Museum game-based learning: innovative approaches from a constructivist perspective

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Constructivist learning theory emphasizes the subjectivity, sociality, and contextuality of learning, promoting learning through the creation of problem situations and guiding learners to collaborate and interact. Museums conduct educational activities for visitors through exhibits composed of physical objects and other supplementary forms. This paper proposes a model that integrates constructivist learning with game-based learning design, exploring the intrinsic mechanisms and implementation paths of game-based learning in museums to enhance the promotion of cultural heritage. Based on a hypothetical game scenario and analysis of museum game design practices, the paper discusses museum game design schemes grounded in constructivist principles, delves into the design methods of game-based learning in museums, and clarifies the pathways for embedding game elements and mechanisms into the use of cultural heritage resources. Through the analysis of the hypothetical game and established museum game design practices, this study demonstrates that museum game-based learning offers an effective approach to enhancing visitor engagement and learning. The application of the proposed constructivist GBL framework reveals how its six dimensions: self-determination, contextualization, social interaction, knowledge construction, meaning-making, and immediate feedback are reflected in actual implementations to varying degrees. The results of the analysis indicate that constructivist game-based learning holds strong potential for enhancing museum education. It is recommended that museums consider using a game-based learning model to design educational activities and exhibitions. To strengthen its applicability, future work could integrate inclusive design, ethical reflection, and longitudinal strategies. These efforts will help museums create more adaptive, inclusive, and sustainable learning experiences.

KEYWORDS

museum education, constructivist learning, game-based learning, gamification learning, heritage education, space education

1 Introduction

As cultural and educational hubs, museums have evolved from their traditional roles as archives and repositories into dynamic social spaces and interactive learning environments. This shift moves beyond a sole focus on collections to emphasize the relationship between objects and people. The increasing recognition of individual agency in museum experiences has driven a transformation in both educational philosophies and learning approaches. Meaning-making within museums is no longer dictated solely by institutions; instead, it is increasingly shaped by visitors, whose needs and experiences

have become central to museum education. As a result, "learning and experience" has emerged as the dominant paradigm in museum education (Chang, 2006). With museums playing an increasingly prominent role in social education, traditional didactic and interpretive teaching models have been challenged, giving way to a learner-centered approach (Hein, 2006). Constructivist learning theory, which emphasizes learning as an active process grounded in prior experience, provides a valuable framework for understanding the complex interactions between visitors and museums (Hein, 1998). Under the influence of constructivist principles, museums have shifted their focus toward individual engagement, incorporating participatory and experiential strategies to facilitate storytelling and knowledge dissemination.

In recent years, museums, as informal learning environments, have experienced a shift in their educational role, moving from traditional one-way knowledge transmission, historically controlled by cultural authorities, toward more participatory and interactive models (Ćosović and Brkić, 2020). Game design has emerged as an effective way to enhance museum education, fostering greater engagement and interactivity. Gamification allows museums to integrate elements such as points, badges, and challenges into non-game contexts, thereby increasing visitor motivation and encouraging self-directed exploration (Hanus and Fox, 2015). In contrast, game-based learning (GBL) uses complete games as the medium for instruction, combining narrative, interactivity, and problem-solving to provide personalized and emotionally engaging experiences with cultural content (Breien et al., 2022; Khan et al., 2017). While the two approaches are often discussed together, they represent distinct points along a continuum of game use in education (Lester et al., 2023). These approaches not only enrich visitor engagement, but also support museums in fulfilling their evolving educational mission in contemporary society (Ćosović and Brkić, 2020). This study adopts GBL as the primary framework for understanding how museums can create immersive, learner-centered educational experiences.

From the Palace Museum's early online educational game A Day in the Life of an Emperor (China Daily, 2014) to the widespread popularity of in-person "scripted mystery" games in museums across China (China Daily, 2024), the integration of game has not only enriched audience interaction but also diversified game-based learning formats. This ongoing exploration of game-based learning in Chinese museums has become an effective means of enhancing visitor experiences and improving learning outcomes.

However, while current museum game-based learning practices incorporate both game design and heritage elements, their integration remains largely limited to embedding knowledge, with a disconnect still existing between teaching content, instructional methods, and game design (Madsen, 2020; Fuchs, 2023). Additionally, the lack of theoretical analysis in this field makes it challenging to develop well-established applications guided by the museum's social education objectives.

Therefore, this paper positions constructivist learning theory as the foundational framework for designing and understanding game-based learning (GBL) in museums. Section 2 reviews relevant literature on constructivist pedagogy, its application in educational game design, and its integration within museum contexts. Section 3 introduces a constructivist GBL framework for museums and demonstrates its practical relevance through a hypothetical game scenario. The proposed model is further validated through comparative analysis with real museum practices, highlighting its

applicability across multiple dimensions of learning. Section 4 reflects critically on the strengths and limitations of the proposed framework. It summarizes key findings from its application, identifies conceptual and practical challenges, and suggests directions for future development. Together, these sections offer theoretical grounding and design guidance for advancing the use of game-based learning in museum education.

2 Constructivism and museum game-based learning

2.1 Constructivism and museums

The theory of constructivism, which was proposed after continuous reflection on behaviourist learning theories in the first half of the 20th century, emphasizes the process of learners actively constructing knowledge during interaction with the environment rather than passively accepting externally transmitted information (Yan, 2024). The core idea of constructivist learning is that knowledge is not simply transferred from teacher or textbook to student, but learners actively construct and organize knowledge in their own cognitive structure through interaction with the environment, others, and even with their own experience and thinking. Learners are not only recipients of knowledge, but also creators and builders of knowledge (Richardson, 1997). Accordingly, the goal of learning is no longer simply to memorize facts, but to promote deeper understanding and the construction of cognitive structures through active inquiry, cooperation and reflection, which can bring out the autonomy to the individuals (Barr and Tagg, 1995; Biggs and Tang, 2011).

The concept of constructivism is highly suitable for the key objective of museum education, which is to promote active learning and knowledge internalization among the audience. The application of constructivist theory to museum management and operations is an inevitable trend in museum development. It plays a crucial role in shifting museum education from mere knowledge transfer to a more interactive and inquiry-based approach (Barr and Tagg, 1995; Biggs and Tang, 2011; Hein, 1995). This transformation allows visitors to move beyond passive acceptance, fostering active learning, self-construction, and independent exploration within museum spaces. Additionally, it encourages audiences to integrate their personal experiences, evolving from passive cultural consumers into active cultural producers (Wang and Nunes, 2019). Guided by this concept, museums are increasingly adopting innovative designs that emphasize interactivity, immersion, and situational experiences. This approach shapes a modern museum management and operational model centered on individual experience and meaning-making, extending to conceptual frameworks, architectural design, exhibitions, and educational programs (Lan, 2015).

2.2 Core principles of museum game-based learning design

Abt (1970)'s creation of the term "Serious Games" in the last century is often attributed as the origin of the field. This

theory later gave rise to related terms such as "Game-Based Learning" and "Educational Games" (Kirchner-Krath et al., 2021). Game-based learning goes beyond game elements such as points, rewards, tasks, and rules; it is a systemic game design approach that incorporates a variety of mechanisms, structures, and frameworks to foster curiosity, creativity, and exploration, thereby ultimately enhancing learning outcomes (Abdul Jabbar and Felicia, 2015; Meng et al., 2024; Khan et al., 2017). This approach can be applied through comprehensive, structured frameworks that integrate narrative and interdisciplinary learning (Breien et al., 2022), or through simpler models that focus on playful learning and engagement within interactive environments (Mystakidis, 2021).

In recent years, game-based learning has been widely applied across diverse educational contexts, including formal settings such as primary, secondary, and higher education (Sun et al., 2023, Guan et al., 2024; Platz, 2022; Bakhsh et al., 2022), as well as informal and technology-enhanced environments (Mystakidis, 2021; Meng et al., 2024). Immersive technologies like virtual and augmented reality have further expanded the possibilities of game-based learning by enabling interactive, situated, and emotionally engaging learning experiences (Radianti et al., 2020; Parong and Mayer, 2018). Analyzing game-based learning cases and evaluation outcomes over the past few decades, it is evident that game-based learning can stimulate learners' enthusiasm, encourage active exploration, and enhance comprehensive skills such as creativity, leadership, and decision-making (Olesen and Holdgaard, 2024). These benefits have driven innovations in learning methods, fostered social interactions during the learning process, and improved the evaluation of learning outcomes, leading to significant progress (Zhang and Shang, 2018).

Given their evolving role as educational and socially responsive institutions, museums increasingly recognize the need to adopt game-based learning, respond to changing audience expectations, and align with their broader mission to serve as inclusive, interactive, and impactful public learning environments (Paliokas and Sylaiou, 2016; Cuseum, 2020; Smithsonian Education, 2021). In recent years, a growing body of research has explored how museums integrate game-based strategies into their educational practices. Türkmen and Savasta (2024) divided the museum visit into three stages based on the exhibition content and designed a role-playing game model to critically explore how to integrate these stages into the visitor experience. Kiili et al. (2012) discuss the importance of flow theory in designing educational games that effectively engage learners. It presents a flow framework based on associative, cognitive, and situative learning theories, and tests it through the RealGame case study, demonstrating that well-designed games can enhance student engagement and provide meaningful learning experiences. Wu (2021), drawing on the ARCS motivation model (Attention, Relevance, Confidence, Satisfaction) and Thomas Malone's intrinsic motivation theory, examined museum game design principles through the case study of Time-Space Museum Cards, a children's educational app developed by Hunan Museum. Similarly, Anderson (2019) explores how games, like Valiant Hearts: The Great War, use world-building and role-playing as effective teaching tools in museums and history classrooms. Additionally, Nie (2021) explored museum

game design principles based on inquiry-based learning, the 5E instructional model, and other educational theories. Beavis et al. (2021) analyzed the design considerations when incorporating digital games into museums. They highlighted the construction of history, historical interpretation, and the processes of historical research, exploring the differing values and priorities behind design group's perspectives and their implications for museum education.

Beyond these pedagogical applications, researchers have also examined a wide range of technological approaches to gamification in museum settings. Yiannoutsou et al. (2009) proposed mobile-based educational games that enable young children to interact playfully with physical exhibits. Mystakidis et al. (2024) explored virtual museum exhibitions in the Metaverse, showing how immersive environments and gamified mechanics can increase learner motivation and engagement. Liang et al. (2024) developed an AI-supported alternate reality game (ARG) learning model that provided adaptive feedback and improved learners' emotional and metacognitive engagement. Kleftodimos et al. (2023) demonstrated that location-based augmented reality (AR) applications, combined with gamification and storytelling, can transform educational visits to museums and archaeological sites into interactive and satisfying learning experiences.

In addition to their educational roles, gamification strategies in museums have also been applied to enhance the overall visitor experience and support institutional development. For example, López-Martínez et al. (2020) introduced a low-maintenance smart object platform based on linked data, designed to generate interactive content and enrich visitor engagement. Beyond direct gamification use, Swacha (2015) examined digital strategies for knowledge transfer in oceanographic museums, highlighting the importance of integrated technological solutions in supporting internal collaboration and institutional learning processes.

While existing research has provided valuable practical insights into museum game-based learning by deconstructing game design principles and embedding these elements into museum educational programs, it still lacks a comprehensive theoretical analysis from the perspective of museum education research. Key aspects, such as the diversity of target audiences, theoretical integration, assessment of educational outcomes, and the broader operational strategies of museums, remain insufficiently explored.

Therefore, this study proposes a design framework grounded in constructivist learning theory, aiming to offer a more systematic and educationally oriented approach to museum game-based learning. The innovation of museum game-based learning design goes beyond the mere incorporation of game elements; it lies in the construction of its underlying mechanisms. Specifically, museum games leverage points, rewards, missions, and structured rules to stimulate learners' intrinsic motivation and foster active participation. Immersive scenario design helps maintain learners' focus on educational objectives, facilitating deep engagement. Competitive and collaborative mechanics enhance social interaction and emotional connections, enriching the overall learning experience. Meanwhile, interactive roles and virtual identities create an immersive environment, while task-driven

progression and real-time feedback mechanisms enable learners to refine their strategies, ultimately optimizing learning outcomes.

3 Innovations in museum game-based learning from a constructivist perspective

3.1 The constructivist GBL framework in museum context

Constructivist learning theory highlights that knowledge is actively constructed through engagement with meaningful, contextualized, and socially mediated experiences (Richardson, 1997; Yan, 2024). Building on similar principles, game-based learning creates structured environments where learners can explore narratives, take on roles, solve problems, and receive immediate feedback, all within an interactive setting (Kiili et al., 2012; Anderson, 2019). This alignment allows game-based learning to serve not only as a motivational tool, but as a pedagogical approach that reinforces autonomy, inquiry, and deep understanding. In the museum context, such integration encourages a shift from passive knowledge consumption to active, participatory learning, transforming visitors into co-constructors of knowledge through personal and collaborative exploration. To support such transformation, this study proposes a constructivist-informed design framework for museum game-based learning, aiming to provide a systematic and educationally grounded reference for both practice and research.

Figure 1 outlines the alignment between constructivist concepts and gamification design strategies in the museum context.

Findings from this study highlight several key components of game-based learning design in museums: self-determination, context design, collaborative learning, collaborative and competitive, immersive learning, task-based learning and immediate feedback. These elements align closely with constructivist learning theory and the core principles of gamification learning, fostering deeper engagement, active exploration, and meaningful knowledge acquisition among learners. By integrating interactive game mechanics and constructivist learning theory, museum education can be transformed from passive knowledge transfer to a dynamic learner-centered experience that encourages social interaction, critical thinking and sustained engagement.

3.2 A conceptual proposal for applying the constructivist GBL framework in museum learning

To demonstrate the practical relevance of the proposed constructivist framework for game-based museum learning, this section presents a theoretical design for a museum game based on the real-world exhibition "Marco Polo for a Day: Discovering the Wisdom of the Silk Road," held at the China Science and Technology Museum in 2020 (China Science, and Technology Museum, 2020). While the game is not intended as an empirically

implemented product, it serves as a conceptual validation of how each dimension of the framework can be systematically applied to museum learning contexts (Table 1). This approach aligns with previous scholarship on theoretical instructional design, where conceptual models are used to explore the feasibility and educational implications of learning frameworks prior to implementation (Gustafson and Branch, 2002; Plass et al., 2015).

Rather than assigning fixed learning objectives to individual exhibition zones, the game design reflects a multi-dimensional integration of six constructivist learning principles: self-determination, contextualization, social interaction, knowledge construction, meaning-making, and immediate feedback, which are embedded throughout the entire gameplay experience (Table 2). These dimensions operate concurrently as players navigate different zones, tasks, and decisions, shaping how content is accessed, interpreted, and reflected upon.

Building on constructivist learning theory, the proposed design presents a conceptual model for museum game-based learning that integrates six pedagogical dimensions into a coherent experiential structure. Although the framework remains theoretical at this stage, it illustrates the educational rationale and design logic behind applying constructivist principles to gamified museum contexts. In order to further explore the applicability and explanatory potential of this model, the following sections will examine a series of museum game-based learning cases. These cases discussions will apply the model as an analytical framework to interpret various practices and to investigate how its core elements are embedded within actual implementations.

3.3 Student centered learning and self-determination

Constructivist learning emphasizes learner agency, marking a shift from traditional teacher-centered instruction to student centered learning (Piaget, 1952; Vygotsky, 1978; Richardson, 1997; Jonassen, 1999; Yan, 2024). This approach encourages learners to actively engage in the learning process, construct their own understanding based on feedback from their actions, and develop problem-solving strategies in response to real-world challenges (Bada and Olusegun, 2015). Similarly, game-based learning fosters self-determination by providing opportunities for choice, autonomy, and meaningful action, which enhance intrinsic motivation and ownership over learning outcomes (Deci and Ryan, 2000; Nicholson, 2015). By offering greater autonomy and interactive decision-making opportunities, game-based learning could enhances learners' intrinsic motivation and reinforces the impact of their own decisions on behavior.

Game-based learning design in museums incorporates elements such as choices, badges and points to encourage active participation shifting learners from passive recipients of knowledge to active seekers of information who construct their own understanding. A notable example is the Beamish Museum Monopoly Game, developed to promote awareness of rural cultural heritage. Inspired by the traditional Monopoly board game, this customized version integrates historical artifacts and real-world locations from the museum into the game board (Beamish Museum, 2020). To further illustrate this approach, a conceptual
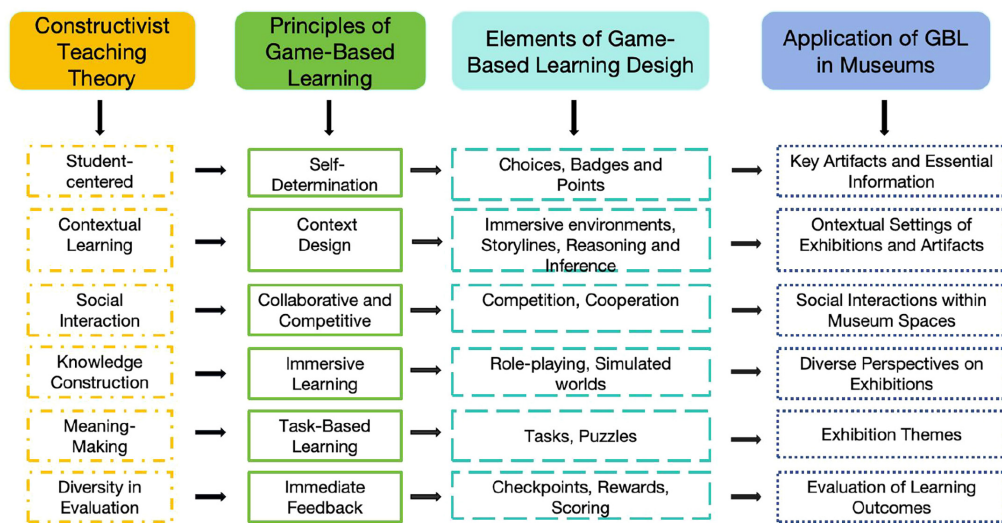
FIGURE 1
Constructivist teaching concepts combined with game-based learning design for museum education.

model was created to simulate how a Monopoly Game format might be used to structure museum GBL. The model is intended for illustrative purposes only (Figure 2). Players engage with the museum's content by selecting cards, accumulating points, and managing assets, allowing them to actively shape their learning experience. Through decision-making and strategic adaptation based on randomly drawn cards and accumulated points, learners not only explore different historical periods and narratives but also deepen their understanding of rural heritage preservation through personalized engagement and self-directed exploration. This case illustrates how the self-determination dimension of the proposed framework can be meaningfully integrated into museum game-based learning designs, demonstrating the model's practical applicability in supporting learner autonomy within informal educational contexts.

3.4 Contextual learning and context design

Constructivist learning theory emphasizes the importance of learning contexts, asserting that learning should be connected to specific socio-cultural backgrounds (Piaget, 1952; Vygotsky, 1978; Richardson, 1997; Jonassen, 1999; Yan, 2024). This approach facilitates learners in building upon their pre-existing knowledge structures and prior experiences, enabling them to assimilate and accommodate new knowledge (Bada and Olusegun, 2015). Game-based learning often employs immersive design to embed learning content within concrete situations. Through this way, a multidimensional contextual environment is created, incorporating elements such as virtual environments, narrative storytelling, and mystery-solving mechanics (Anderson, 2019).

In recent years, the popularity of museum-based immersive role-playing games, has grown significantly (Ji, 2022). These games leverage the museum's contextual setting by embedding authentic historical narratives, using exhibitions and artifacts as narrative clues to guide participants through immersive and educational storylines (Wang, 2024).

One of the earliest applications of museum mystery games in China is The Dream of Famen (Famen Mengying), a collaborative project between Changsha Museum and Famen Temple Museum (D-arts, 2021). This game utilizes the museum's cultural spaces to create a unique learning context, embedding the historical background of the Tang Dynasty into the game scenario (Deng and Zhang, 2024). Throughout the engaging deduction process, it incorporates interactive experiences such as tea brewing and incense burning, enhancing participant engagement. By integrating auditory, tactile, gustatory, and olfactory elements, the game reconstructs a multisensory representation of a specific socio-cultural context, fostering hands-on engagement. Furthermore, it moves away from conventional didactic information delivery methods, instead guiding learners to draw upon their own experiences.

This case demonstrates how the contextual learning dimension of the proposed framework can be effectively embedded in museum game design, reinforcing the framework's theoretical applicability to real-world educational settings.

3.5 Social interaction and competitive-cooperative mechanisms in learning

Constructivist learning theory emphasizes that learners' interactions with their surrounding environment play a crucial role in shaping their understanding of learning content (Piaget, 1952; Vygotsky, 1978; Richardson, 1997; Jonassen, 1999; Yan, 2024). Learning is a social process, where knowledge construction emerges through collective critique, dialogue, and interaction within a group (Barr and Tagg, 1995). Game-based learning similarly integrates social dynamics by employing competitive and cooperative mechanisms to facilitate interaction and deepen

TABLE 1 Game proposal of Marco Polote Mission: Secrets Of The Silk Road.

Game Title	Marco Polp's Mission: Secrets of the Silk Road
Museum setting	"Marco Polo for a Day" Exhibition, China Science and Technology Museum.
Game overview	Marco's Mission: Secrets of the Silk Road is an educational role-playing game designed for museum-based learning. Set in the historical context of the Silk Road, the game allows participants to join a caravan led by Marco Polo, whose journey from Venice to Yuan China between 1,271 and 1,295 offers a symbolic narrative frame (Polo and Rustichello, 2004). Players assume various roles such as Marco Polo, merchants, interpreters, craftsmen, or scholars, each with unique goals and decision paths. Through a series of interactive, context-based tasks embedded in exhibition zones, players explore trade routes, engage with historical artifacts, solve cultural and technological challenges, and make take decisions. The game emphasizes learner agency, collaboration, and critical reflection, transforming the museum experience into a personalized and participatory learning journey.
Target audience	General museum visitors, with a focus on youth and young adult learners, family groups, and culturally engaged audiences (ages 12+).
Educational objectives	To foster public understanding of the Silk Road's historical role in trade, science, and intercultural exchange To cultivate historical empathy and cross cultural awareness through role-based narrative experiences To support inquiry-driven learning and reflective thinking across different age groups and backgrounds To promote collaboration, communication, and strategic decision-making in a shared learning environment To encourage emotional engagement, curiosity, and personal meaning-making through immersive interactions To enhance public appreciation of cultural heritage by linking ancient technologies to contemporary global challenges.

TABLE 2 Constructivist GBL design framework in Marco Polo's Mission: Secrets of the Silk Road.

Constructivist teaching theory	Principles of GBL design	Application of GBL in museums	Game flow design
Student-centered	Self-determination	Choices of characters and exploration paths	Players choose roles (e.g., merchant, interpreter), each with distinct goals and paths. This supports learner autonomy and personalized engagement with content.
Contextual learning	Context design	Themed exhibition zones with contextual tasks	Learners explore exhibition zones using AR tools and historical maps. Tasks are grounded in authentic cultural and technological environments to enhance contextualized understanding.
Social interaction	Collaborative and competitive	Group-based tasks and negotiation scenarios	Players form caravans and make collective decisions. This fosters cooperative learning, peer dialogue, and social negotiation in historically inspired team work settings.
Knowledge construction	Immersive learning	Multi sensory environments and narrative immersion	Tasks of game require learners to decode inscriptions and analyze tools. These activities prompt active meaning construction through interpretation and evidence seeking.
Meaning-making	Task-based learning	Artifact-based puzzles and role-relevant tasks	Open-ended dilemmas challenge learners to make ethical or cultural decisions, encouraging reflection on historical values, intercultural awareness, and critical thinking.
Diversity in evaluation	Immediate feedback	Points and rewards, progress tracking, reflection tools	At the end of the journey, the points will be calculate. Each learner receives a personalized "Silk Road Chronicle" with badges and summaries, reinforcing learning through narrative closure and formative evaluation.

emotional engagement (Kiili et al., 2012; Wu and Xie, 2020; Anderson, 2019).

The Beamish Museum's Monopoly game which mentioned before uses cumulative points and property markers to motivate participants to randomly form competitive or collaborative relationships during the course of the game (Beamish Museum, 2020). This promotes communication and sharing among participants, leading to a deeper understanding of the museum's exhibits and related knowledge. For example, in the museum game "Monopoly," players may need to share knowledge or discuss strategies with other players for the completion of a certain task, and may also compete for the allocation of resources or conflicting goals. This dynamic social interaction breaks through the previous single learning path in museums, creates an environment of group communication and interaction, and takes social interaction as

a key factor to promote the learning process, which not only increases the fun of the game, but also strengthens the learners' knowledge and memory of the cultural content.

This case illustrates how the social interaction dimension of the proposed constructivist framework can be effectively implemented through collaborative and competitive mechanics, demonstrating the model's practical value in designing meaningful, multi-participant learning experiences in museum settings.

3.6 Knowledge construction and immersive learning

Constructivist learning theory emphasizes that knowledge is actively constructed by learners (Piaget, 1952; Vygotsky, 1978;

FIGURE 2
Museum Monopoly game concept map.
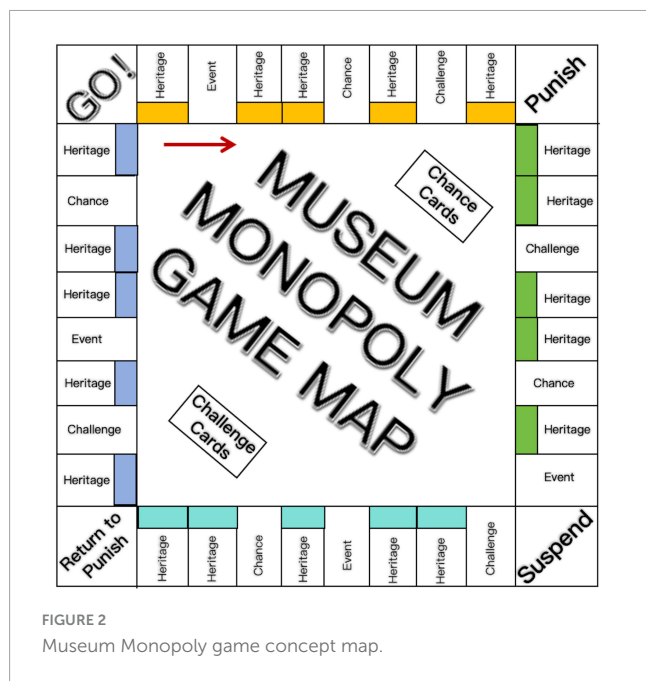
Richardson, 1997; Jonassen, 1999; Yan, 2024). Game-based learning can provide a space for learners to explore through contextualized tasks and interactive mechanisms (e.g., role-playing, simulated worlds) so as to creating an immersive experience, prompting the audience to integrate new information and construct new meanings in the process of completing tasks (Deng and Chai, 2024; Wu and Xie, 2020). Unlike museum visits which typically frame audiences as passive recipients of information, game-based learning could fosters active engagement by encouraging learners to explore through immersive roles, purposeful tasks, and interactive settings.

For example, the online game Secret Seekers at the Victoria and Alberta Museum in the United Kingdom guides learners to explore the museum's collections and stories through eight characters that are tied to the history of the museum's construction (Victoria and Albert Museum, n.d.). Learners participate in the game route by choosing different characters and answering questions to gain information about the levels (Price, 2017). The approach of the game breaks the single linear narrative thread and provides opportunities to construct identity information from different characters, enabling learners to learn about the museum's collections and historical information from multiple narrative perspectives and to construct knowledge in an immersive identity experience.

This case demonstrates how immersive, role-based design can support knowledge construction in museum game-based learning, reinforcing the pedagogical value of this dimension within the proposed framework.

3.7 Meaning-making and task-based learning

Constructivist teaching emphasizes that the ultimate purpose of learning is the construction of meaning, rather than focusing on the completion of teaching objectives (Piaget, 1952; Vygotsky,

1978; Richardson, 1997; Jonassen, 1999; Yan, 2024). Under this concept, the purpose of teaching and learning is more diversified. In addition to the acquisition of knowledge, it can also be centered on the interest of learners and the transformation of their perceptions and attitudes. Game-based learning guides learners to participate in the process of knowledge exploration through tasks, puzzles and other mechanisms, and also has more diversified criteria for judging the results, and can drive learners to enhance the value of emotions, concepts, ideas and other feelings through the setting of tasks (Meng et al., 2024). This multifaceted, task-based approach reorients the evaluation of museum learning outcomes from traditional knowledge-recall formats toward more diverse, process-oriented assessment methods (Wu, 2021; Liang et al., 2024). It linked to individual participation in practice and experience, and focuses on learners' emotions, thinking and conceptual changes in the museum learning process. The Hong Kong National Palace Museum of Culture has launched a parent-child night game inspired by artifacts and combined with ancient traditional time and ritual customs (Hong Kong Palace Museum, 2024). It aims to convey historical knowledge through the game while cultivating the participating children's life skills. It sets up task objectives from the perspectives of emotional communication, thinking shaping and value establishment, promotes emotional interaction among family members, and creates a deeper understanding of traditional customs and etiquette and culture in the process of interaction.

This case illustrates how the meaning-making dimension of the proposed framework can be effectively realized through task-based learning. By embedding emotional, social, and conceptual learning objectives into interactive challenges, the game encourages visitors to construct personal interpretations and deepen their connection with cultural content in museum settings.

3.8 Diversity in evaluation and immediate feedback

Constructivism emphasizes process evaluation, which pays more attention to learners' thinking process, practical performance and ability development in learning activities than traditional summative evaluation (e.g., examination results), and believes that evaluation should accompany the whole process of learning, and attaches importance to learners' initiative, participation and reflective ability (Piaget, 1952; Vygotsky, 1978; Richardson, 1997; Jonassen, 1999; Yan, 2024). Game-based learning, meanwhile, reinforces learners' performance through real-time feedback mechanisms (e.g., unlocking new levels, obtaining rewards), helps them adjust their learning strategies in a timely manner, and sums up the learning process with a multi-dimensional evaluation system, which is dynamic and flexible in nature (Nie, 2021; Deng and Chai, 2024; Zheng, 2021). The Grand Canal Museum's interactive experience exhibition for young people, "The Canal Mystery of Daming Du Shui Supervisor," creates a historical background of the construction of the Grand Canal and Yangzhou's shipping and commerce through immersive interactive experiences, setting up the four main parts of the exhibition as different game levels, and designing instant feedback with restored scenes and interactive organs, so that the participants need to pass the levels through the interaction to participate in the whole game

(Grand Canal Museum, n.d.). Participants need to pass through the interactive levels and thus participate in the whole process of the game. This design adds real-time feedback and multi-dimensional evaluation in the whole process of game learning, which can assist learners to deepen their understanding of the content of the exhibition, and at the same time enhance the positive feedback of learning (Zheng, 2021).

This case demonstrates how the evaluation and feedback dimension of the proposed constructivist GBL framework can be effectively operationalized through immersive, feedback-rich systems. By embedding evaluation into interaction itself, the design promotes adaptive learning, reflective awareness, and sustained engagement in museum contexts.

4 Reflection and future directions of constructivist game-based learning in museums

4.1 Summary of framework application

The preceding section illustrated the practical application of the Constructivist GBL Framework across multiple museum-based case studies. Each dimension of the model: self-determination, contextualization, social interaction, knowledge construction, meaning-making, and immediate feedback, was reflected to varying extents through real-world examples. For instance, the Beamish Museum Monopoly game (Beamish Museum, 2020) and the V&A's Secret Seekers (Victoria and Albert Museum, n.d.) incorporated role-based decision-making and narrative branching, effectively supporting learner autonomy and identity-driven exploration. Similarly, games like The Dream of Famen (D-arts, 2021) and the Grand Canal (Grand Canal Museum, n.d.) interactive exhibition integrated multisensory environments and real-time feedback to deepen engagement and support meaning construction. These confirms the constructivist GBL framework's capacity to guide the development of pedagogically meaningful and experience-driven museum learning environments (Deci and Ryan, 2000; Nicholson, 2015; Anderson, 2019; Wu and Xie, 2020; Deng and Zhang, 2024; Meng et al., 2024). Moreover, the alignment between the constructivist principles and the design strategies observed in these examples suggests that the model can serve to diagnose existing practice and guiding future innovation in museum game-based learning (Anderson, 2019; Meng et al., 2024).

4.2 Limitations of the proposed framework

While the Constructivist GBL Framework has demonstrated coherence in aligning constructivist learning principles with game-based design in museums, it remains a general model that requires further refinement for application in more ethically, socially, and pedagogically complex settings.

First, the framework emphasizes agency and social interaction as central tenets of constructivist learning. However, for museums dealing with sensitive themes, such as war, trauma, gender, colonial history, or contested memory, game-based learning design may

require additional ethical scaffolding. The model does not yet integrate interpretive frameworks that address how players engage with sensitive or emotionally charged historical narratives, nor how ethical reflection might be supported during gameplay (Schrier, 2015; Symeonidi, 2018). These concerns are particularly relevant when learners' choices and experiences within the game have the potential to influence their understanding of complex moral or cultural issues.

Second, while the framework is intended to be broadly inclusive, its applicability across diverse audience groups, some special communities has not yet been empirically validated. Questions remain about how different visitor demographics interpret game mechanics, respond to feedback systems, and construct meaning in personalized ways (Seaborn and Fels, 2015). The model may thus require expansion to incorporate adaptive strategies for differentiated instruction and inclusive design.

Third, the current framework focuses heavily on real-time interaction and immediate feedback, which are effective for short-term engagement and motivation. However, it does not yet address how such systems can support long-term learning retention, sustained inquiry, or post-visit reflection (Hamari et al., 2014). This limitation reduces its potential for supporting deeper learning and evaluating long-term educational outcomes.

In response to these limitations, future iterations of the Constructivist GBL Framework should be refined not only at the conceptual level but also through concrete practices in design, implementation, and evaluation. In practical terms, this requires expanding the framework's ethical sensitivity, social inclusivity, and longitudinal capacity within real museum learning environments. This can be achieved by integrating interdisciplinary perspectives such as moral education, inclusive design principles, and learning analytics into the development process (Seaborn and Fels, 2015). In addition, building long-term partnerships with schools, cultural institutions, and community organizations will help facilitate co-design, user testing, and iterative refinement (Hamari et al., 2014). Through these applied and collaborative efforts, the framework can evolve into a more dynamic model that enhances game-based learning in museums while supporting equitable, reflective, and socially engaged cultural education.

4.3 Future directions for museum game-based learning

Despite growing interest in game-based learning, many museums still face challenges in implementing meaningful educational games. These include limited theoretical guidance, fragmented content integration, unclear pedagogical objectives, and the absence of systemic evaluation strategies (Nie, 2021; Wang and Nunes, 2019; Beavis et al., 2021). In many cases, game elements are adopted superficially, driven by technology or novelty rather than educational purpose, which undermines the potential of museum learning experiences.

Looking ahead, the application of game-based learning in museums is expected to become increasingly widespread, driven by digital innovation, audience demand for interactivity, and the evolving role of museums as inclusive, participatory cultural institutions (Mystakidis, 2021; Smithsonian Education, 2021).

With advancements in immersive technologies, interdisciplinary collaboration, and the shift toward experience-centered design, museums are likely to expand their use of games to support both educational engagement and social communication.

The constructivist GBL framework proposed in this study offers a valuable tool to support this development. By aligning game design with principles of constructivist learning, the framework provides museums with a structured reference for designing pedagogically grounded, user-centered learning experiences (Hein, 1995; Yan, 2024; Jonassen, 1999). As museums continue to explore innovative educational strategies, this framework can assist institutions in integrating game-based learning more effectively into their programming, supporting both immediate engagement and long-term knowledge transformation.

5 Conclusion

Museums serve as dynamic spaces for preserving history and fostering cultural dialogue, playing a vital role in public education and identity formation. As education and audience engagement become central to modern museum practices, the development of game-based learning in museums has accelerated. Grounded in constructivist learning theory, this study conducts a comparative analysis of the evolution of game-based learning in museums and proposes core design principles. It outlines a learner-centered framework that emphasizes key dimensions such as self-determination, context design, collaborative and competitive, immersive learning, task-based learning and immediate feedback. Building on this model, a hypothetical game Marco Polp's Mission: Secrets of the Silk Road was designed to demonstrate its practical implications. The design model of this game was then examined through a discursive validation process, using different cases of museum game-based learning to test the framework's applicability and relevance. By integrating theory with practice in a reflective and iterative manner, the study provides both a diagnostic lens and a design tool for future applications.

Ultimately, the constructivist GBL framework offers museums a pedagogically grounded approach to developing meaningful game experiences. It also offers new directions for interdisciplinary collaboration, inclusive learning design, and long-term educational integration areas that will be increasingly important as museums redefine their role as interactive and socially engaged learning institutions.

Data availability statement

The original contributions presented in this study are included in this article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

HL: Funding acquisition, Project administration, Supervision, Writing – review and editing. MZ: Data curation, Investigation, Methodology, Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Generative AI was used in the creation of this manuscript.

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