accordance with the spaced practice component gave the result that 5% of 65 respondents stated that they quite agree, 52% and the remaining 43% stated that they strongly agree, and agree. The statement that the performance of the virtual museum has been in accordance with the retrieval practice component gave the result that 22% of 65 respondents stated that they quite agree, 34% and the remaining 45% stated that they strongly agree, and agree. The statement that the performance of the virtual museum has been in accordance with the elaboration component gave the result that 3% of 65 respondents stated that they disagree, while 6% stated that they quite agree, 26% stated that they agree, and 65% strongly agree. The statement that the performance of the virtual museum has been in accordance with the concrete example component gave the result that 3% of 65 respondents stated that they quite agree, while 25% stated that they agree, and 72% stated that they strongly agree. The statement that the performance of the virtual museum has been in accordance with the dual coding component gave the result that 11% of 65 respondents stated that they disagree, while 17% stated that they quite agree, 48% stated that they agree, and 25% strongly agree. The statement that the performance of the virtual museum was in accordance with the interleaving components resulted in 8% of 65 respondents stating that they quite agreed, while 26% stated that they agreed, and 66% stated that they strongly agreed.

The results of the evaluation of the performance measurement of the Ranggawarsita virtual museum which focuses on: access to information, enough information, learning, immersive experiences, and virtual visits, also showed positive results. 3% of the 77 respondents stated that they quite agree that virtual museums provide easy access to information, while 21% and 77% of the rest stated that they agree and strongly agree. 22% of the 77 respondents stated that they quite agree that virtual museums provide sufficient information to memorize cultural heritage objects, while 25% and 53% of the rest stated that they agree and strongly agree. 18% of the 77 respondents stated that they agree that virtual museums provide an interesting learning experience, and 82% of the rest stated that they strongly agree. 12% of the 77 respondents stated that they quite agree that virtual museums provide an immersive experience, while 42% and 47% of the rest stated that they agree and strongly agree. 8% of the 77 respondents stated that they quite agree that virtual museums provide the same visiting experience as actual museums, while 18% and 74% of the rest stated that they agree and strongly agree.

The finding that 72% of respondents strongly agree that the virtual museum reflects the ‘concrete example’ component suggests that the visualization and contextualization of artifacts are highly effective in enhancing comprehension. This aligns with cognitive learning theories that emphasize the importance of concrete examples in aiding abstract understanding. Despite the high agreement with most components, the relatively lower strong agreement (25%) on the dual coding component may indicate a need for better integration between verbal explanations and visual representations. Meanwhile, social diversity, accessibility, and inclusion which are issues that must be essentially considered [5] can be accommodated through the proposed virtual museum model, in which 77% of respondents strongly agreed that ease of access to information and learning provided a valuable experience for respondents from various social backgrounds. Instead of transforming museum-based learning into a game format as done in [9], the virtual museum model we developed transforms real museum activities into a virtual environment, allowing visitors to experience a museum visit virtually. Nevertheless, integrating game elements as an additional feature in our model could serve as a complementary tool for enhancing the learning experience.

4. DISCUSSION

This study develops a virtual cultural heritage museum as a learning agent based on effective learning strategies. The qualitative approach with thematic analysis method was applied to design a virtual museum based on the perspective of museum management as a provider of

learning facilities. The opinions collected were in the form of challenges and obstacles in functioning the museum as a provider of learning facilities. Furthermore, the opinions were used to identify the theme of the virtual museum to then be synthesized with six strategies in effective learning. The resulting synthesis was then used to build a virtual museum model using a game-based learning approach. Furthermore, the Ranggawarsita virtual museum application was developed based on the proposed model. The application was designed to run on Android and iOS mobile phone platforms. The Photogrammetry technique was used for 3D reconstruction of cultural heritage objects with high precision results, both in terms of object shape details and texture.

The measurement of the suitability of the virtual museum application as a learning agent based on effective learning strategies showed positive results. This can be seen from the percentage of respondents who stated that they strongly agree, which is the largest of the five components of effective learning strategies. While in the dual coding component, the percentage of respondents who stated that they strongly agree is smaller than the respondents who stated that they agree, which is 25%. This can happen because the statement containing the mastery of drawing skills has an effect on memory, making respondents hesitate to state that they strongly agree. However, the percentage of respondents who stated that they agree is the largest, which is 48%. Meanwhile, if the range of opinion values is summarized from five into two categories, with values 1, 2, and 3 representing poor performance, and values 4, and 5 representing good performance, the virtual museum application that was developed showed good performance, with the percentage of respondent support for each component of spaced practice, elaboration, concrete example, and interleaving greater than 90%, while the percentage of respondent support for the retrieval practice component, and dual coding is in the range of 70%. Memorizing (retrieval practice), and then actualizing it in the form of simple images (dual coding) seems to still be a problem that needs to be studied further. However, it can be concluded that the proposed model and method in developing a virtual cultural heritage museum as an effective learning strategy-based learning agent have provided good results.

The performance measurement of virtual museums focusing on: information access, learning, immersive experiences, virtual visits, showed positive results. This can be seen from the percentage of respondents who stated that they strongly agree and agree, which is the largest percentage and the second largest percentage of the five components. In these five components, the percentage of respondents who stated that they strongly agree and agree is greater than the percentage of respondents who stated that they strongly disagree, disagree, and quite agree. In fact, no respondents stated that they disagreed or strongly disagreed. The components of information adequacy, and immersive experience still need to be studied further, since the percentage of respondents who stated that they agreed and strongly agreed were 78% and 88%, respectively. Meanwhile, the other three components, information access, learning, immersive experience, virtual visits, have a percentage greater than 90%. The conclusion obtained is that the proposed model and method in developing a virtual cultural heritage museum is appropriate to support the performance of virtual museums in: information access, information adequacy, learning, immersive experiences, virtual visits,

The findings from this study open several avenues for further investigation. Future research could delve deeper into the personalization of effective learning strategies within virtual museum environments, particularly how different user profiles respond to elements such as spaced practice, retrieval practice, or elaboration. Longitudinal studies may also be conducted to assess the long-term impact of these strategies on knowledge retention and understanding. Moreover, the integration of game-based learning elements presents another promising area. Incorporating gamification, such as points, challenges, or quests—could enhance user engagement and motivation, and comparative studies between gamified and non-gamified virtual museums may yield valuable insights into their respective educational effectiveness.

Accessibility and social inclusion also warrant further exploration. Research focusing on underrepresented or marginalized groups, including individuals with disabilities or those from

remote areas, can inform the development of more inclusive virtual museum designs. Enhancing accessibility features, such as audio navigation or simplified interfaces, is crucial to ensure equitable learning opportunities. Additionally, future work may focus on evaluating users' cognitive and emotional responses to virtual museum experiences. Employing techniques like eye-tracking or biometric feedback could provide a deeper understanding of user engagement and learning outcomes. Technologically, the integration of artificial intelligence for personalized content delivery, as well as immersive technologies such as augmented or virtual reality, could further enrich the learning experience and sense of presence in virtual museum settings. These potential research directions not only extend the scope of the current study but also contribute to the evolving landscape of technology-enhanced learning through virtual cultural spaces.

5. CONCLUSIONS

Thematic analysis and game-based learning approaches are appropriate for developing virtual cultural heritage museums as learning agents based on effective learning strategies. The proposed model and method can actualize components of spaced practice, retrieval practice, elaboration, concrete example, dual coding, and interleaving in an effective learning strategy well. In general, the proposed models and methods can also actualize the performance of virtual museums in providing information access, information adequacy, learning, immersive experiences, and virtual visits, well.

The implementation of the game-based learning approach shows positive results. In general, the proposed models and methods can also actualize the performance of virtual museums in providing information access, information adequacy, learning, immersive experiences, and virtual visits, well. However, gamification to improve user performance in memorizing and recalling still needs to be explored further. This finding correlates with the achievement of virtual museum performance in providing information, and the level of immersion that is less than optimal. Although it has not been proven with certainty that the developed virtual museum is able to transfer information from short-term memory to long-term memory, the results achieved show a positive trend towards this achievement.

For future works, the development of virtual museums will focus on increasing the number of collections of cultural heritage objects exhibited virtually, the implementation of virtual museum applications on Head-Mounted Devices, and the exploration of gamification in presenting information that can be more easily accepted and memorized by users.

ACKNOWLEDGMENTS

We would like to thank the Education and Culture Office of Central Java Province, Indonesia, for their support and cooperation in developing the Ranggawarsita virtual museum. We would also like to thank the Lembaga Penelitian dan Pengabdian kepada Masyarakat (Institute for Research and Community Service), Universitas Dian Nuswantoro for funding support through the Internal Research Grant, Special Scheme, 2024.

REFERENCES

[1] N. Mamur, V. Özsoy, and I. Karagöz, "Digital learning experience in museums: Cultural readings in a virtual environment," *International Journal of Contemporary Educational Research*, vol. 7, no. 2, pp. 335-350, 2020. DOI: 10.33200/ijcer.799643.

[2] L. Daniela, Linda, "Virtual Museums as Learning Agents," *Sustainability*, vol. 12, no. 7, pp. 2698. 2020. Doi: 10.3390/su12072698.

[3] M. Özdemir, "The Educational Role of Virtual Museums in Cultural Transfer: Ottoman Artifacts," *The Turkish Online Journal of Educational Technology*, vol. 23, no. 3, pp. 100-109, 2024.

[4] A.J. Zarrabi, L.J. Morrison, B.A. Reville, J.M. Hauser, P. DeSandre, M. Joselow, J. deLima Thomas, and G. Wood, "Museum-Based Education: A Novel Educational Approach for Hospice and Palliative Medicine Training Programs," *Journal of Palliative Medicine*, vol. 23, no. 11, pp. 1510–1514, 2020. Doi: 10.1089/jpm.2019.0476.

[5] K. Springinzeisz, "Social inclusion in museum education: a literature review," *Museologica Brunensia*. vol. 11, no. 2, pp. 4-20, 2022. Doi: 10.5817/MuB2022-2-1.

[6] S. Tackett, L. Eller, S. Scharff, K.S. Balhara, K.M. Stouffer, M. Suchanek, S.L. Clever, P. Yenawine, S. Wolffe, and M.S. Chisolm, "Transformative experiences at art museums to support flourishing in medicine," *Medical Education Online*, vol. 28, no. 1, 2202914, 2023. Doi: 10.1080/10872981.2023.2202914.

[7] D.R. Bell, and J.K. Smith, "Inside the digital learning laboratory: new directions in museum education," *Curator: The Museum Journal*, vol. 63, no. 3, pp. 371-386. 2020. Doi: 10.1111/cura.12376.

[8] O. Fedotova, V. Zhurakovskij, P. Ermakov, I. Cherkashin, and E. Cherkashina, "Virtual museum in the system of informal education (based on sports materials)," *In E3S Web of Conferences*, vol. 273, 12072, 2021.

[9] S. Morard, E. Sanchez, and C. Bonnat, "Museum Games and Personal Epistemology: A Study on Students' Critical Thinking with a Mixed Reality Game," *International Journal of Serious Games*, vol. 10, no. 4, pp. 131-151, 2023. Doi: 10.17083/ijsg.v10i4.695.

[10] Six strategies foreffective learning, www.torontomu.ca/content/dam/tedrogersschool/success/resources/TRSM-ASC_Tip-Sheet_Six-Effective-Learning-Strategies.pdf., accessed on March 27, 2025.

[11] M. Smith, and Y. Weinstein, "Six Strategies for Effective Learning," 2016, www.learningscientists.org/blog/2016/8/18-1. Accesed on March 27, 2025.

[12] A.M. Kiswardhani, and M. Ayu, "Memorization Strategy during Learning Process: Students' Review," *Journal of English Language Teaching and Learning*, vol. 2, no. 2, pp. 68-73, 2021.

[13] J. Caulfield, "How to Do Thematic Analysis: Step-by-Step Guide & Examples. Scribbr," https://www.scribbr.com/methodology/thematic-analysis/. Accessed on April 2, 2025.

[14] S. De Paoli, "Performing an inductive thematic analysis of semi-structured interviews with a large language model: An exploration and provocation on the limits of the approach," *Social Science Computer Review*, vol. 42, no. 4, pp. 997-1019, 2024.

[15] K. Szolin, D.J. Kuss, F.M. Nuyens, and M.D. Griffiths, "I am the character, the character is me": A thematic analysis of the user-avatar relationship in videogames," *Computers in Human Behavior*, vol. 143, 107694, 2023.

[16] B.K. Sovacool, M. Iskandarova, and J. Hall, "Industrializing theories: a thematic analysis of conceptual frameworks and typologies for industrial sociotechnical change in a low-carbon future," *Energy Research & Social Science*, vol. 97, 102954, 2023. Doi: 10.1016/j.erss.2023.102954.

[17] G. Ferrigno, G., N. Di Paola, K.F. Oguntegbe, and S. Kraus, "Value creation in the metaverse age: a thematic analysis of press releases," *International Journal of Entrepreneurial Behavior & Research*, vol. 29, no. 11, pp. 337-363, 2023. Doi: 10.1108/IJEBR-01-2023-0039.

[18] A. Cernasev, D.R. Axon, "Research and scholarly methods: Thematic analysis," *Journal of the American College of Clinical Pharmacy*, vol. 6, no. 7, pp. 751-755, 2023.

[19] M. Naeem, W. Ozuem, K. Howell, and S. Ranfagni, "A step-by-step process of thematic analysis to develop a conceptual model in qualitative research," *International Journal of Qualitative Methods*, 22, 16094069231205789, 2023.

[20] M. Xu, Y. Luo, Y. Zhang, R. Xia, H. Qian, and X. Zou, "Game-based learning in medical education," *Front. Public Health*, vol. 11, 1113682, 2023. Doi: 10.3389/fpubh.2023.1113682.

[21] M. Hartt, H. Hosseini, and M. Mostafapour, "Game on: Exploring the effectiveness of game-based learning," *Planning Practice & Research*, vol. 35, no. 5, pp. 589-604, 2020. Doi: 10.1080/02697459.2020.1778859.

[22] Z.Y. Liu, Z.A. Shaikh, and F. Gazizova, "Using the Concept of Game-Based Learning in Education," *International Journal of Emerging Technologies in Learning*, vol. 15, no. 14, pp. 53-64, 2020. Doi: 10.3991/ijet.v15i14.14675.

[23] D. Camuñas-García, M.P. Cáceres-Reche, and M.D.L.E. Cambil-Hernández, "Mobile game-based learning in cultural heritage education: a bibliometric analysis," *Education+Training*, vol. 65, no. 2, pp. 324-339, 2023, Doi: 10.1108/ET-06-2022-0247.

[24] W. Zhao, L. Su, and F. Dou, "Designing virtual reality based 3D modeling and interaction technologies for museums," *Heliyon*, vol. 9, no. 6. pp. 1-12, 2023. Doi: 10.1016/j.heliyon.2023.e16486.

[25] F. Condorelli, and S. Morena, S, "Integration of 3D modelling with photogrammetry applied on historical images for cultural heritage," *Vitruvio - International Journal of Architectural Technology and Sustainability*, vol. 8, pp. 58–69, 2023. Doi: 10.4995/vitruvio-ijats.2023.18831.

[26] I. Tavantzis, Z.E. Tsifodimou, I. Skalidi, E. Karachaliou, I. Giannaris, A. Bakousi, A. Skondras, K. Katakalos, and E. Stylianidis, "Restoration workflows by means of photogrammetry: the case study of pashas bridge," *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLVIII-M-2-2023, pp. 1543–1548, 2023. Doi: 10.5194/isprs-archives-XLVIII-M-2-2023-1543-2023.

[27] D. Abdalhaleem, Duaa, and A.A. Elkhalifa, "Capturing the Past: Photogrammetry for Safeguarding Sudanese Cultural Heritage Digitally," in *Informatik*, 2024, pp. 1037-1047, 2024. Doi: 10.18420/inf2024_93.