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Translating Museum Artifacts into Narrative Augmented Reality Games: A Design Framework and Controlled Evaluation

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Abstract

Designing augmented reality (AR) games for museums requires choices about how artifact meanings become narrative tasks, yet these design decisions are rarely traced from their cultural sources. We developed a mobile narrative AR game around five artifacts in a Chinese museum exhibition. Grounded theory analysis of cultural and design materials identified four design dimensions and 12 indicators; the Analytic Hierarchy Process, using judgments from 10 experts, gave the highest priority to narrative design and spatial guidance. These findings guided the development of artifact-derived characters, sequential tasks, and on-site interactions. In a randomized study of 80 participants (40 per group), the AR group showed greater gains in artifact-related cultural knowledge than the traditional viewing group (mean increases: 1.20 versus 0.25 points; Group × Time: $F(1, 78) = 4.457$, $p = 0.038$). Cultural heritage sharing intention was also higher in the AR group (3.66 versus 3.13, $p = 0.001$), whereas immersion did not differ significantly ($p = 0.164$). Interviews indicated that the tasks prompted closer observation and provided cues for recalling and describing artifacts. The findings connect cultural resource analysis with observable outcomes in a real museum setting.

Keywords: augmented reality; museum learning; cultural heritage; narrative games; cultural resource transformation; Analytic Hierarchy Process

1. Introduction

Museum visitors encounter cultural heritage through objects and the information surrounding them. Exhibition labels shape what visitors notice and how they interpret what they see [1]. Augmented reality (AR) places digital content alongside physical exhibits, allowing visitors to examine an object while interacting with related

information [2–4]. Yet effective interpretation depends on more than the presence of digital media. It also depends on which aspects of an artifact become part of the experience and how visitors are asked to engage with them.

Narrative games offer one way to connect interpretation with action. Location-based heritage games use routes and encounters to guide exploration [5,6], while digital storytelling can support visitors' engagement with cultural content [6,7]. In a museum, these interactions need to remain connected to the objects on display. A task can direct attention to a distinctive feature, and the result of that task can lead visitors to the next exhibit. The design challenge is to make this progression meaningful across several artifacts rather than treating each AR scene as a separate activity.

The "Color" section of the Traditional Chinese Technology and Art exhibition at the Museum of Archaeology and Art, Jilin University, offers a setting for examining this challenge. Its artifacts are organized around the traditional colors blue, red, white, black, and yellow. In Chinese cultural history, these colors carry associations with the Five Phases, directions, and ritual practices [8]. The artifacts differ in form and function but belong to a shared cultural theme. Their relationships provide a basis for developing a narrative that moves between physical exhibits while retaining each object's particular meaning.

Previous studies have explored the use of AR to connect museum artifacts with cultural narratives and interactive tasks [2,4,6,7]. However, the relationship between cultural resource analysis and game design remains insufficiently explained. Museum records provide information about an artifact's form, history, and cultural meaning, but this information does not directly determine how it should be translated into narrative content and interactive tasks. This issue is particularly relevant to thematic exhibitions, where multiple artifacts need to be connected within a continuous visitor experience. Simply converting exhibition information into digital content does not establish how cultural meanings should inform game-design decisions. A more systematic approach is therefore needed to connect artifact-based cultural resources with the narrative and interactive structure of museum AR games.

This study focuses on the five-color artifacts in the "Color" section of the Traditional Chinese Technology and Art exhibition at the Museum of Archaeology and Art, Jilin University. It examines how the cultural resources of these artifacts can be organized and translated into a narrative AR game suitable for a real museum environment. The study further evaluates the resulting game by comparing its effects on visitors' cultural cognition, immersive experience, and cultural heritage sharing intention with those of traditional museum viewing.

Four research questions guide the study:

RQ1: How can cultural resources derived from five-color artifacts and game interaction logic be structured into a design framework for museum narrative AR games?

RQ2: What are the relative importance and priority of the design elements identified for narrative AR games?

RQ3: How can the identified design elements and their weights be translated into a narrative AR game suitable for a real museum setting?

RQ4: Compared with traditional museum viewing, does a narrative AR game enhance visitors' cultural cognition, immersive experience, and cultural heritage sharing intention?

2. Literature Review

2.1. Applications of Augmented Reality in Museums and Cultural Heritage Communication

AR has been used in heritage interpretation to show lost or altered settings alongside the places where they once existed. Innocente et al. [9] reviewed how immersive technologies shape the experience of cultural heritage. In a mobile mixed reality reconstruction of the demolished church of Sant'Elia, De Luca et al. [10] placed a virtual entrance at the original site. Visitors could explore a reconstructed building in relation to its surviving surroundings. Such work demonstrates the value of linking digital content to a physical point of reference.

Inside museums, interpretation also unfolds as visitors move between exhibits. Khan et al. [11] developed a story-based guide at Chakdara Museum: when visitors approached an artifact, the system presented the relevant information and directed them to the next object. Its contribution lies in connecting interpretation to the visitor's position and the order of encounters.

Digital presentation may also affect learning and subjective experience differently. Zhou and Li [12] reported differences in aesthetic experience between students using VR/AR scenarios and those viewing traditional exhibits at the Palace Museum. Agostinelli et al. [13], comparing AR and VR interfaces for archaeological artifacts, found higher knowledge-test performance with AR but greater reported immersion with VR. These results support evaluating knowledge and immersion as separate outcomes.

For the present study, AR must do more than reveal additional information about a single object. It must connect the cultural meaning of each artifact to an experience that continues across the gallery.

2.2. Gamified Interaction and Narrative AR Experiences

Heritage games make cultural interpretation part of the player's actions. Rauterberg et al. [14] describe how puzzles and narratives can support exploration. In a virtual bronze museum, Li et al. [15] linked curation tasks to information visitors had examined earlier; the game group performed better on a knowledge test than the desktop museum group. In both cases, the task gives visitors a reason to apply what they encounter.

AR brings these tasks into direct contact with displayed objects. Yan et al. [16] used pattern recognition and character guidance in a serious game at the Blue Calico Museum. Narrative can also connect separate encounters: in Alice Dalí AR, players followed location-based clues to discover episodes inspired by Dalí's illustrations [17]. These projects show different ways of linking cultural material to play. The present study focuses on keeping that link visible as visitors move among several artifacts in one exhibition.

Game controls shape the experience as well. Alatrash et al. [18] found more favorable interaction and immersion ratings for a VR museum game version with simpler controls and guidance. For gallery-based AR, task instructions should be clear enough that the visitor can return attention to the artifact.

The five-color game therefore treats each artifact as the source of a task and uses task completion to advance the story. The design needs to make the action relevant to the object and the transition meaningful to the next exhibit.

2.3. Digital Design Translation of Cultural Heritage Resources

Translating a museum collection into an interactive experience begins with reliable information about the objects. Work on digital heritage documentation stresses the accuracy, provenance, and reuse of collection records [19,20]. In this study, design translation means selecting cultural information that visitors can encounter through a game and giving it a form that can be expressed through scenes and interactions.

The relationship between a design choice and its source should remain clear. In their reconstruction of lost heritage, Gherardini and Sirocchi [21] compared evidence from several sources to develop an informed digital representation. The same principle applies when an exhibit inspires a game: a visual motif or narrative cue should be connected to identifiable information about the artifact.

An artifact's visible features can become cues for recognition, while its use and cultural associations can inform the task itself. Yang and Hou [22] organized heritage information through geometric models and semantic relationships. Hu et al. [23] likewise linked physical referents with visual and cultural meanings. This connection helps designers preserve the identity of a museum object when it is represented

through a character or an AR scene. And cultural information also determines how game activities relate to one another. A game about Dunhuang colors arranged mineral gathering, pigment preparation, and mural painting as sequential tasks [24]. Feng et al. [25] used semiotic analysis and grounded theory to identify culturally significant architectural features for subsequent design work. These studies show how cultural analysis can guide both the content of an interaction and its place in a sequence.

The London Charter [26] calls for digital heritage visualization to document its sources and interpretive decisions. Research on the translation of cultural attributes into design criteria has also linked resource analysis with explicit design choices [27]. Together, these approaches provide a basis for explaining why particular artifact features are used and how they enter the game.

For a thematic exhibition, design translation thus involves preserving each artifact's meaning while building connections that visitors can follow from one object to another.

2.4. Evaluation of Cultural Cognition, Immersive Experience, and Cultural Heritage Sharing Intention

The evaluation of museum AR should examine what visitors learn as well as how they experience the visit. This study distinguishes artifact-related cultural knowledge, immersion, and willingness to share cultural content after viewing the exhibition.

Cultural cognition is assessed here through knowledge of the artifacts and their cultural meanings. Chiang et al. [28] studied learning outcomes in AR-supported cultural heritage education across on-site and off-site settings. Cheng et al. [29] distinguished factual knowledge, measured through pre- and post-tests, from deeper understanding assessed through scenario tasks. These approaches inform the use of objective questions to assess knowledge acquired during the visit.

Immersion concerns how involved visitors feel while experiencing the exhibition. Cheng et al. [30] examined its relationship with AR quality and technology acceptance, including aesthetic and escapist experience. In the present study, immersion is measured separately from knowledge performance rather than treated as evidence of learning.

Sharing intention concerns whether visitors want to communicate what they encountered. Yi et al. [31] associated emotional responses to digital heritage with self-reported dissemination tendencies. In a Palace Museum AR study, Zhu et al. [32] linked presence with word-of-mouth intention through perceived authenticity. Participants in a Dunhuang color game also reported greater willingness to explore and share cultural content [24]. These findings support examining sharing intention as a post-visit

outcome.

Taken together, the three measures distinguish knowledge gained during the visit from participants' experience of the exhibition and their willingness to share it afterward.

2.5. Limitations of Existing Research

Existing heritage games demonstrate ways to embed cultural content in tasks. The Dunhuang color game, for example, used successive steps in pigment production and painting to organize learning [24]. A museum exhibition presents a different design problem: several objects with distinct histories must be connected within the same physical route. The present study examines how shared cultural meanings can guide that connection and give each exhibit a task of its own.

Evaluation methods provide different views of these experiences. Barbara et al. [33] drew on focus-group responses to an AR prototype, while comparisons of XR systems have examined presence and visitor experience [34]. Prior gaming experience can also shape responses to narrative interaction [35]. This study combines an on-site controlled comparison with interviews to examine measured outcomes alongside visitors' accounts of using the game.

3. Research Methods

3.1. Study Context and Artifact Selection

This study focuses on the five-color artifact resources presented in the "Color" section of the Traditional Chinese Technology and Art exhibition at the Museum of Archaeology and Art, Jilin University. The section is organized around artifacts associated with blue, red, white, black, and yellow, presenting relationships among object form, decorative motifs, material techniques, and traditional color concepts. This thematic structure provides a coherent cultural basis for subsequent narrative translation.

To ensure the representativeness of the research materials and the feasibility of subsequent design translation, artifact samples were selected on the basis of clear cultural associations with the five-color system, visual recognizability, and sufficiently complete exhibition information. Three criteria guided the selection. First, the artifacts had to express the traditional five-color system and its cultural meanings through color, form, decorative motifs, or craftsmanship. Second, their formal and symbolic characteristics had to offer clear potential for translation into AR characters, narrative cues, interactive tasks, or feedback mechanisms. Third, sufficient exhibition texts, visual materials, contextual information, and museum documentation had to be available to support subsequent coding and design development.

3.2. Research Methods

This study adopted an integrated four-stage research framework to examine the translation of five-color cultural resources into a narrative AR game experience, comprising qualitative coding, priority weighting, system development, and empirical evaluation. The framework takes the five-color artifact resources in the “Color” section as its cultural basis, narrative AR interaction design as the translation process, and visitor outcomes as the object of empirical evaluation.

In the first stage, grounded theory was used to construct a design framework for translating five-color artifact resources into narrative AR interactions. Grounded theory was selected because its systematic yet open-ended analytical process is suited to heterogeneous data sources and conceptually layered research materials [36]. Its application enabled the study to identify relationships among color concepts, artifact forms, decorative motifs, material techniques, and cultural meanings, and to examine how these cultural contents could inform narrative AR interaction design. Because the interactive translation of five-color artifact resources involves multiple layers of cultural and design information, reliance on designer judgment alone could reduce the framework to subjective categorization. Grounded theory addresses this problem by deriving conceptual categories from source materials through iterative coding, thereby grounding the design framework in empirical data. The analytical corpus comprised artifact records, exhibition texts, visual materials, relevant museum AR cases, literature on game interaction design, and expert interview transcripts. Through iterative open, axial, and selective coding, relationships between artifact features, cultural meanings, and interaction design were identified, providing an empirically grounded basis for the subsequent framework.

In the second stage, the Analytic Hierarchy Process (AHP) was used to quantify the relative importance of the categories and indicators within the design framework. AHP enables hierarchical criteria to be evaluated through expert pairwise judgments and consistency testing, allowing their relative importance to be expressed quantitatively [37]. Given the multilevel structure of the framework, AHP was used to systematically compare the four axial categories and their corresponding secondary indicators and to establish their design priorities. Ten experts with backgrounds in museum exhibition, cultural heritage, interaction design, game design, and digital media participated in the AHP assessment. Their pairwise comparisons were used to construct judgment matrices for each hierarchical level. The AHP hierarchy consisted of the design framework as the goal level, the four axial categories Form Semantics, Narrative Genes, Spatial Guidance, and Game Tasks as the criteria level, and their corresponding secondary indicators as the indicator level. Weight vectors, the maximum eigenvalue (λmax), the consistency index (CI), and the consistency ratio (CR) were calculated for

each judgment matrix. A matrix was considered to demonstrate acceptable consistency when CR < 0.10.

In the third stage, a mobile narrative AR game was developed as the practical implementation of the design framework. AR enables digital content to be integrated with physical exhibits and supports context-sensitive information presentation and narrative interaction through mobile devices. The category structure derived from grounded theory and the priority ranking obtained through AHP were operationalized in the game design. Higher-priority design elements were translated into gameplay flow, interface hierarchy, and interaction rules, while artifact images, exhibition texts, and cultural interpretations informed the design of recognition targets, character narratives, task content, and feedback screens. Unity was used as the development and integration environment to combine artifact recognition, in-gallery navigation, task interaction, and experiential feedback into a narrative AR game prototype for on-site museum use. Expert review and manual calibration were then conducted to refine interface logic, task prompts, recognition performance, and system stability.

In the fourth stage, a controlled study was conducted in the actual museum gallery, with a narrative AR game group and a traditional viewing group examining the same target artifacts. All participants first completed a cultural cognition pre-test and were assigned to the two conditions using random numbers. After the visit, they completed the cultural cognition post-test, followed by measures of immersive experience and cultural heritage sharing intention. After anonymization and validity screening, the quantitative data were analyzed using SPSS 27.0. Descriptive statistics, reliability analysis, independent-samples t tests, paired-samples t tests, and a 2 × 2 mixed-design analysis of variance (ANOVA) were conducted to examine between-group differences, within-group pre–post changes, and the Group × Time interaction. Following the questionnaires, five participants from each group were selected for semi-structured interviews. The interviews explored how participants understood the artifacts, experienced the museum visit, and developed intentions to share cultural heritage content, providing qualitative context for the quantitative findings. Quantitative results were used to identify between-group differences and pre–post changes, while the interview data were used to interpret how these patterns were manifested in participants' actual museum experiences. The four-stage research framework is summarized in Figure 1.

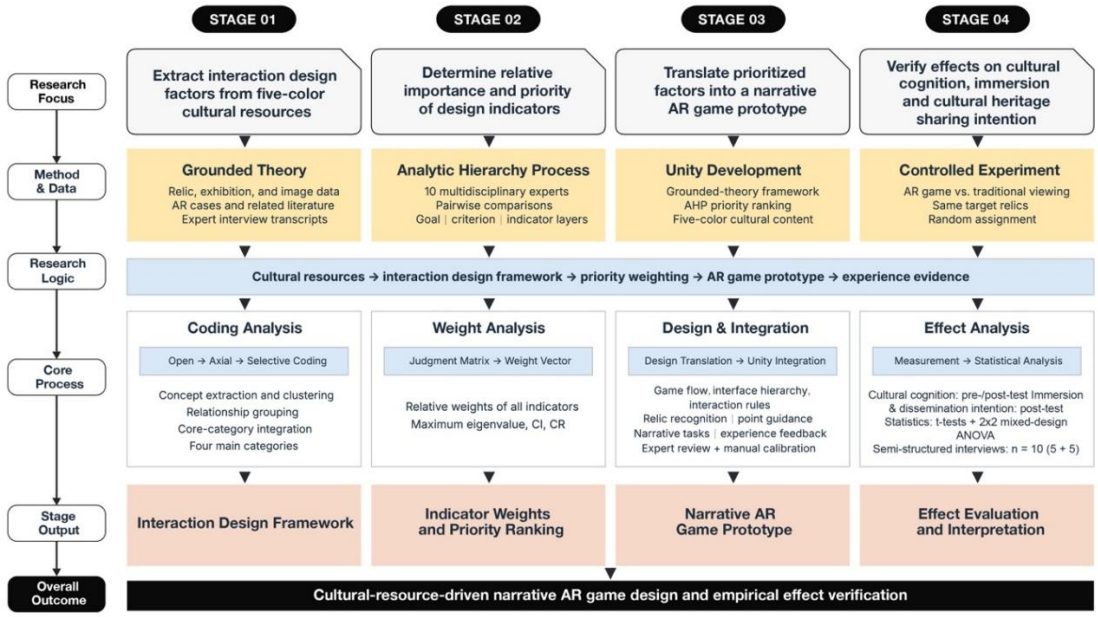


Figure 1. Research Methods and Experimental Validation Process

3.3. Data Sources and Processing

The data used in this study were obtained from three primary sources.

(1) Data for grounded theory analysis. The qualitative corpus included artifact records, exhibition texts, and visual materials from the “Color” section of the Traditional Chinese Technology and Art exhibition, together with books on traditional color culture and literature and case materials concerning museum AR, cultural heritage narratives, and game interaction design. Eight semi-structured expert interviews were also conducted, focusing on the cultural translation of five-color artifact resources and narrative AR interaction design in museum settings. The interviews were audio-recorded with consent, transcribed verbatim, and checked against the original recordings. The collected materials were organized by source and type, yielding approximately 140,000 words of text for initial coding. Coding was conducted by the researcher using NVivo 15, with concepts and categories refined through constant comparison across data sources and repeated examination of the original materials.

(2) Expert AHP questionnaires. Ten experts from relevant fields, including design and museum studies, completed an AHP pairwise-comparison questionnaire using Saaty’s 1–9 scale to evaluate indicators at the same hierarchical level. The expert judgments were subsequently organized into pairwise-comparison matrices for weight calculation and consistency testing.

(3) User experiment data. User experiment data were collected through a randomized controlled experiment conducted in the museum gallery. A total of 80 participants were recruited and randomly assigned in equal numbers to the narrative AR game group and the traditional viewing group (n = 40 per group). Quantitative data

comprised cultural cognition pre- and post-tests, together with post-visit measures of immersive experience and cultural heritage sharing intention. Following completion of the questionnaires, five participants from each group (n = 10) were selected for semi-structured interviews. The audio-recorded interviews were transcribed verbatim and used as supplementary qualitative data. Quantitative data were anonymized and screened for completeness and invalid responses before statistical analysis, while the interview transcripts were organized and analyzed to support the interpretation of the experimental findings.

The study protocol was approved by the Academic Ethics Review Committee, College of Art and Design, Xinjiang Hetian College (approval no. XHC-AD-ER-2026-001; 7 September 2026). All methods involving human participants were performed in accordance with the relevant guidelines and regulations and the Declaration of Helsinki. Written informed consent was obtained from all participants prior to their participation in the study.

4. Development of a Narrative AR Game Design Framework for Five-Color Artifact Resources Using Grounded Theory

4.1. Data Coding

(1) Open Coding

During open coding, the source materials were analyzed at the textual level using NVivo 15. Materials related to five-color artifact resources and narrative AR interaction design were coded line by line, with attention to information concerning artifact color, form and structure, decorative motifs, materials and craftsmanship, historical references, cultural meanings, navigation routes, recognition triggers, and user feedback. Specific expressions in the source materials were first assigned initial labels (aax). Through constant comparison and conceptual aggregation, labels with similar meanings were then grouped into concepts (ax). This process resulted in 110 concepts (ax), which were further consolidated into 12 categories (Ax). Unlike conventional approaches that focus primarily on extracting visual motifs or formal features, the coding process also considered the design translatability of the identified concepts. Concepts with potential relevance to visual recognition, narrative organization, spatial triggering, or task feedback in AR environments were retained for subsequent category development (Table 1). The resulting coding structure therefore provided a traceable empirical basis for the subsequent AHP weighting and development of the narrative AR game.

Table 1. Examples of Open Coding Results

Data type	Excerpt from source material	Conceptualization
Exhibition labels and images	Peacock-blue-glazed vase, Yongzheng period, Qing dynasty: Everted rim, long neck, broad shoulders, olive-shaped body, and shallow ring foot. Fine crackles appear on the surface, which is entirely covered with an evenly applied peacock-blue glaze of varying intensity, creating a restrained and elegant appearance…	a51 Artifact form and silhouette (aa12, aa14, aa16, aa103, aa57…) a09 Glaze color and texture (aa90, aa07, aa66, aa41…) a15 Craftsmanship and three-dimensional decoration (aa73, aa18, aa107, aa45…)
Books on traditional color culture	"The East is associated with qing (blue), the South with red, the West with white, and the North with black; Heaven is associated with xuan (dark), and Earth with yellow." The traditional five colors originate from observations of nature and are associated with spatial directions, Heaven and Earth, and ritual concepts…	a42 Spatial order of the five colors (aa69, aa10, aa96, aa39…) a06 Natural and ethical imagery (aa77, aa23, aa110, aa52…)
Reference literature	With "symbolic extraction + creative translation" as the core approach, and translated into IP characters with personality traits, growth experiences, values, and behavioral logic. Location is a key component of interactive narrative…. Users explore along POI routes and complete searching, puzzle-solving, or collection tasks after recognizing designated targets.	a67 Extraction of artifact symbols (aa01, aa64, aa36, aa88…) a31 Character identity construction (aa20, aa101, aa47, aa75…) a56 Location-based narrative progression (aa105, aa17, aa60, aa79…)
Curatorial expert interview	"I believe the value of the 'Color' section lies in allowing visitors to see how colors are manifested in different materials and types of artifacts. For example, blue appears as a soft glaze on ceramics but looks brighter on enamelware. Red can reveal the layered craftsmanship of lacquerware and is also frequently associated with auspiciousness and ritual. If visitors only read the exhibition labels, they often remember only the names of the objects..."	a25 Interpretation of five-color culture (aa58, aa09, aa80, aa35…) a71 Color-seeking narrative organization (aa98, aa22, aa76, aa15…)

(2) Axial Coding

Axial coding constituted the second stage of the coding process and was used to examine structural relationships among the categories generated during open coding. Based on the process through which artifact resources are translated into narrative AR game design, the 12 subcategories were compared in terms of their conceptual relationships and further grouped into four axial categories: Form Semantics, Narrative Genes, Spatial Guidance, and Game Tasks (Table 2).

Table 2. Results of Axial Coding

Code	Concepts	Initial Category
A1	Everted rim and long neck; ring-foot structure; double-layer lotus petals; symmetrical composition; layered relationships; overall artifact silhouette	Form Feature Extraction
A2	Hope associated with blue; ceremonial meanings of red; refined elegance of white; contemplative symbolism of black;	Cultural Meaning Expression
A3	Phoenix-and-peony composition; lotus motif; diaper-ground borders; pattern layering; color–pattern combinations	Pattern Symbol Transformation
A4	Anthropomorphized artifact identity; family roles; differentiated appearance; cultural origins; character-based guidance; virtual character activation	Character Identity Setting
A5	Historical allusions; spatiotemporal contexts of five-color culture; artifact craftsmanship contexts; historical events;	Narrative Context Setting
A6	Main tasks; physical-object cues; sequential exploration; character dialogue; location cues; chapter structure; interactive narrative chain; linkage of stage goals	Narrative Cue Organization
A7	Map routes; location markers; current position; display-case sequence; route following; directional guidance; level routes; target searching; connections among exhibition points	Location Guidance
A8	Mobile scanning; image recognition; QR-code markers; three-dimensional objects; camera focusing; location activation;	Recognition Trigger

Code	Concepts	Initial Category
A9	Spatial anchoring; information labels; 3D models; model enlargement; model rotation; audio presentation; multimodal supplementation; overlay of artifact details	Real-Scene Overlay
A10	Object-finding tasks; exploratory mini-games; character-assigned tasks; target searching; POI interaction; difficulty levels; route-based tasks; cultural quizzes	Task Setting
A11	Real-time interaction response; audio feedback; visual changes; progress status; remaining challenge quantity; completion indicators; historical animation presentation	Process Feedback
A12	Card collection; sticker collection; collection-book unlocking; stage completion; level mechanism; progress ranking; social co-play; motivation for exploration	Reward Mechanism

(3) Selective Coding

In the final stage of data coding, selective coding was used to clarify the logical relationships among the four axial categories and identify a core category that integrated the overall theoretical framework. Further analysis of the 4 axial categories and 12 subcategories revealed a sequential transformation process. The form, color, and cultural meanings of the five-color artifacts were first translated into content for character development and narrative organization. Characters, narrative contexts, and narrative cues were then situated within the gallery through spatial routes, recognition triggers, and real-scene overlays, while tasks, feedback, and rewards supported continued visitor participation. The four axial categories thus extend from cultural content extraction to narrative organization, spatial activation, and gamified interaction, together constituting the complete process through which five-color artifact resources are translated into a narrative AR game experience. Accordingly, “Narrative AR Game Transformation Mechanism for Five-Color Artifact Resources” was identified as the core category. Form Semantics (Z1) comprises A1 Form Feature Extraction, A2 Cultural Meaning Expression, and A3 Pattern Symbol Transformation; Narrative Genes (Z2) comprises A4 Character Identity Setting, A5 Narrative Context Setting, and A6 Narrative Cue Organization; Spatial Guidance (Z3) comprises A7 Location Guidance, A8 Recognition Trigger, and A9 Real-Scene Overlay; and Game Tasks (Z4) comprises A10 Task Setting, A11 Process Feedback, and A12 Reward Mechanism (Table 3).

Table 3. Category Structure Derived from Selective Coding

Core Category	Axial Category	Subcategory
Narrative AR Game Transformation Mechanism for Five-Color Artifact Resources	Z1 Form Semantics	A1 Form Feature Extraction
		A2 Cultural Meaning Expression
		A3 Pattern Symbol Transformation
	Z2 Narrative Genes	A4 Character Identity Setting
		A5 Narrative Context Setting
		A6 Narrative Cue Organization
	Z3 Spatial Guidance	A7 Location Guidance
		A8 Recognition Trigger
		A9 Real-Scene Overlay
	Z4 Game Tasks	A10 Task Setting
		A11 Process Feedback
		A12 Reward Mechanism

(4) Theoretical Saturation Test

To assess theoretical saturation, 11 additional data samples that had been withheld from the initial coding process were analyzed separately to determine whether any new concepts or categories would emerge. The additional coding produced no new concepts or structural categories and remained consistent with the four axial categories and 12 subcategories identified above. In addition, 10 experts from relevant fields reviewed the source materials and coding results as a supplementary verification procedure (Table 4). The results confirmed that no new structural categories emerged and that the coding framework had reached theoretical saturation. The grounded theory coding process and the resulting category structure are illustrated in Figure 2.

Table 4. Qualifications of Experts Involved in the Theoretical Saturation Test

ID	Research Field	Age	Degree	Professional Background and Qualifications
P1	Visual Communication Design	36	Master's degree	Design director at a design company with 12 years of experience in visual design

ID	Research Field	Age	Degree	Professional Background and Qualifications
P2	Museology	42	PhD	Associate professor with 15 years of experience in museum exhibition planning and cultural heritage research
P3	Cultural IP Character Design	31	Master's degree	Senior designer with 6 years of experience in cultural IP and character development
P4	AR Interaction and User Experience Design	40	PhD	University lecturer with 11 years of experience in interaction design and 7 years of teaching experience
P5	Digital Media and Virtual Exhibition Design	37	Master's degree	University lecturer with 9 years of design experience and 10 years of teaching experience
P6	Intangible Cultural Heritage Creative Design	34	Master's degree	Cultural heritage designer with more than 5 years of experience in ICH-related design
P7	Game Design	35	Master's degree	Game design director with 10 years of experience in game design
P8	Human–Computer Interaction and User Experience	44	PhD	University professor with 16 years of teaching experience
P9	Museum Exhibition Planning	31	Master's degree	Exhibition designer with more than 7 years of experience in exhibition design
P10	Smart Museum Guidance	36	PhD	Associate professor with 10 years of experience in design research

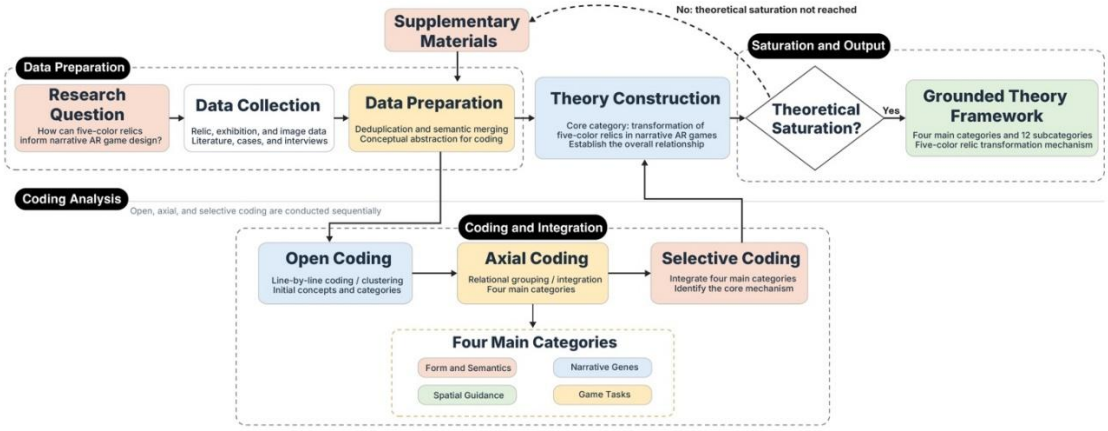


Figure 2. Relationships among Grounded Theory Coding Results and the Core Category

4.2. AHP-Based Weighting Analysis of the Narrative AR Game Design Framework for Five-Color Artifact Resources

Grounded theory coding established a hierarchical structure for translating five-color artifact resources into narrative AR game design. To further determine the relative importance of the identified categories within this transformation process, the Analytic Hierarchy Process (AHP) was applied to calculate their weights. AHP converts expert pairwise judgments of relative importance into numerical weights, while consistency testing is used to assess the internal consistency of the judgments.

The goal level was defined as the "Narrative AR Game Transformation Mechanism for Five-Color Artifact Resources." The criteria level comprised Form Semantics (Z1), Narrative Genes (Z2), Spatial Guidance (Z3), and Game Tasks (Z4). Their 12 subcategories (A1–A12) formed the indicator level (Figure 3).

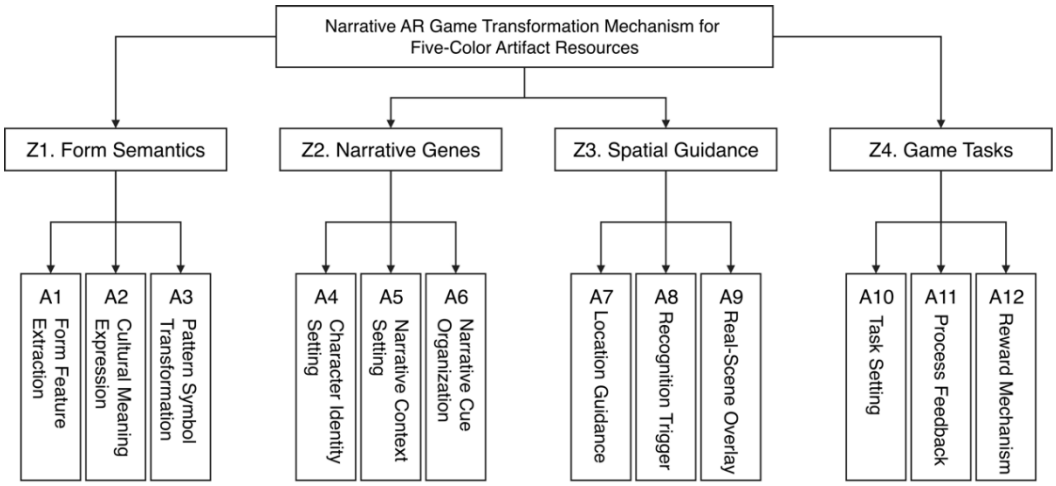


Figure 3. Narrative AR Game Transformation Mechanism for Five-Color Artifact Resources

Experts used Saaty's nine-point scale for pairwise comparisons (Table 5). Reciprocal values represented inverse judgments; the resulting matrices were used for weight and consistency calculations. By combining qualitative coding with quantitative weighting, the relative importance of each category within the transformation of five-color artifact resources into narrative AR game design was determined.

The AHP weights were used to determine the relative priority of Form Semantics, Narrative Genes, Spatial Guidance, and Game Tasks in digital presentation, and to indicate the degree of emphasis assigned to categories such as character identity, narrative cues, spatial triggering, and task feedback within the experience flow. Categories with higher weights were treated as higher-priority content in subsequent AR system development, whereas lower-weighted categories were incorporated more selectively according to narrative pacing, interaction load, and contextual requirements. In this way, AHP complemented grounded theory by adding a

quantitative assessment of category importance, enabling the extracted cultural-resource structure to be translated into a prioritized and operational basis for narrative AR game development.

Table 5. Saaty's 1–9 Scale and Its Meaning

Scale Value	Meaning
1	Two factors are equally important
3	One factor is moderately more important than the other
5	One factor is strongly more important than the other
7	One factor is very strongly more important than the other
9	One factor is extremely more important than the other
1/3	One factor is moderately less important than the other
1/5	One factor is strongly less important than the other
1/7	One factor is very strongly less important than the other
1/9	One factor is extremely less important than the other
2, 4, 6, 8	Intermediate values between adjacent judgments

Ten experts conducted pairwise comparisons among the elements at the same hierarchical level using Saaty's 1–9 scale shown in Table 5. For a hierarchical level containing (n) evaluation indicators, the expert judgments were used to construct judgment matrix A:

$$A = \left[a_{ij}\right]_{n\times n},\ a_{ij} > 0,\ a_{ij} = \frac{1}{a_{ji}},\ a_{ii} = 1\ (i, j = 1,2,3,\dots,n) \qquad (1)$$

where a_{ij} represents the importance of indicator i relative to indicator j. All diagonal elements of the matrix are 1, and the comparison values on opposite sides of the main diagonal are reciprocals of each other.

For criteria-level comparisons, the 10 experts' judgments were aggregated using the geometric mean to construct the group judgment matrix (Table 6). Narrative Genes (Z2) showed greater relative importance than the other three criteria. Spatial Guidance (Z3) connects artifacts, gallery locations, and AR content. Game Tasks (Z4) organizes continued user participation. Form Semantics (Z1) translates artifact features and cultural meanings into visual AR content. The column-normalized criteria-level judgment matrix is presented in Table 7.

Table 6. Criteria-Level Judgment Matrix

Criteria	Z1	Z2	Z3	Z4
Z1 Form Semantics	1	1/3	1/2	1/2
Z2 Narrative Genes	3	1	2	3
Z3 Spatial Guidance	2	1/2	1	2
Z4 Game Tasks	2	1/3	1/2	1

Table 7. Normalized Criteria-Level Judgment Matrix

	Z1	Z2	Z3	Z4
Z1	0.1250	0.1538	0.1250	0.0769
Z2	0.3750	0.4615	0.5000	0.4615
Z3	0.2500	0.2308	0.2500	0.3077
Z4	0.2500	0.1538	0.1250	0.1538

The criteria-level weights were estimated using column normalization and row averaging. Each matrix entry was divided by its column sum, and the mean of each normalized row was taken as the weight. The normalized matrix yielded criteria weights of 0.1202 for Form Semantics (Z1), 0.4495 for Narrative Genes (Z2), 0.2596 for Spatial Guidance (Z3), and 0.1707 for Game Tasks (Z4). The ranking was Z2 > Z3 > Z4 > Z1 (Table 8).

$$\mathrm{Wi} = \frac{\sum_{j=1}^{n} a_{ij}}{n} \tag{2}$$

$$w_{Z_1} = \frac{0.1250 + 0.1538 + 0.1250 + 0.0769}{4} = 0.1202 \tag{3}$$

$$w_{Z_2} = \frac{0.3750 + 0.4615 + 0.5000 + 0.4615}{4} = 0.4495 \tag{4}$$

$$w_{Z_3} = \frac{0.2500 + 0.2308 + 0.2500 + 0.3077}{4} = 0.2596 \tag{5}$$

$$w_{Z_4} = \frac{0.2500 + 0.1538 + 0.1250 + 0.1538}{4} = 0.1707 \tag{6}$$

Table 8. Criteria-Level Weights and Ranking

Criterion	Weight	Rank
Z1 Form Semantics	0.1202	4
Z2 Narrative Genes	0.4495	1
Z3 Spatial Guidance	0.2596	2

Criterion	Weight	Rank
Z4 Game Tasks	0.1707	3

To assess the consistency of the judgment matrix, the consistency index (CI) and consistency ratio (CR) were calculated. The maximum eigenvalue (λ_{max}) determined by multiplying the original judgment matrix by the weight vector, dividing each element of the resulting weighted-sum vector by its corresponding weight, and averaging the resulting values. For a matrix of ($n = 4$), the random consistency index (RI) was 0.90.

$$\lambda_{max} = \frac{\sum\left(\frac{\text{Weighted Sum Vector}}{\text{Weight Vector}}\right)}{n} \tag{7}$$

$$\lambda_{max} = \frac{\frac{0.4852}{0.1202} + \frac{1.8413}{0.4495} + \frac{1.0661}{0.2596} + \frac{0.6907}{0.1707}}{4} = 4.0716 \tag{8}$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{9}$$

$$CI = \frac{4.0716 - 4}{4 - 1} = 0.0239 \tag{10}$$

$$CR = \frac{CI}{RI} \tag{11}$$

$$CR = \frac{0.0239}{0.90} = 0.0265 \tag{12}$$

Following the calculation procedure described above, the criteria-level judgment matrix yielded ($\lambda_{max} = 4.0716$) and CI = 0.0239. For the four-order judgment matrix, RI was 0.90, resulting in CR = 0.0265 < 0.10, indicating that the judgment matrix satisfied the consistency requirement.

Each of the four criteria contained three subcriteria. Based on pairwise comparisons among the three subcriteria under each criterion, the corresponding subcriteria-level judgment matrices were constructed and subjected to consistency testing (Table 9).

Table 9. Subcriteria-Level Judgment Matrices

Criterion	Subcriterion	C 1	C 2	C 3
Z1 Form Semantics	A1 Form Feature Extraction	1	2	5
	A2 Cultural Meaning Expression	1/2	1	3
	A3 Pattern Symbol Transformation	1/5	1/3	1
Z2 Narrative Genes	A4 Character Identity Setting	1	3	2
	A5 Narrative Context Setting	1/3	1	1/2

Criterion	Subcriterion	C 1	C 2	C 3
	A6 Narrative Cue Organization	1/2	2	1
	A7 Location Guidance	1	1/2	2
Z3 Spatial Guidance	A8 Recognition Trigger	2	1	2
	A9 Real-Scene Overlay	1/2	1/2	1
	A10 Task Setting	1	2	2
Z4 Game Tasks	A11 Process Feedback	1/2	1	1/2
	A12 Reward Mechanism	1/2	2	1

The CR values of the subcriteria-level judgment matrices under Z1, Z2, Z3, and Z4 were 0.0032, 0.0079, 0.0463, and 0.0463, respectively, all below 0.10, indicating that all four matrices satisfied the consistency requirement. The global weight of each subcriterion was calculated by multiplying its local weight by the weight of its corresponding criterion.

Table 10. Local and Global Weights of Subcriteria and Overall Ranking

Criterion	Subcriterion	Local Weight	Global Weight	Overall Rank
	A1 Form Feature Extraction	0.5813	0.0699	7
Z1 Form Semantics	A2 Cultural Meaning Expression	0.3092	0.0372	10
	A3 Pattern Symbol Transformation	0.1096	0.0132	12
	A4 Character Identity Setting	0.5390	0.2423	1
Z2 Narrative Genes	A5 Narrative Context Setting	0.1638	0.0736	6
	A6 Narrative Cue Organization	0.2973	0.1336	2
	A7 Location Guidance	0.3119	0.0810	5
Z3 Spatial Guidance	A8 Recognition Trigger	0.4905	0.1273	3
	A9 Real-Scene Overlay	0.1976	0.0513	9
	A10 Task Setting	0.4905	0.0837	4
Z4 Game Tasks	A11 Process Feedback	0.1976	0.0337	11

Criterion	Subcriterion	Local Weight	Global Weight	Overall Rank
	A12 Reward Mechanism	0.3119	0.0532	8

Among the 12 subcriteria, Character Identity Setting (A4, 0.2423) ranked first, followed by Narrative Cue Organization (A6, 0.1336) and Recognition Trigger (A8, 0.1273). These elements informed character development, continuity across exhibits, and the link between physical artifacts and AR content. Table 10 gives the remaining weights and rankings. The global weights of the 12 subcriteria are visualized in Figure 4.

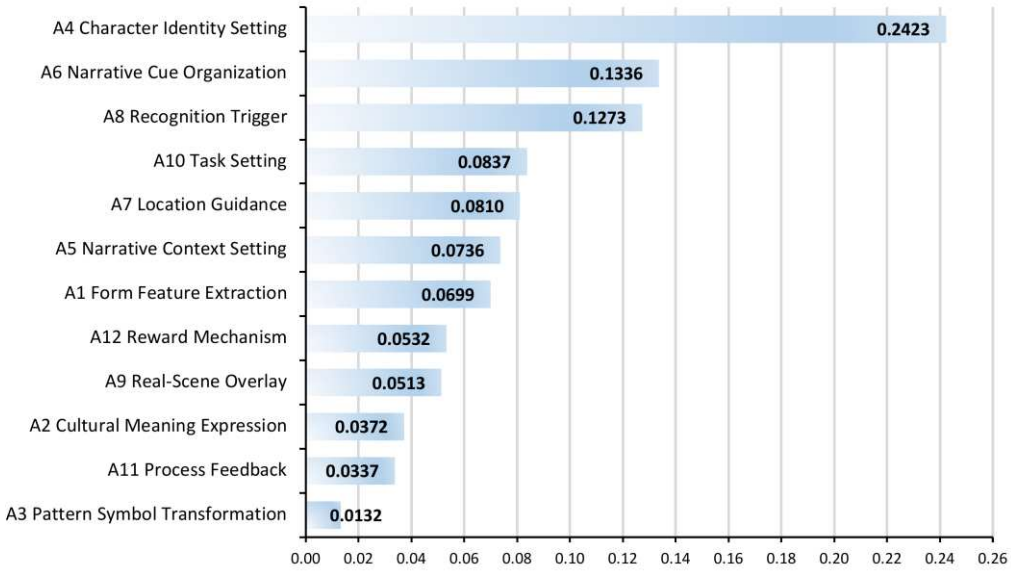


Figure 4. Global Weights of Narrative AR Game Interaction Design Elements

5. Design and Implementation of a Narrative AR Cultural Exploration Game

To address RQ3, we selected the “Color” section of the Museum of Archaeology and Art, Jilin University, as the application setting. We translated the blue, red, white, black, and yellow artifact resources, together with the preceding cultural-resource analysis, narrative AR game transformation framework, and AHP-based priority ranking, into a mobile narrative AR game prototype. Before development, an on-site survey documented artifact locations, visitor routes, display-case conditions, and viewing conditions. Digital materials were also collected for the selected artifacts and relevant gallery spaces.

5.1. Design Objectives and Overall Framework

The three highest-weighted elements were Character Identity Setting (0.2423), Narrative Cue Organization (0.1336), and Recognition Trigger (0.1273). We therefore foregrounded artifact characters, linked stages through narrative cues, and activated

content by recognizing physical exhibits. The five-color theme organized the game into artifact-specific units, each with a character, narrative context, and task. Character forms retained recognizable artifact features and colors so that digital content remained tied to the exhibits.

Visitors used a gallery map to reach a display case, scanned its artifact, and entered the corresponding AR scene. Completing a task unlocked its content and the next stage; the final stage brought the five characters together.

5.2. Selection of Five-Color Artifacts and Character Narrative Development

5.2.1. Selection of Five-Color Artifacts

Five artifacts were selected to represent blue, red, white, black, and yellow within the existing route. Each offered recognizable features and sufficient cultural material for character and task design. Table 11 documents the artifact-to-design translation.

We analyzed each artifact's visual features, cultural meaning, and gallery position. Silhouette, color, and motifs informed recognition and character design; historical and symbolic information informed narrative cues; location shaped task order. These decisions are summarized in Table 11.

Table 11. Five-Color Artifact Resources and Design Translation Directions

Color Unit	Core Artifact	Key Features	Image	Character
Blue	Qing Yongzheng Peacock-Blue-Glazed Vase	Long neck; fine crackle pattern		
Red	Qing Yixing Kiln Hexagonal Lotus Zisha Teapot	Hexagonal teapot form; lotus motif		
White	Tang White-Glazed Vessel with Double Dragon Handles and Dish-Shaped Mouth	Dish-shaped mouth; double-dragon handle structure		
Black	Ming Black-Glazed Incised Fish-Motif Jar with Double Lugs	Fish-motif decoration; double lugs on both shoulders		
Yellow	Sancai Horse	Horse-shaped silhouette; distinctive saddle details		

5.2.2. Character Design and Narrative Relationships

Earlier work has placed digital narrative characters within a museum setting [38]. In the present design, the selected artifacts became simplified anthropomorphic characters that guided the five-color narrative. Each retained recognizable color and form cues, allowing characters to support artifact identification as well as progression between stages.

Nearly human virtual agents may elicit discomfort, a phenomenon commonly described as the uncanny valley [39]. In this study, the five characters adopted a simplified artifact-based anthropomorphic style as a design choice. Artifact form remained the primary visual structure, while simplified eyes, limbs, and movements provided character cues without obscuring the recognizable forms, glaze colors, and motifs listed in Table 11. The five characters provided task prompts, stage-unlocking cues, and completion feedback, while remaining directly associated with their corresponding physical artifacts.

The narrative followed exploration, unlocking, and convergence. Visitors encountered blue, red, white, black, and yellow in sequence, unlocking artifact content and characters before a final scene joined the five units.

5.3. Stage Mechanics and Interaction Flow Design

5.3.1. Gallery Route and AR Scene Activation

All five stages used the same interface and completion logic. Artifact narratives, character prompts, and on-site interactions connected each task to observation of the physical exhibit. Scanning an artifact activated its AR stage. The character introduced the task, and visitor actions produced feedback tied to artifact features. Completion saved the stage result and enabled progression. Gamified cultural heritage experiences can support visitor participation and deeper engagement [6], while AR further integrates virtual information with physical exhibits through visual overlays and task-based interaction. Here, recognition and task feedback were used to keep the digital actions anchored to the five physical artifacts.

5.3.2. Five-Color Stage Tasks and Feedback Mechanisms

The blue unit was developed around the Peacock-Blue-Glazed Vase, with its long neck and mouth serving as the spatial anchor for bouquet generation. After recognition, flowers, branches, leaves, and insects appeared around the vase. Visitors selected the flower branches as prompted; once completed, they formed a bouquet that grew upward from the vase mouth, followed by the appearance of the blue vase character. This maintained a direct relationship between the task outcome and the artifact's form.

The red unit retained the hexagonal silhouette and lotus motif of the Zisha Teapot, while its functional context was translated into a tea-making task. After recognition, visitors sequentially lit the stove, heated the water, and poured the tea, creating a complete tea-making sequence while drawing attention to the teapot's hexagonal form and lotus decoration. Upon completion, the tea-making scene reached its final state, and the red character remained beside the artifact as a stage-completion marker.

The white unit used the double dragon handles as its primary visual cue. After recognition, a pale mist initially covered the artifact. Visitors swiped to disperse the mist, gradually revealing the vessel, after which dragon forms emerged from the double handles to emphasize its distinctive structure.

The black unit translated the jar's static fish motif into an interactive water scene. After recognition, visitors tapped the water surface to generate ripples and activate a school of fish that moved around the physical jar. This transformed the static decorative motif into a dynamic scene anchored to the artifact.

The yellow unit was positioned as the final artifact along the existing gallery route. After visitors completed the first four stages, scanning the Sancai Horse unlocked a final stage in which all five artifact characters appeared together. The Sancai Horse also linked stage completion, collection results, and the results page.

Feedback operated at three levels. Visitor actions triggered immediate changes within each AR scene; completing a stage unlocked its character and artifact card; completing all five stages generated a combined result for review and sharing. This sequence made progress visible without removing the physical exhibit from the task context. Figure 5 shows the AR tasks and scene feedback for the blue, red, white, and black stages.



Figure 5. AR Tasks and Scene Feedback in the First Four Levels.

5.3.3. Game Interface and Interaction Flow

The interface was organized around the live gallery view. The flow comprised preparation and navigation, artifact recognition and interaction, and results and sharing. The opening screen introduced the route and the five-color goal.

During interaction, the display case and artifact remained visible through the camera. Brief prompts and character cues guided each task without replacing the live view. After a stage, the interface showed completion feedback and the next location; visitors could revisit unlocked artifact information.

A collection page displayed unlocked artifacts, stage photographs, and cards in a consistent layout. Poster export and sharing controls were available after completion. The game interfaces and interaction flow are presented in Figure 6.



Figure 6. Game Interface and Interaction Flow

5.4. Game System Implementation and Testing

Before system development, an on-site survey of the five-color exhibition area was conducted to document artifact images, the exhibition environment, and recognition locations, providing the basis for subsequent AR content activation. The system was developed using Unity 2022.3.62f3 for portrait-mode mobile devices. Artifact models, character assets, scene animations, and interface materials were imported into Unity, and the functional interfaces were organized using Unity UI (UGUI). The introduction, artifact recognition, task interaction, completion display, photo capture, and 3D artifact viewing functions were implemented within a single Unity scene. Interface transitions were controlled through panel states and event handling, reducing repeated scene loading and maintaining continuity during the experience.

The AR view used the live gallery feed from the rear camera as its background, while the system loaded the corresponding character, task content, and dynamic effects for the current artifact. Interaction states were recorded by the system and linked to stage completion, photo saving, and 3D artifact viewing. Artifact models were imported in GLB format, and visitors could adjust the viewing angle using single-finger swipe gestures. The photo-capture function used screen capture to save the current AR view as a personal record of the museum experience. The Unity development environment and Android build interface are shown in Figure 7.

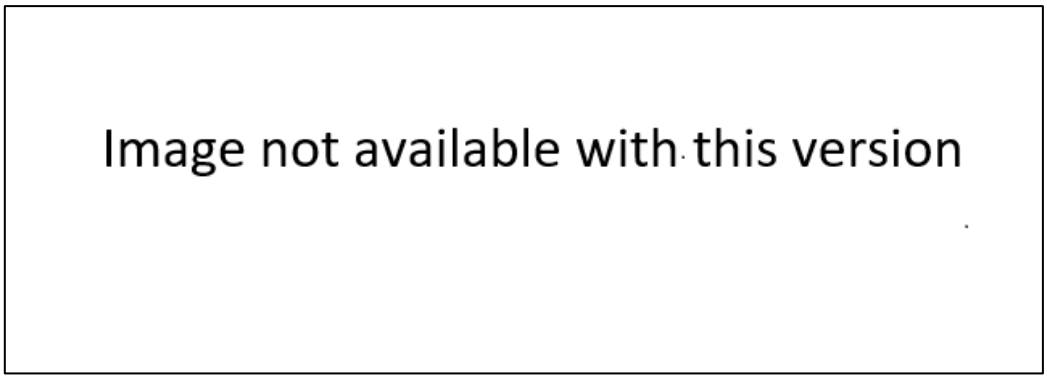


Figure 7. System development and Android build interface of the narrative AR game in Unity. (a) Game view; (b) Scene view; (c) Console and Android build log; (d) Hierarchy; (e) Project assets; and (f) Inspector.

The Android build supported portrait orientation, camera permissions, and device safe areas. Interface scaling and control placement were adjusted for different screen sizes, and the system was exported as an APK. Unity Editor testing covered transitions, responses, rendering, and state changes. Testing on a HUAWEI Pura 70 smartphone covered camera access, AR presentation, touch input, model rotation, and portrait layout. We adjusted field of view, element movement, model scale, materials, and controls after these checks. The main interaction functions operated continuously during the reported on-site testing.

6. Experimental Design

To evaluate the effects of the narrative AR game in an authentic museum-visiting context, a randomized controlled experiment was conducted in the “Color” section of the Traditional Chinese Technology and Art exhibition at the Museum of Archaeology and Art, Jilin University. Participants were assigned to a narrative AR game group or a traditional viewing group, with both groups viewing the same five-color artifacts. Outcomes were assessed using a cultural cognition test, an immersive experience scale, and a cultural heritage sharing intention scale. Cultural cognition was assessed using a pre-test–post-test design, whereas immersive experience and cultural heritage sharing intention were measured after the visit. Following the quantitative assessment, semi-structured interviews were conducted to supplement the test and questionnaire findings and to further examine how participants understood the artifact content and which aspects of the design influenced their experience.

6.1. Participants and Group Assignment

Participants were recruited through an open recruitment process. Eligible participants were 18 years of age or older, able to use a smartphone, and capable of independently performing basic mobile AR interactions. None of the participants had previously experienced the narrative AR game developed in this study. A total of 80 participants were included in the formal experiment.

Participants received study information and provided written informed consent before taking the cultural cognition pre-test. They were then assigned by random numbers to the narrative AR game group or the traditional viewing group (n = 40 per group). Both groups viewed the same five target artifacts in the same gallery.

6.2. Measures

6.2.1. Cultural Cognition Test

Cultural cognition was operationalized as participants' knowledge of the five-color artifacts and their cultural meanings. To limit recall of test questions, parallel forms A and B were used before and after the visit. The forms contained different questions covering the same artifact content and were designed to be comparable in structure and difficulty. Each consisted of ten four-option multiple-choice questions. Correct answers received one point; incorrect or unanswered items received zero, yielding scores from 0 to 10.

For cultural cognition, independent-samples t tests were first used to compare the two groups at pre-test and then at post-test. Paired-samples t tests were used separately within the narrative AR game group and the traditional viewing group to examine pre–post changes. To further determine whether the magnitude of change from pre-test to post-test differed between the two groups, a 2 × 2 mixed-design ANOVA was conducted to examine the Group × Time interaction.

6.2.2. Immersive Experience and Cultural Heritage Sharing Intention Scales

Immersive experience and cultural heritage sharing intention were measured using post-visit questionnaires. The items were adapted from previous studies on immersive experience and behavioral intention [30,32,40]. Each construct was measured using four items rated on a five-point Likert scale. Responses ranged from 1 ("strongly disagree") to 5 ("strongly agree"). Higher scores indicated greater immersive experience and stronger intention to share the cultural content with others. Immersive experience primarily assessed participants' attention and sense of presence during the visit, whereas cultural heritage sharing intention assessed their tendency to recommend or share the cultural content and museum experience with others.

Before analysis, participant characteristics and measurement data were organized and screened for missing values and invalid responses. Questionnaire data were analyzed using descriptive statistics, and the immersive experience and cultural heritage sharing intention scales were subjected to reliability analysis to assess internal consistency. Internal consistency was evaluated using Cronbach's α, with values above 0.70 indicating good internal consistency.

All experimental sessions were conducted in the same gallery area, and both

groups viewed the same five artifacts. The cultural cognition tests also covered the same knowledge domain for both groups. During the experiment, researchers only explained the procedure and addressed necessary technical issues; they did not provide participants with explanations of artifact knowledge covered by the test.

6.2.3. Semi-Structured Interviews

To provide further explanation for the differences observed in the quantitative measures, five participants from each group (n = 10) were selected for semi-structured interviews after completing the questionnaires. Each interview lasted approximately 20 minutes. With participants' consent, the interviews were audio-recorded and subsequently transcribed into text.

The interviews first explored participants' understanding of the five-color artifacts, with particular attention to the impressions retained after the visit and the reasons those impressions had formed. Questions then focused on the on-site visiting experience, including which parts of the visit directed participants' attention toward the artifacts and which aspects influenced the pace of their visit. Participants in the narrative AR game group were additionally asked about whether the tasks were naturally integrated into artifact viewing, whether the characters and feedback supported their understanding of the cultural content, and whether they encountered any operational problems.

Finally, participants were asked whether they would be willing to introduce or share the cultural content encountered during the visit with others. The interview data were used to complement the quantitative findings and to help explain why participants formed different evaluations of their actual experiences (Figure 8).



Figure 8. Experimental Procedure

7. Results

7.1. Pre-Test and Post-Test Analysis of Cultural Cognition

A total of 80 participants were included, comprising 48 women (60.0%), 15 men (18.8%), and 17 participants who identified otherwise or preferred not to disclose their

gender (21.3%). Participants ranged in age from 18 to 60 years, with the largest proportion aged 26–30 years (n = 24, 30.0%), followed by those aged 31–40 years (n = 22, 27.5%). A total of 63.8% of participants had previous experience with AR-related applications; however, none had previously experienced the AR-based interactive guidance developed for the five-color artifact exhibition examined in this study. Most participants reported being relatively proficient in smartphone use, with 49 participants (61.3%) selecting either “proficient” or “very proficient.”

Before the experimental intervention, an independent-samples t test was conducted to compare the cultural cognition pre-test scores of the narrative AR game group and the traditional viewing group. As shown in Table 12, the narrative AR game group had a mean pre-test score of 4.08 ± 1.49, compared with 4.42 ± 1.74 in the traditional viewing group. The difference was not statistically significant, $t(78) = -0.967$, $p = 0.337$, Cohen’s $d = 0.216$. These results indicate that the two groups had no statistically significant baseline difference was detected of cultural cognition before the intervention.

Table 12. Between-Group Comparison of Pre-Test Cultural Cognition Scores

Variable	Group	N	M	SD	t	df	p	d
Pre-test Cultural Cognition Score	Narrative AR Game Group	40	4.08	1.49	-0.967	78	0.337	0.216
	Traditional Viewing Group	40	4.42	1.74				

After the experimental experience, an independent-samples t test was conducted to compare the cultural cognition post-test scores of the two groups. As shown in Table 13, the narrative AR game group achieved a mean post-test score of 5.28 ± 1.28, compared with 4.67 ± 1.10 in the traditional viewing group. The between-group difference was statistically significant, $t(78) = 2.252$, $p = 0.027$. The effect size was Cohen’s $d = 0.504$, indicating a moderate effect. The higher post-test score in the narrative AR game group, together with the moderate effect size, indicates that participants who experienced the narrative AR game performed better on the five-color artifact cultural cognition test than those in the traditional viewing group.

Table 13. Between-Group Comparison of Post-Test Cultural Cognition Scores

Variable	Group	N	M	SD	t	df	p	d
Post-Test Cultural Cognition Scores	Narrative AR Game Group	40	5.28	1.28	2.252	78	0.027	0.504
	Traditional	40	4.67	1.10				

Variable	Group	N	M	SD	t	df	p	d
	Viewing Group							

Paired-samples t tests were further conducted to examine pre–post changes within each group, as shown in Table 14. In the narrative AR game group, the mean score increased from 4.08 ± 1.49 at pre-test to 5.28 ± 1.28 at post-test, representing a mean increase of 1.20 points. This change was statistically significant, $t(39) = -3.652$, $p = 0.001$, Cohen's $d = 0.577$, indicating a moderate pre–post improvement in cultural cognition. By contrast, the traditional viewing group increased from 4.42 ± 1.74 to 4.67 ± 1.10, corresponding to a mean increase of 0.25 points; however, this change was not statistically significant, $t(39) = -0.813$, $p = 0.421$, Cohen's $d = 0.129$.

These results show that cultural cognition scores increased significantly within the narrative AR game group, whereas the change observed within the traditional viewing group was small and nonsignificant. Taken together with the between-group comparisons, no statistically significant baseline difference was detected, whereas the narrative AR game group achieved a significantly higher post-test score than the traditional viewing group and also demonstrated a significant within-group improvement.

Table 14. Paired-Samples t Tests of Pre- and Post-Test Cultural Cognition Scores by Group

Group	Test	N	M	SD	Mean Change	t	df	p	d
Narrative AR Game Group	Pre-test	40	4.08	1.49	+1.20	-3.652	39	0.001	0.577
	Post-test	40	5.28	1.28					
Traditional Viewing Group	Pre-test	40	4.42	1.74	+0.25	-0.813	39	0.421	0.129
	Post-test	40	4.67	1.10					

A 2 × 2 mixed-design ANOVA was conducted, with Time as the within-subjects factor and Group as the between-subjects factor. The main effect of Time was statistically significant, $F(1, 78) = 10.383$, $p = 0.002$, partial $\eta^2 = 0.117$, indicating that, overall, cultural cognition scores were significantly higher at post-test than at pre-test. The main effect of Group was not statistically significant, $F(1, 78) = 0.310$, $p = 0.579$, partial $\eta^2 = 0.004$, indicating no significant overall difference between the two groups when scores were averaged across the two measurement occasions.

More importantly, the Group × Time interaction was statistically significant, $F(1, 78) = 4.457$, $p = 0.038$, partial $\eta^2 = 0.054$, indicating that the magnitude of pre–post change differed between the two groups. The mean increase was larger in the narrative AR game group than in the traditional viewing group. This interaction supports a greater improvement in cultural cognition in the narrative AR game group under the conditions tested (Tables 15 and 16).

Table 15. Results of the 2 × 2 Mixed-Design ANOVA for Cultural Cognition

Effect	df	F	p	partial η^2
Time	1, 78	10.383	0.002	0.117
Group	1, 78	0.310	0.579	0.004
Group × Time	1, 78	4.457	0.038	0.054

Table 16. Descriptive Statistics of Pre- and Post-Test Cultural Cognition Scores by Group

Group	N	Pre-test M ± SD	Post-test M ± SD	Mean Change (ΔM)
Narrative AR Game Group	40	4.08 ± 1.49	5.28 ± 1.28	+1.20

Group	N	Pre-test M ± SD	Post-test M ± SD	Mean Change (ΔM)
Traditional Viewing Group	40	4.42 ± 1.74	4.67 ± 1.10	+0.25

7.2. Analysis of Immersive Experience

Immersive experience during the museum visit was assessed using a questionnaire scale. The immersive experience scale comprised four items assessing attention, sense of involvement in the experience, and overall engagement. All items were rated on a five-point Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree").

The internal consistency of the scale was first examined. The immersive experience scale showed good internal consistency, with Cronbach's $\alpha = 0.831$, supporting its use in the subsequent analysis.

An independent-samples t test was then conducted to compare immersive experience scores between the narrative AR game group and the traditional viewing group. As shown in Table 17, the narrative AR game group reported a higher mean immersive experience score (3.44 ± 0.77) than the traditional viewing group (3.21 ± 0.70). However, the between-group difference was not statistically significant, $t(78) = 1.404$, $p = 0.164$. The effect size was Cohen's $d = 0.314$, indicating a small effect.

Table 17. Comparison of Immersive Experience Scores Between the Narrative AR Game and Traditional Viewing Groups

Variable	Group	N	M	SD	t	df	p	d
Immersive Experience	Narrative AR Game Group	40	3.44	0.77	1.404	78	0.164	0.314
	Traditional Viewing Group	40	3.21	0.70				

7.3. Analysis of Cultural Heritage Sharing Intention

Cultural heritage sharing intention after the museum visit was measured using four items rated on a five-point Likert scale. The internal consistency of the scale was first examined. The cultural heritage sharing intention scale showed good internal consistency, with Cronbach's $\alpha = 0.856$, supporting its use in the subsequent analysis.

An independent-samples t test was then conducted to compare cultural heritage sharing intention scores between the narrative AR game group and the traditional viewing group. As shown in Table 18, the narrative AR game group reported a mean score of 3.66 ± 0.66, compared with 3.13 ± 0.69 in the traditional viewing group, corresponding to a mean difference of 0.53 points. The between-group difference was

781 statistically significant, t(78) = 3.524, p = 0.001. The effect size was Cohen's d = 0.788,
782 indicating a moderate-to-large effect.

783 This result indicates a higher post-visit cultural heritage sharing intention in the
784 narrative AR game group than in the traditional viewing group under the conditions
785 tested.

786 **Table 18.** Comparison of Cultural Heritage Sharing Intention Scores Between the
787 Narrative AR Game and Traditional Viewing Groups

Variable	Group	N	M	SD	t	df	p	d
Cultural Heritage Sharing Intention	Narrative AR Game Group	40	3.66	0.66	3.524	78	0.001	0.788
	Traditional Viewing Group	40	3.13	0.69				

788

7.4. Semi-Structured Interview Findings

Ten participants, five per group, completed interviews after the questionnaires. Responses were organized into themes corresponding to cultural cognition, immersion, and sharing intention (Table 19).

Table 19. Summary of Themes Derived from the Semi-Structured Interviews

Interview Dimension	Group	N	Theme	n	Representative Response
Cultural Cognition	Narrative AR Game Group	5	Task processes supported recall of artifact content	4	"When I think of this artifact, I first remember what I did during the task, and then I remember the artifact itself." (E1)
	Narrative AR Game Group	5	AR scenes encouraged re-examination of artifact details	3	"After the mist disappeared, I went back to look at where the dragon handles were actually located on the artifact." (E3)
	Narrative AR Game Group	5	Characters and colors helped distinguish among artifacts	2	"When the red character appeared, I naturally associated it with the Zisha teapot." (E2)
	Traditional Viewing Group	5	Mainly retained impressions of color and artifact form	4	"I can still remember several artifacts with distinctive colors, but the details are easier to confuse." (C1)
	Traditional Viewing Group	5	Exhibition-label information was difficult to match to specific artifacts after the visit	2	"I understood it at the time, but afterward I could not remember which artifact some of the information belonged to." (C5)
Immersive Experience	Narrative AR Game Group	5	Tasks encouraged more focused observation	3	"Because I had to complete the task, I spent more time looking at that artifact than I normally would." (E1)
	Narrative AR Game Group	5	Recognition or operational problems temporarily interrupted the experience	2	"When recognition did not work smoothly, I started wondering whether I had done something wrong, and my attention was pulled away." (E5)

Interview Dimension	Group	N	Theme	n	Representative Response
	Traditional Viewing Group	5	Self-directed viewing provided a more relaxed pace	3	“The visit was relatively free. I could control my own viewing time and decide how long to stay in front of each artifact.” (C3)
	Traditional Viewing Group	5	Lack of clear viewing goals could lead to rapid browsing	3	“If something did not catch my attention at first, I might just look at it briefly and move on.” (C1)
	Narrative AR Game Group	5	Developed specific content that could be described to others	4	“I would tell my friends about the flower-arranging interaction with the blue vase artifact.” (E1)
Cultural Heritage Sharing Intention	Narrative AR Game Group	5	Characters and results pages provided clear shareable content	3	“The whole interaction process and the results could be shared. I could also share a photo of myself with the artifact character from the interactive game.” (E2)
	Traditional Viewing Group	5	Sharing focused mainly on photographs and exhibition recommendations	4	“If I took a nice photo of an artifact, or really liked the museum environment, I would post it on social media.” (C2)

AR participants often recalled artifacts through the tasks they had performed. Four of five described task processes as memory cues, three revisited artifact details after AR scenes, and two linked characters to colors. In the traditional viewing group, four mainly remembered visual features, while two had difficulty linking label information to particular artifacts. These accounts suggest different recall cues within the interview sample.

Three AR interviewees said tasks encouraged closer observation, while two described recognition or operational problems that interrupted the visit. Three traditional-viewing interviewees valued control over their pace, although three also said they could pass exhibits quickly without a viewing goal. The accounts distinguish task-directed from self-directed viewing without establishing a difference in measured overall immersion.

Four AR interviewees described specific tasks they could recount to others, and three mentioned characters or results pages as shareable content. Traditional-viewing

interviewees more often discussed photographs and exhibition recommendations. These interviews help explain the questionnaire difference in sharing intention by showing that AR participants had more concrete interaction content available for retelling.

Overall, task performance provided AR participants with concrete recall and sharing cues. Recognition problems sometimes disrupted the flow, whereas traditional viewing offered greater control over pace.

8. Discussion

8.1. Discussion of the Research Findings

This study examined how five-color artifact resources can be translated into narrative AR game design and how the resulting design performs in a real museum setting. The findings indicate a continuous relationship between the structuring of cultural resources, the prioritization of design elements, and their implementation in on-site interaction. Compared with traditional viewing, the narrative AR game produced significantly stronger outcomes in cultural cognition and cultural heritage sharing intention, while immersive experience showed a higher but nonsignificant trend. The findings are discussed below in relation to the four research questions.

For RQ1, grounded theory organized artifact resources into Form Semantics, Narrative Genes, Spatial Guidance, and Game Tasks. Prior work has linked narrative AR to engagement and learning [7], but has less often described the steps from source material to design decisions. In this case, relationships among the five colors informed characters and narrative cues across gallery locations. Grounded theory therefore served not merely to classify cultural information, but to establish a transformation logic linking cultural analysis with interaction design.

For RQ2, experts prioritized Character Identity Setting, Narrative Cue Organization, and Recognition Trigger. Earlier research identifies storytelling, participation, and game mechanics as components of heritage AR [41]. The AHP results assigned the highest weight to Narrative Genes (0.4495), followed by Spatial Guidance (0.2596). This ranking highlights the importance of connecting individual artifacts through a continuous narrative and organizing interactions around the gallery visit. Artifact characteristics also informed character development and task design.

For RQ3, the proposed framework was translated into an operational game in which each five-color artifact provided the basis for a character and task, while the gallery route determined the sequence of the experience. Higher-priority design elements were thus incorporated directly into the interaction flow, linking cultural resources to concrete design decisions. Digital characters and tasks remained anchored

to the physical exhibits, informed by earlier museum AR work situating digital narrative characters within the physical setting [38]. The framework therefore served as a bridge between cultural analysis and system implementation while maintaining a clear connection between game interactions and artifact content.

For RQ4, the significant Group × Time interaction supports a larger cultural cognition gain in the AR group. This is consistent with prior evidence that narrative AR can support heritage learning [7]. Interviews indicated that AR tasks encouraged participants to examine artifact details and provided cues for recalling cultural information. This helps explain the greater knowledge gains observed in the AR group and suggests that artifact-related interaction can support visitors' attention to cultural content.

Immersion scores were numerically higher in the AR group, but the between-group difference was not significant. Interviews described task-focused attention alongside interruptions from recognition problems; traditional viewers reported more control over pace. These accounts suggest different forms of engagement without establishing higher overall immersion, consistent with the multidimensional view of museum AR experience [30]. The higher sharing-intention score was accompanied by AR interviewees' descriptions of characters, tasks, and scenes they could recount. Earlier museum AR work has examined museum takeaway experiences and personalized cultural-content sharing [42]. Here, interaction episodes may have supplied more concrete material for retelling. Because the study focused on sharing intention, the findings primarily reflect participants' willingness to share cultural content after the visit.

8.2. Research Contributions

The main contribution of this study lies in explaining how artifact-based cultural resources can inform narrative AR game design. The proposed framework connects the cultural meanings of artifacts with character development and narrative organization, allowing interactive tasks to unfold across the exhibition. This approach provides a basis for designing coherent narrative AR experiences around thematically related museum collections.

Methodologically, this study integrates grounded theory and AHP to connect cultural resource analysis with design prioritization. Grounded theory establishes the relationships between artifact information and narrative interaction design, while AHP identifies the relative importance of the resulting design indicators. These findings guide the development of the AR game, which is subsequently evaluated through a controlled experiment and semi-structured interviews in a real museum setting. This approach establishes a coherent research process linking design framework

development with empirical evaluation.

Practically, the study translated the proposed design framework into a functioning narrative AR game implemented in a real museum gallery, demonstrating its practical applicability under on-site conditions. The system was designed around the physical artifacts themselves: digital tasks redirected visitors' attention to the exhibits, while narrative progression remained aligned with the existing gallery route. This implementation suggests that AR experiences for thematic exhibitions can be organized around existing cultural relationships among artifacts and explicit design priorities, rather than relying primarily on technological novelty to attract attention. For museum practice, the study demonstrates how artifact-based tasks can be integrated into existing exhibition routes, allowing digital interaction to support the interpretation of physical collections.

8.3. Research Limitations and Future Directions

Participants ranged in age from 18 to 60 years, with a greater concentration in the 26–40 age group. Future research could examine whether differences in age and prior AR experience influence learning outcomes and interaction preferences.

This study was conducted in a real museum gallery, allowing the evaluation to reflect actual spatial conditions and visitors' viewing pace. However, museum layouts and exhibition formats vary, potentially influencing how narrative tasks are integrated into the visiting experience. Future research could apply the same design approach to different types of museums and compare its performance across exhibition settings. Cross-site evaluation would help determine how the proposed approach can be adapted to different museum contexts and support its broader application.

The experiment compared the complete narrative AR game with traditional museum viewing, assessing the overall effects of the implemented design. Future studies could further examine the contributions of specific game components by comparing different narrative structures and interaction designs. Such comparisons would help clarify how individual design decisions influence cultural learning and visitor experience.

The evaluation primarily focused on immediate outcomes following a single museum visit, capturing changes in cultural cognition and participants' assessments of their experience. Longer-term outcomes were not examined. Future studies could incorporate delayed tests and behavioral follow-up measures to assess the retention of cultural information and whether cultural heritage sharing intention translates into actual sharing or return visits.

9. Conclusion

This study developed and evaluated an artifact-centered approach to narrative augmented reality game design in a real museum. Grounded theory identified four connected design dimensions—Form Semantics, Narrative Genes, Spatial Guidance, and Game Tasks—comprising 12 indicators. AHP assigned the highest relative importance to Narrative Genes (0.4495), followed by Spatial Guidance (0.2596). These priorities informed a mobile game in which characters, narrative cues, and tasks were derived from five exhibits and encountered beside the physical artifacts. The implementation shows how the cultural relationships within an exhibition can guide specific interaction decisions.

The randomized comparison involving 80 participants found a larger gain in cultural knowledge for the AR group than for traditional viewing (1.20 versus 0.25 points; Group × Time: $F(1, 78) = 4.457$, $p = 0.038$). The AR group also reported greater cultural heritage sharing intention (3.66 versus 3.13, $p = 0.001$), while the difference in immersion was not significant ($p = 0.164$). Interviewees linked their recall of artifacts to tasks and characters, and some described technical interruptions during the experience. These accounts help explain the viewing experience without establishing which individual game component produced the measured differences.

The findings connect an explicit process of cultural resource interpretation with the observed outcomes of a museum AR game. They suggest that narrative interactions can support artifact-focused learning when the tasks retain a clear relationship to the objects on display. The evidence concerns immediate outcomes from one exhibition; testing the approach in other galleries and measuring longer-term knowledge retention and sharing behavior would establish how far these results extend.

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