Mu-nopoly: Design and Evaluation of a Board Game for Museum Edutainment

Jiachen Liang, Yue Li, *Member, IEEE*, Fanpei Liu, Yu Cheng, Richard Koeck, and Hai-Ning Liang

***Abstract*—Edutainment, namely, education and entertainment, has become an important part of the museum experience. Previous research has discussed the significance of edutainment in museums, but there is still a need to explore the effectiveness of edutainment activities through specific system designs and evaluations in real-world museum contexts. This study focuses on board games as an edutainment means. We identified three types of activities that are highly relevant to a board game: playing, learning, and socializing, and proposed a *Playing–Learning–Socializing (PLS)* framework for museum edutainment. Based on this framework, we designed a board game, *Museum Monopoly* (*Mu-nopoly*), and evaluated the edutainment effectiveness of two board game mediums, Card and Augmented Reality (AR). We conducted a between-group experimental study evaluating the use of Card and AR in *Mu-nopoly*, measuring users' perceptions of playfulness, learning effectiveness, and social presence. With a comprehensive evaluation, the results provided detailed insights into the edutainment effectiveness of both conditions, showing that the Card condition better supported the sensory and imaginative immersion and allowed a greater sense of flow. This study provides design guidelines and brings insights into the interaction design and edutainment research in museums and cultural heritage.**

***Index Terms*—Augmented reality (AR), cultural heritage, edutainment, serious game.**

I. Introduction

MUSEUMS are important institutions responsible for conducting, conserving, interpreting, and presenting tangible and intangible cultural heritage, also serving as vital public spaces for education [1]. The integration of interactive technologies into museum environments [2] has received significant attention in recent years as museum institutions seek to increase visitor engagement and learning [3]. This shift is aligned with a broader societal trend that emphasizes the digitization of cultural heritage and the need for innovative educational tools. Museums are increasingly adopting edutainment strategies, combining education and entertainment to engage diverse audiences and provide enriching experiences [4], [5]. This approach is particularly important in the context of cultural heritage preservation, where engaging and interactive learning can create a deeper connection between visitors and historical content. Despite advances in museum edutainment, research exploring the effectiveness of edutainment activities in real-world museum environments through specific system design and evaluation still highlights some gaps.

Notably, board games have seen significant applications for edutainment purposes. While a number of studies have explored digital interventions, such as augmented reality (AR) [6] and interactive exhibits [7], there is limited understanding of how board games can be utilized in a museum setting. Current literature tends to emphasize the technical aspects of digital media and may overlook the unique benefits that tangible interactions with digital augmentations can provide. In addition, the impact of different media on the edutainment experience remains under-explored. Thus, this study presents two main research questions (RQs), aiming to understand the edutainment effectiveness of board games as museum educational tools and the impact of board game mediums on the edutainment experience.

RQ1: How to design a board game that effectively supports museum edutainment?

RQ2: To what extent do different mediums (i.e., Card and AR) of a board game affect players' edutainment experience?

After the game feature review, we identified three types of activities relevant to a board game: playing, learning, and socializing, and proposed the Playing–Learning–Socializing (PLS) framework for museum edutainment with associated game features. Guided by the PLS framework, we conducted a design practice for a board game, which we named *Museum Monopoly*, abbreviated as *Mu-nopoly*. Based on eight core artifacts from the Museum of Wu, which is a local museum in Suzhou, China, we explored the process of applying cultural heritage knowledge into a board game. We employed an in-the-wild user study approach and conducted a between-group comparison experiment with 32 participants, collecting both quantitative and qualitative evaluations. Specifically, we measured the system usability, playfulness, learning effectiveness, and social presence that were perceived by players using *Mu-nopoly*. The

Received 20 December 2024; revised 30 July 2025; accepted 29 November 2025. This work was supported in part by the National Natural Science Foundation of China under Grant 62207022 and in part by Suzhou Municipal Key Laboratory for Intelligent Virtual Engineering under Grant SZS2022004. *(Corresponding author: Yue Li.)*

Jiachen Liang, Yue Li, and Yu Cheng are with the School of Advanced Technology, Xi'an Jiaotong-Liverpool University, Suzhou 215123, China (e-mail: yue.li@xjtlu.edu.cn).

Fanpei Liu is with the School of AI and Advanced Computing, Xi'an Jiaotong-Liverpool University, Suzhou 215123, China.

Richard Koeck is with the School of the Arts, University of Liverpool, L69 7ZX Liverpool, U.K.

Hai-Ning Liang is with the Computational Media and Arts Thrust, The Hong Kong University of Science and Technology (Guangzhou), Guangzhou 511453, China.

Digital Object Identifier 10.1109/TCSS.2025.3641787

results showed that *Mu-nopoly* provides positive effectiveness toward three aspects, and the Card medium outperformed the AR condition in terms of game experience.

In summary, we made the following contributions.

1) We proposed a *PLS* framework for museum edutainment and identified associated design features.
2) Based on the proposed design method and the eight key collections of the Museum of Wu, we developed a board game *Mu-nopoly* that contains two media (Card and AR), focusing on the edutainment experience.
3) Through an in-the-wild study in the museum, we evaluated the effectiveness of *Mu-nopoly* in terms of playfulness, learning effectiveness, and social presence. Based on the results, we provided insights into the design of the board game and explored how they impact the edutainment experience in cultural heritage learning.

II. Related Work

A. Museum Edutainment: An Approach to Disseminating Cultural Heritage

Edutainment was first introduced by Robert Heyman [8] from the American National Geography Academic Union in 1973, generally indicating the aim of supporting education with entertainment. Since then, the concept of edutainment has evolved with various definitions. Researchers have described it as encouraging entertaining learning with the way of interaction and communication [9], a hybrid type based on visualization and animation made with formats like games, diegetic things, and visual materials [10], a marriage of education and entertainment that aims to enhance learning through engaging methods [11], and so on. While, regardless of the variations in specific definitions, the essence of edutainment is rooted in combining educational objectives with engaging and entertaining approaches [12]. Edutainment is found significant and has been integrated into fields such as education [13], [14] and leisure [15]. Nuraini et al. [16] designed edutainment environments using audio-visual tools to foster an immersive and stress-free learning atmosphere. Mukherjee's research [17] highlighted that the edutainment approach showed promise in addressing the educational needs of physically and mentally challenged children and has the potential to help them achieve a stable position in society. Similarly, Putra [18] adopted methods like snakes and ladders and crosswords to improve subject knowledge and encourage active participation in tourism learning. Building on the success of edutainment in these fields, museums have increasingly adopted this approach to enhance their educational and cultural offerings.

The International Council of Museums states that "Museums should seize every opportunity to develop their function as educational resources for people from all walks of life" [19]. Museums have been undergoing a significant transformation in recent years, shifting from being traditional repositories of artifacts to becoming dynamic spaces for cultural interaction and education [20], [21]. As an important resource of lifelong learning, museums provide effective spaces for socializing, learning, and entertainment [22]. In addition to exhibitions, museums around the globe are making various attempts to target educational activities, aiming to appeal to different audiences, including younger audiences who are more engaged in interactive and gamified learning experiences [4]. For instance, the *National Museum of China* has organized various Parent–Child Classroom, Youth Activity, and so on, aiming to carry forward the traditional Chinese culture to the younger generation [23]. Similarly, the *Metropolitan Museum of Art* offers lesson plans to assist elementary, middle, and high school instructors in integrating arts into class [24]. Some European museums designed diverse educational programs, emphasizing experiential learning and cooperation [19].

Furthermore, a growing body of research has demonstrated the value of technology-enhanced strategies in supporting edutainment in museums [25]. Interactive systems such as mobile applications [26], [27], digital games [28], and AR-based artifacts [29], along with QR-code guided tours [30] and mixed-reality installations [31], have been shown to increase engagement, support personalized learning, and enhance visitors' emotional connection to cultural content. For example, Xu et al. [29] found that users are more motivated and engaged in learning museum artifact knowledge with tangible AR interfaces compared to the traditional leaflet approach. Turner et al. [32] suggested that children engaged with objects by materializing cultural-historic information through a 3-D-driven design process. Furthermore, Kara [33] has demonstrated that serious games have a significant positive effect on cultural heritage learning. While previous research has highlighted technical feasibility or user satisfaction, there still remain some research gaps with less attention paid to systematically evaluating how different technological implementations influence learning outcomes and social engagement. Besides, prior studies rarely offer comparative insights across different media formats (e.g., physical versus AR) within the same game-based experience. Thus, our study aims to address these gaps by introducing a board game designed for museums that functions in both Card-based and AR-enhanced media formats, enabling a side-by-side examination of their edutainment effectiveness.

B. Board Game: A Practical Form for Museum Edutainment

Board games have emerged as effective educational tools in various contexts, such as history, culture, museums, and so on. They offer engaging, experiential learning experiences that enhance understanding of complex concepts [34]. There is a wealth of previous academic research that has explored the educational effects of board games [35], [36]. For instance, a simplified Monopoly game was developed to teach elementary students about animal movement organs, promoting active learning [37]. The "Our Museum" game facilitates collaborative exhibition design among museum professionals [34]. In museum settings, technology-enhanced games like "Mystery at the Museum" can increase visitor engagement, encourage exploration of exhibits, and promote collaboration among participants [38]. These studies demonstrate that board games, whether physical or digital, are effective means to integrate entertainment and learning, making them valuable tools for edutainment in museum settings.

Nevertheless, the survey results in Frapolli et al.'s [39] study noted that the popularity of traditional board games has not found a corresponding acceptance in the digital environment. They listed seven game characteristics to consider that contribute to this gap. In physical board games, players showed high levels of satisfaction with social interactions between players, the use of physical objects, and immersion during gameplay. In digital board games, players rated the importance of these features as roughly the same as in the physical environment but pointed out more improvements needed compared to the physical one, suggesting that it is challenging to reach a comparable level of satisfaction when transitioning from traditional to digital tabletop gaming.

Recent practices have shown that AR technology has significant promise in bridging these gaps. Nordin and Omar [35] examined students' experience in using a board game with web-based AR named REV-OPOLY in their learning. Their research has demonstrated that such interactive experiences can significantly enhance students' motivation and learning outcomes. Similarly, Chou et al. [40] demonstrated the use of AR technology to create a 3-D Monopoly-like game showcasing Taiwan culture and cuisine. These AR board games have been used to create immersive experiences that allow visitors to visualize historical events or artifacts in their original context, thereby deepening their understanding and emotional connection.

Prior research has demonstrated the feasibility of board games in edutainment, but there is limited research on the extent to which board games support various aspects of edutainment experiences for visitors, such as their playfulness, learning effectiveness, and social presence. In addition, there is also a research gap in the understanding of whether board games in different media provide different experiences for players.

III. Proposing the PLS Framework for Museum Edutainment

Based on the review of the related works, we aim to design a board game that facilitates the edutainment needs of the museum context. Drawing from prior literature in board game [41], [42], game-based learning [43], [44], [45], and museum education [4], [19], we identified three core activity types relevant to museum edutainment: Playing, Learning, and Socializing. The three activity types are interrelated. In this section, we introduce the PLS framework for museum edutainment (see Fig. 1).

A. Playing

Playing refers to the set of rule-based actions and strategic mechanisms through which players interact with the game system. Playing encompasses having fun activities such as moving pieces, controlling territories, and manipulating tangible components, which support engagement, decision-making, and immersion during gameplay. For the playing aspects, *actions, area control*, and *tangible objects* were considered as fundamental mechanisms in traditional board games.

Actions refer to specific actions that the player can perform in the game, which affect the game's interactivity and strategy choices. The selection and integration of actions in a game can control the complexity of the game, including the number of actions a player can perform consecutively, the interrelationships between the actions, the interactions between players, and other features. *Area control* refers to the player's control of the game area, which affects the game's territorial contests and strategic layout. Additionally, *tangible objects* offer cognitive advantages through sensory engagement, including tactile, proprioceptive, and kinesthetic senses [46]. Based on these aspects, we identified the first design goal (DG) for an edutainment board game:

DG1: To include specific actions and area control to enhance player interactivity based on tangible objects.

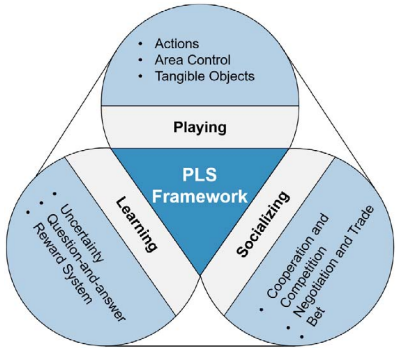

Fig. 1. Proposed Playing–Learning–Socializing (PLS) framework for museum edutainment design.

B. Learning

Learning is one of the core goals of educational activity. It involves the acquisition and reinforcement of knowledge through structured game mechanics, emphasizing cognitive engagement, recall, and motivation to understand content embedded within the game environment. For the learning aspect, mechanisms like *uncertainty*, *question-and-answer*, and *reward systems* will facilitate motivation to learn.

Uncertainty is a key element for the games to be engaging. This could also increase the complexity and facilitate a learning curve for the game. Moreover, Yuna et al. [47] showed that an interactive *quiz* approach to viewing exhibits is effective in creating a more memorable museum experience. Together, a *reward system* provides positive feedback and drives users to engage in the learning process [35]. This leads to:

DG2: To incorporate the mechanism of uncertainty, quiz, and reward systems to facilitate learning and knowledge retention in the gameplay.

C. Socializing

Socializing captures the interpersonal dynamics that occur between players during the game. These interactions foster shared meaning-making and enhance the social presence and enjoyment of the gameplay experience.

For socializing in board game development, *cooperation and competition* are commonly used game mechanisms [48]. In addition, we incorporated *negotiation and trade*, which have

Fig. 2. Eight featured artifacts used in *Mu-nopoly*. (a) Chu Tu He. (b) Celadon flat pot. (c) Jar with tubular ears. (d) Silver raft-shaped cup made by Zhu Bishan. (e) Underglaze red covered jar with cloud and dragon patterns. (f) Guqin. (g) Bronze mirror decorated with mythical birds and auspicious animals. (h) Blue and white ceramic plate with lotus pattern.

been shown to moderate peer interactions between users [49]. Additionally, the bet mechanism was shown to enhance player engagement during downtime. For example, Wits and Wagers [50] allows all players to place *bet* on numerical answers, promoting discussion and learning. This leads to:

DG3: To integrate cooperative and competitive through negotiation, trading, and betting mechanisms to promote social interactions and keep players socially engaged.

IV. Design

Mu-nopoly is a multiplayer board game based on eight featured artifacts from the Museum of Wu, Suzhou, China. Fig. 2 shows the eight artifacts. Specifically, we designed and developed two versions based on the Card and AR mediums. Similar to a traditional monopoly game, the Card game supports up to four players to engage in face-to-face communication and interactions through the use of tangible props. For the AR game, each player is provided with a mobile device for viewing the augmented 3-D artifacts and initiating game actions such as answering questions, trading, and auctioning.

A. Technical Details

The development of the board game was separated into the *physical* and *digital* phases. The *physical* component contained a set of tangible toolkits, including the board (game map), cards, dice, money tokens, role pieces, and so on. The detailed specifications are presented in Table I. The *digital* component was developed in Unity (version 2021.3.9f1c1). We used FishNet and ParrelSync for the networking development, and used Vuforia for the AR image identification and tracking. The mobile application with AR features was deployed on Android smartphones (Samsung Galaxy S21). An overview of the board game setup can be seen in Fig. 3.

Under the AR condition, users could play the board game with a mobile device equipped with an AR digital application (see Fig. 3(d)). With the mobile application, users can click different buttons on the main page to perform game actions (e.g., trading, answering the quiz). Some Clue Cards and Artifact Cards provide an augmented view with 3-D virtual artifacts where players can slide one finger on the screen to rotate the 3-D model, or use two fingers to rescale the size.

TABLE I
COMPREHENSIVE INVENTORY LIST FOR *MU-NOPOLY* COMPONENTS

	Name	Number		Size	Material
		Card	AR		
1	Board	1	1	60 × 60 cm	Foam board
2	Call bell	1	1	5 × 5 cm	Stainless steel
3	Dice	4	4	1.5 × 1.5 cm	Plastics
4	Role piece	4	5	2.5 × 2.5 cm	Wood
5	Artifact Card	8	8	5.4 × 8.6 cm	Card stock
6	Clue Card	16	1	5.4 × 8.6 cm	Card stock
8	Function Card	24	1	5.4 × 8.6 cm	Card stock
7	Quiz Card	16	/	12 × 21 cm	Card stock
9	10 Liang (Money)	30	/	5.8 × 8.3 cm	Copy paper
10	20 Liang (Money)	30	/	5.8 × 8.3 cm	Copy paper
11	50 Liang (Money)	30	/	5.8 × 8.3 cm	Copy paper
12	100 Liang (Money)	30	/	5.8 × 8.3 cm	Copy paper
13	200 Liang (Money)	30	/	5.8 × 8.3 cm	Copy paper
14	500 Liang (Money)	30	/	5.8 × 8.3 cm	Copy paper
15	Mobile device	/	4	15 × 7 cm	Composite material
16	Holder	/	4	24 × 20 × 13 cm	Plastics

B. Game Mechanisms in Mu-nopoly

Based on the DGs outlined in Section III, we described the detailed game mechanisms implemented in our proposed board game.

1) DG1: Playing: The board is divided into a total of 40 small areas and includes 5 types of actions: move, card draw, trading, reward, and quiz. Each player is assigned a role with designated trading areas for them to conduct actions like purchasing and manipulating miniature houses. For each round, players draw cards to determine whether they can view object information or answer multiple-choice questions. We also included tangible objects, such as a call bell and character pieces that players can press and move to increase excitement and tension to enhance player engagement. These tangible objects were also retained in the AR version.

2) DG2: Learning: We introduced uncertainty in the gameplay by randomly providing players with clues about different artifacts and asking different questions in each turn. The Quiz mechanic is a core component of the educational aspect of the game. The game asks players questions related to museum exhibits, encouraging active learning and reinforcing the players' knowledge acquisition. This interactive questioning not only helps retain information but also stimulates curiosity and discussion among participants. Questions that are answered incorrectly by the player will be put back into the question bank until the correct answer is given. We also include a reward system that incentivizes players to actively participate in learning activities. When players correctly answer a question or successfully complete a Quiz challenge, they get to earn additional money. This system not only incentivizes players but also reinforces their learning by associating achievements with positive outcomes.

3) DG3: Socializing: Two types of Quiz events were included: solo and dual. Players could exchange artifact clues and engage in negotiations and trades during each Quiz. This setup blends competition and cooperation to promote player interaction. In addition, the betting mechanism allows the rest three players to acquire money when one player is engaged

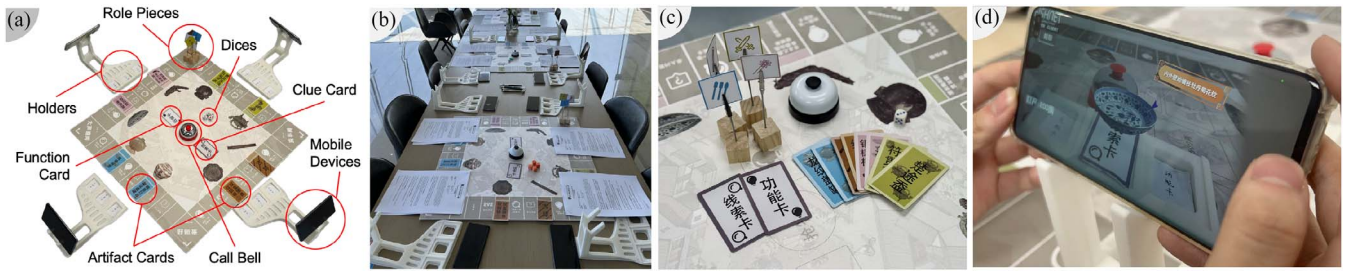

Fig. 3. Gameplay environment setting for participants. (a) Overview of the *Mu-nopoly* board game. (b) Setup of the experimental environment in the museum. (c) Tangible props. (d) AR view of a 3-D virtual artifact shown on the mobile.

in a solo Quiz. The tension and excitement created by betting keep players engaged and attentive to the outcome of the Quiz, ensuring that all players are attentive to the questions.

C. Design Iterations

We adopted an Iterative Design methodology [42] for the development of the board game. This approach emphasizes game testing and prototyping. Specifically, we underwent three iterations in the board game design.

1) First Iteration: We defined the basic rules of the game and designed prototypes of the main mechanisms. At this stage, we did not consider any style or artwork. The target audience was identified at this stage, i.e., young adults who enjoy visiting museums and playing board games. As identified by the museum stakeholders, this group of people stood out as the most frequent group of visitors. We summarized the pedagogical content from the museum courses of our partner museums and designed the topics accordingly. The content is then reviewed by them to ensure its accuracy. We conducted a 6-person (2 females and 4 males, aged between 20 and 28) focus group from our target audience to test the game features and general usability. The feedback not only confirmed the usefulness of the game features like quiz, reward, and bet but also mentioned the negative feelings toward the duration time, the number of cards, and redundant information.

2) Second Iteration: Addressing the feedback from the first iteration, we optimized the game mechanics and introduced design elements and artwork. A lab-based user study with 16 participants (6 females and 10 males, aged 19–28, $M = 23.13, \mathrm{SD} = 3.03$) was conducted to identify further issues and enhance usability. The System Usability Scale (SUS) [51] was employed, yielding a score of 77.66, surpassing the benchmark of 68 and indicating good usability.

To assess knowledge retention, we conducted a follow-up during the second design iteration, where participants were contacted seven days after the initial gameplay to complete the same learning outcome questionnaire. Each learning outcome question includes four options plus an "I don't know" option. A correct answer receives 1 score, and the total learning outcome score is computed as $\sum_{i=1}^{8} \mathrm{LO}_i$. A Friedman test was conducted to examine whether there were significant differences in participants' artifact knowledge scores across three time points: before gameplay learning outcome score (LO1), immediately after the gameplay (LO2), and one week later (LO3). The results indicated a statistically significant difference in scores across the three time points, $\chi^2(2) = 26.000, p < .001$. Wilcoxon signed-rank tests were used for post hoc comparisons with Bonferroni adjustment. The results showed significant increases in artifact knowledge from LO1 ($M = 0.25, \mathrm{SD} = 0.77$) to LO2 ($M = 6.19, \mathrm{SD} = 1.91$), $Z = -3.518, p < .001$ and from LO1 to LO3 ($M = 5.31, \mathrm{SD} = 1.01$), $Z = -3.516, p < .001$, which indicated significant increase in the learning outcomes through the board game. Despite that there was a slight decrease in knowledge score from LO2 to LO3, the difference was not statistically significant ($Z = -1.933, p = .053$).

Additionally, we gathered requirements for an AR board game, focusing on AR-recognized content (e.g., Clue Cards, Function Cards, Artifact Cards), interaction design (rotate, move, and scale). We also determined the use of mobile devices over head-mounted displays to maintain eye contact.

3) Third Iteration: Based on feedback and requirements, we developed a mobile AR board game, integrating high-precision 3-D models of cultural artifacts provided by the museum.

D. Mu-nopoly: How to Play

The game starts by placing the board on a table and putting the Function, Clue, and Artifact cards facedown on their allotted spaces on the board. Each player chooses one role piece to represent themselves while traveling around the board. When starting the game, each player has 200 *Liang* (money).

1) *Rolling the Dice*: Players take turns to roll a six-sided dice and move their role pieces clockwise on the board.
2) *Landing on the Board*:
   a) *Move:* Follow the instructions to move your role piece to the designated location.
   b) *Artifact Property:* You can purchase it if it is an unowned property, or pay the rent if it is owned by another player.
   c) *Function:* Take a Function card from the deck/Scan the chance card and follow the instructions (AR).
   d) *Clue:* Take a Clue card from the deck/Scan the clue card and read the clues' information (AR).
   e) *Quiz:* The player answers the question; other players can choose to bet or not.
3) *Ending the Game*: The game ends when the game reaches the duration (e.g., 1 hour) or all artifact properties

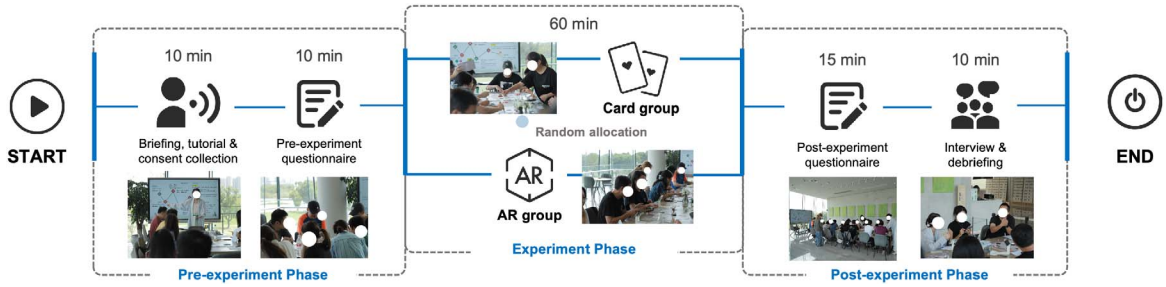

Fig. 4. Flow chart showing the experiment procedure including pre-experiment, experiment, and post-experiment—the three main phases.

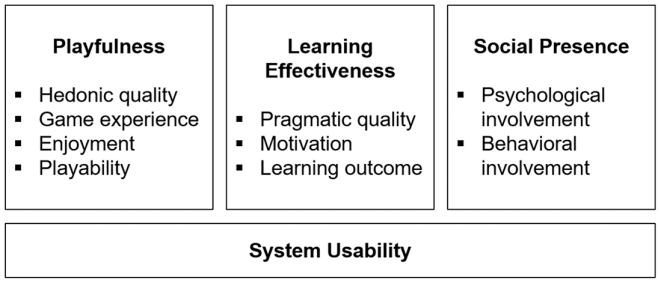

Fig. 5. The constructs and measures used in the study: system usability, playfulness, learning effectiveness, and social presence.

have been purchased. The wealthiest player (property + money) will win the game.

V. Evaluation

We designed a between-group experiment to evaluate the extent of players' edutainment experiences supported by *Mu-nopoly* (*RQ1*), and the effects of different media used in *Mu-nopoly* on edutainment experiences (*RQ2*). The study was based on the two media used in the board game:

1) *Card board game*—a physical board game with our tangible toolkits.
2) *AR board game*—a hybrid physical and digital board game with our tangible toolkits and AR technology.

A. Procedures

The experiments took place in an open public area within the museum see Fig. 3(b). Participants were randomly assigned to groups of four, guided through the three phases of the experiment (see Fig. 4). Ethics approval has been obtained from our institution's ethics committee.

1) *Pre-Experiment Phase*. First, we introduced our research to participants and obtained their informed consent. To maintain consistency in the experimental process, we prepared introductory slides to explain the game rules and relevant operations. Then, participants were asked to fill in a demographic questionnaire and a pre-experiment questionnaire that included eight questions about the artifacts to evaluate their knowledge background.

2) *Experiment Phase*. Participants either play the *Card* or the *AR Mu-nopoly* board game. At this stage, each group was accompanied by an appropriately trained experimenter who guided the participants using a standardized instruction script, observed the entire experiment, and provided assistance and explanations when necessary.

3) *Post-Experiment Phase*. Following the completion of gameplay, participants were asked to complete a post-experiment questionnaire and then invited to join an interview to provide further insights about their experience.

B. Measures

This study collected both quantitative and qualitative data to assess the edutainment experience. Specifically, we adopted validated questionnaires to understand the three aspects of edutainment concerned in a board game: playfulness, learning effectiveness, and social presence (Fig. 5).

1) System Usability: We first assessed the system usability to ensure that both systems meet the standard usability before evaluating a more nuanced user experience. System usability was measured by the SUS [51]. It consists of 10 questions scored on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). After a negation of the even-numbered questions, the usability score can be calculated by $\sum_{i=1}^{10} (\mathrm{SUS}_i - 1) \times 2.5$, with 68 being the threshold value of average usability.

2) Playfulness: We assessed the playfulness from user evaluations on the hedonic quality of the User Experience Questionnaire (UEQ-S) [52], the Game Experience Questionnaire—Core Module (GEQ-C) [53], as well as the enjoyment and playability measured in [54]. We adopted the original scales used in the questionnaires: the hedonic quality items were rated from -3 (horribly bad) to 3 (excellent); the game experience was rated from 0 (not at all) to 4 (extremely); the enjoyment and playability were evaluated using a 5-point Likert scale ranging from 1 (not at all) to 5 (extremely).

3) Learning Effectiveness: We used three constructs to indicate the learning effectiveness, including the pragmatic quality of the UEQ-S [52], users' motivation to learn [54], and eight specific multiple-choice questions related to the artifacts involved in the board game to assess the learning outcomes. The pragmatic quality items were rated from −3 (horribly bad) to 3 (excellent); the motivation was rated from 1 (strongly disagree) to 5 (strongly agree). Each learning outcome question includes four options plus an "I don't know" option. A correct answer receives 1 score, and the total score is computed as $\sum_{i=1}^{8} \mathrm{LO}_i$.

4) Social Presence: We adopted the GEQ—Social Presence Module (GEQ-S) to measure social presence [53], which includes two constructs of psychological involvement (empathy and negative feelings) and behavioral involvement. Items of social presence were scored on a 5-point Likert scale ranging from 0 (not at all) to 4 (extremely).

C. Participants

Participants of the study were self-selected: they voluntarily signed up for the workshop via the museum's official social media channels. A total of 32 participants (8 groups of 4) joined the activity. Three participants played the game but did not provide their evaluations, so we managed to collect 29 sets of evaluation data (17 females, 9 males, 3 preferred not to disclose). Two participants did not disclose their age. The remaining 27 participants were aged between 21 and 53 ($M = 32.52, \mathrm{SD} = 7.70$) years. Participants' self-evaluations were recorded on a 5-point Likert scale, ranging from 1 (not at all familiar) to 5 (extremely familiar). Participants reported an average frequency of museum visits of 4.10 ($\mathrm{SD} = 0.82$), indicating relatively frequent (a couple of times a year) museum visits. They showed a moderate familiarity with board games ($M = 3.03, \mathrm{SD} = 1.05$) and digital board games ($M = 2.97, \mathrm{SD} = 1.15$). In terms of frequency, they occasionally play board games ($M = 2.07, \mathrm{SD} = 0.96$) and digital games ($M = 1.93, \mathrm{SD} = 1.03$). The responses also showed that participants are moderately familiar with AR ($M = 2.62, \mathrm{SD} = 0.94$).

VI. Analysis and Results

We used IBM SPSS Statistics (version 29) to conduct the data analysis. Shapiro–Wilk tests were conducted to examine the data distributions. For data that conformed to a normal distribution, we adopted independent samples *t*-test. Otherwise, we conducted the Mann–Whitney *U* test. The qualitative data collected from the participants were transcribed and translated into English by one researcher and checked by another researcher. The data were analyzed using the theme-based content analysis [55].

A. System Usability

The mean SUS scores of the two conditions were 72.86 (Card) and 70.17 (AR), which exceeded the threshold value of 68.00, indicating satisfactory usability of *Mu-nopoly*.

B. Playfulness

The results of playfulness are demonstrated in Fig. 6(a).

1) Hedonic Quality: The hedonic quality results showed positive ratings for both conditions, with mean scores of 2.58 ($\mathrm{SD} = 0.56$) in Card, and 1.84 ($\mathrm{SD} = 1.52$) in AR. Compared to the UEQ benchmark dataset [56], both conditions had *Excellent* (top 10%) hedonic quality. There is no significant difference between Card and AR in hedonic quality, $t(24) = -0.514$, $p = 0.612$.

2) Game Experience: Participants reported fairly high levels of *Competence* (Card: $M = 2.83, \mathrm{SD} = 0.70$, AR: $M = 3.11, \mathrm{SD} = 0.67$), *Sensory and Imaginative Immersion* (Card: $M = 3.45, \mathrm{SD} = 0.51$, AR: $M = 3.01, \mathrm{SD} = 0.55$), *Flow* (Card: $M = 3.10, \mathrm{SD} = 0.54$, AR: $M = 2.65, \mathrm{SD} = 0.48$), and *Positive Affect* (Card: $M = 3.63, \mathrm{SD} = 0.45$, AR: $M = 3.23, \mathrm{SD} = 0.66$), indicating a generally engaging and skill-appropriate experience. The *Challenge* that users perceived was moderate (Card: $M = 1.81, \mathrm{SD} = 0.60$, AR: $M = 1.60, \mathrm{SD} = 0.59$). Conversely, *Negative Affect* (Card: $M = 0.57, \mathrm{SD} = 0.50$, AR: $M = 0.77, \mathrm{SD} = 0.67$) and *Tension/Annoyance* (Card: $M = 0.69, \mathrm{SD} = 0.79$, AR: $M = 0.71, \mathrm{SD} = 0.92$) scores were relatively low, suggesting minimal frustration or discomfort during gameplay. Independent samples *t*-test showed higher *Flow* in the Card condition than in the AR condition ($t(27) = 2.351, p = 0.026, \eta^2 = 0.511$). The *Sensory and Imaginative Immersion* was also perceived as greater in the Card group than the AR group ($Z = -2.341, p = 0.019$). There was no statistically significant difference in *Competence* ($t(27) = -1.095, p = 0.948, \eta^2 = 0.684$), *Challenge* ($t(27) = 0.965, p = 0.893, \eta^2 = 0.597$), *Tension/Annoyance* ($Z = -0.023, p = 0.982$), *Negative Affect* ($Z = -0.708, p = 0.479$), or *Positive Affect* ($Z = -1.674, p = 0.094$) between the two conditions.

3) Enjoyment: The mean values for the *Likability* of the game were 4.64 ($\mathrm{SD} = 0.50$) and 4.33 ($\mathrm{SD} = 0.62$) for Card and AR conditions, respectively. The high ratings were also seen in the *Entertaining* feature of the game (Card: $M = 4.57, \mathrm{SD} = 0.51$; AR: $M = 4.33, \mathrm{SD} = 0.62$). Mann–Whitney *U* test indicated no significant differences in the *Likeability* ($Z = -1.390, p = 0.164$) or *Entertaining* features ($Z = -1.041, p = 0.298$) between Card and AR board games.

4) Playability: The board game did not provoke significant *Confusion*, *Difficulty*, or *Discomfort* for players. The Mann–Whitney *U* test results showed no significant difference in *Confusion* ($Z = -0.530, p = 0.596$), *Difficulty* ($Z = -0.398, p = 0.691$), or *Discomfort* ($Z = -0.950, p = 0.342$) between Card and AR board games.

C. Learning Effectiveness

The learning effectiveness results are shown in Fig. 6(b).

1) Pragmatic Quality: It was perceived that the board game was found positive in both conditions, with mean scores of 1.65 ($\mathrm{SD} = 0.84$) in Card and 1.48 ($\mathrm{SD} = 1.43$) in AR, both exceeding the threshold value of 0.8 [56]. Compared to the UEQ benchmark dataset, the pragmatic quality of user experience was *Good* (top 25–10%) for Card, and *Above average* (top 50–25%) for the AR group. An independent samples *t*-test

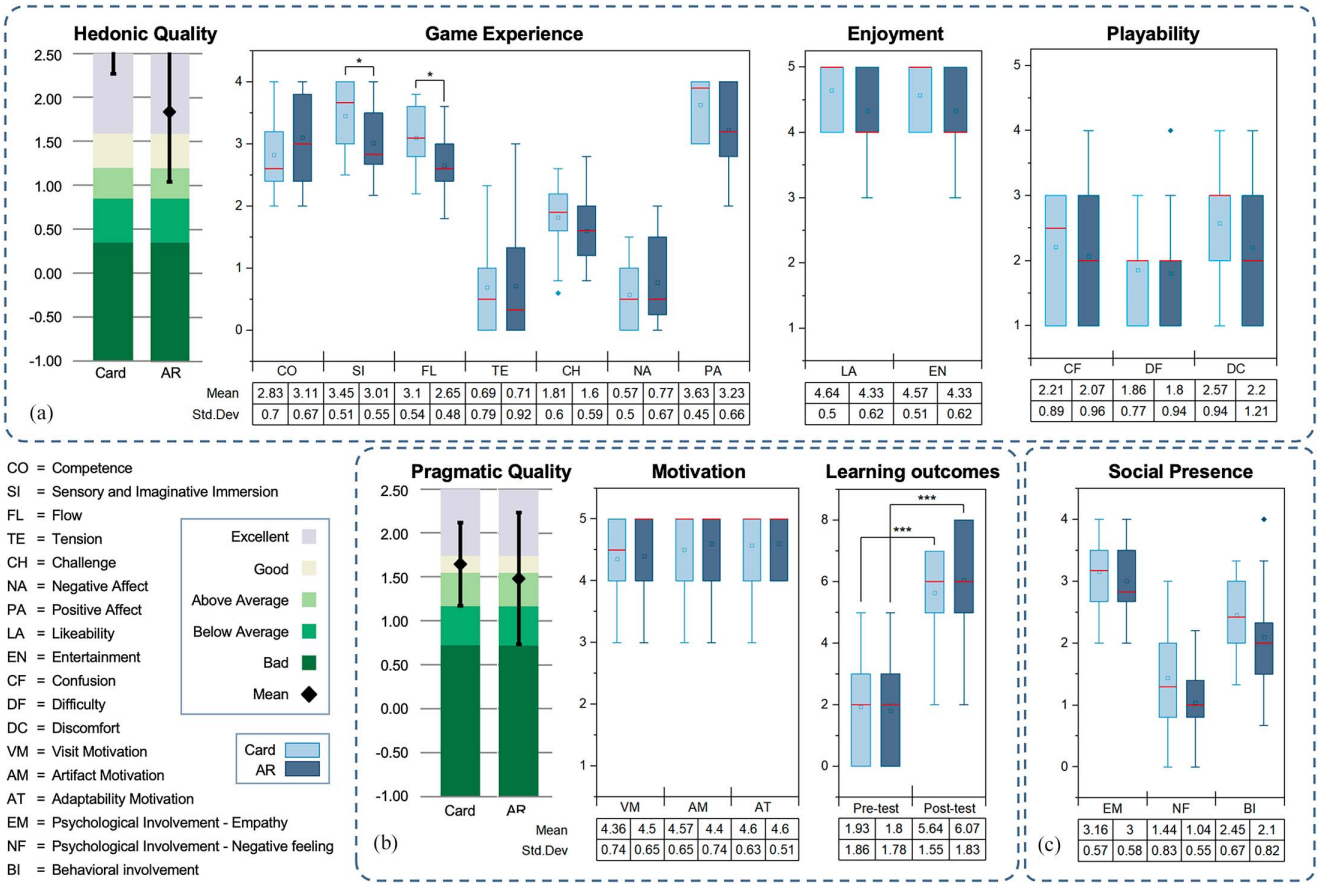

Fig. 6. Evaluation results of: (a) playfulness; (b) learning effectiveness; and (c) social presence for the Card and AR conditions of the board game, respectively. $^{*}p< 0.05$; $^{***}p< 0.001$.

showed no statistically significant difference between the two conditions, $t(24) = -0.514, p = 0.612, \eta^2 = 1.193$.

2) Motivation: Participants showed motivation to visit the onsite museum, and the artifacts contained in board games were 4.36 (Card, SD = 0.74) and 4.50 (AR, SD = 0.65). Participants also showed willingness to see other artifacts in board games (Card: $M = 4.57, \text{SD} = 0.65$; AR: $M = 4.40, \text{SD} = 0.74$) and to apply this board game to different museums (Card: $M = 4.60, \text{SD} = 0.63$; AR: $M = 4.60, \text{SD} = 0.51$). Mann–Whitney U test showed no significant difference in users' *Visit Motivation* ($Z = -0.169, p = 0.866$), *Artifact Motivation* ($Z = -0.485, p = 0.628$), or *Adaptability Motivation* ($Z = -0.077, p = 0.939$) between two conditions.

3) Learning Outcomes: Mann–Whitney U test did not show statistically significant differences in the pre-test learning outcomes between Card ($M = 1.93, \text{SD} = 1.86$) and AR ($M = 1.80, \text{SD} = 1.78$) versions, $Z = -0.180, p = 0.857$, indicating that participants have similar low levels of prior knowledge about the museum artifacts.

Wilcoxon signed-rank tests indicated that for the Card group, the learning outcomes of the post-test ($M = 5.64, \text{SD} = 1.55$) were significantly higher than the pre-test ($M = 1.93, \text{SD} = 1.86$), $Z = 3.315, p < 0.001$. Similarly, a dependent samples t-test showed a significant increase in the learning outcomes of the AR group (Pre-test: $M = 1.80, \text{SD} = 1.78$; Post-test: $M = 6.07, \text{SD} = 1.83$), $t(14) = -10.174, p < 0.001, \eta^2 = 1.62$. The two groups did not show significant differences in their post-test learning outcomes, $Z = 0.849, p = 0.396$.

D. Social Presence

The results toward social presence are shown in Fig. 6(c).

1) Physical Involvement—Empathy: The mean score for *empathy* was slightly higher in the Card condition ($M = 3.16, \text{SD} = 0.57$) compared to the AR condition ($M = 3.00, \text{SD} = 0.58$), but the difference was not statistically significant ($t(27) = 0.220, p = 0.828, \eta^2 = 0.755$).

2) Physical Involvement—Negative Feeling: Participants' perceived *negative feelings* for the Card condition ($M = 1.44, \text{SD} = 0.83$) were slightly higher than the AR condition ($M = 1.24, \text{SD} = 0.55$). Yet, the t-test results did not show a statistically significant difference, $t(27) = 1.553, p = 0.132, \eta^2 = 0.577$.

3) Behavioral Involvement: Regarding the perceived *behavioral involvement*, the Card condition had a mean score of $M = 2.45, \text{SD} = 0.67$, whereas the AR condition had a mean score of $M = 2.10, \text{SD} = 0.82$. An independent samples t-test revealed no statistically significant difference between the conditions, $t(27) = 1.269, p = 0.215, \eta^2 = 0.748$.

E. Qualitative Results

1) Playfulness: Participants generally found the rules of the game easy to understand and required minimal additional explanation after the first round of play. However, some participants felt that the game still had potential for playability improvement. For example, participants in the AR condition appreciated the tactile and interactive nature of the game but suggested that audio feedback and a more engaging narrative be added to further enrich the experience. The Quiz decks in the Card condition were consumed very quickly, and they felt that the number of 32 questions was insufficient.

2) Learning Effectiveness: Participants reported that *Mu-nopoly* facilitated learning in an engaging way. One participant noted, "It felt like the knowledge got into my brain in a strange but effective way." Many participants recognized the educational value of the game and suggested that it could be extended beyond museums to benefit a wider target group, such as students and children studying cultural heritage. They also expressed interest in the replay value of the game, stating that they would like to have a more diverse range of question types and feature cards to maintain interest in playing the game multiple times.

3) Social Presence: The game facilitated a great deal of social interaction, with participants actively engaging in discussions and even creating a secondary market by exchanging knowledge clues for in-game currency. The social nature of the game was also evident, with participants who did not initially know each other continuing to discuss the game for up to 40 min after it had finished, and exchanging contact details afterwards. This highlights the potential of games to facilitate social connections and community building within museums.

In conclusion, the qualitative data support the quantitative findings and emphasize the effectiveness of *Mu-nopoly* as a tool for teaching and learning, enhancing playfulness, learning, and socialization in the museum environment.

VII. Discussion

A. Board Games Support the Museum Edutainment Experience

Our research shows that our proposed board game, *Mu-nopoly*, provides a positive edutainment experience by engaging participants in playing, learning, and socializing through interactive activities. The results data indicate that participants found the game enjoyable and engaging, as evidenced by the high rating for hedonic qualities, game experience, enjoyment, and playability. The results provide empirical support to show that board games can facilitate an environment conducive to learning and social interaction.

The mean SUS scores for both conditions exceeded the commonly accepted usability benchmark of 68.00, suggesting that both versions of *Mu-nopoly* were well-received in terms of ease of use. However, we observed that while functional, the AR system also presented some usability frictions, such as interruptions in flow or increased cognitive load during device handling, which could impact overall engagement. In educational contexts, especially those involving casual museum visitors or learners with varying degrees of technological familiarity, usability plays an important role in shaping user satisfaction and willingness to continue use [57]. The relatively lower SUS score for the AR condition, compared to the Card version, may reflect these challenges. This aligns with participants' qualitative feedback, where some noted that device handling and switching between digital and physical elements interrupted the gameplay flow. These insights highlight the importance of refining AR interaction design to enhance learning motivation and sustained engagement.

In addition, we found that *Mu-nopoly* not only improves learning effectiveness but also fosters users' creativity. During the game, users start to customize the rules and add a secondary market in trading, such as exchanging knowledge clues for in-game currency. Players will actively engage with the game content and with each other, which demonstrates active social interactions. Positive results in terms of playfulness, learning effectiveness, and social presence confirm the game's potential as a valuable educational tool in a museum setting.

B. Challenges in Transforming a Physical Board Game With Technological Means

Previous studies [29], [36] have indicated a strong potential for using AR in board games. Building on top of the findings, *Mu-nopoly* extends the works by introducing a tangible and socially embedded board game structure. The game integrates cooperative and competitive mechanics (DG3), structured quizzes and reward systems for knowledge reinforcement (DG2), and strategic actions tied to physical props and territory control (DG1). These design components promote holistic edutainment experiences that bridge physical interaction with digital augmentation, which were less emphasized in previous systems. However, our comparative analysis shows that the Card condition outperformed the AR condition in terms of the flow in the game and the sensory and imaginative immersion. Players preferred direct interaction with tangible elements, which were found to enhance their connection to the game and foster a deeper sense of presence and engagement [58]. This result can be attributed to several factors inherent in the design and execution of both conditions.

The tactile engagement plays a critical role in sensory immersion [59]. Handling tangible components such as cards, tokens, and game boards provides a multisensory experience that engages both the player's tactile and visual senses. The haptic nature of the card version allows for uninterrupted engagement with the game as players remain focused on the physical elements of the game without having to shift their attention between the digital device and the game board. This constant interaction with tangible elements helps to maintain a seamless flow as players can easily immerse themselves in the game without external distractions. In contrast, the AR version, while visually stimulating, requires the player to divide their attention between the physical and digital realms. The player's interaction with the digital interface disrupts the natural

progression of the game, thus potentially ruining the immersive experience. One of the participants noted that "The frequent transitions between observing AR elements and interacting with the physical board interrupted my experience on the one hand and were very time-consuming on the other".

Additionally, the Card condition supports a more traditional board game atmosphere that encourages face-to-face interaction and communication between players. This social aspect is an integral part of the flow experience, as it fosters a sense of presence and connection for the player. Players who preferred the paper version suggested that "I still favor the pure paper board game atmosphere because when I am focused on my personal screen, my connection with other players diminishes. It feels like everyone is playing on their respective phones."

C. Limitation and Future Work

This study has some limitations. First, the relatively small sample size of 29 participants in this study may limit the generalizability of the findings. Future studies may require a more diverse group of participants in order to validate and extend the findings across different demographic and cultural contexts. Moreover, this study was conducted in a specific museum setting and may not fully reflect the diversity of game-use environments. Future work could explore the adaptation of *Mu-nopoly* in various types of museums to assess broader applicability and impact. It is also worthwhile to explore its use in living rooms or classrooms to further understand its potential to be targeted as museum souvenirs or teaching materials. We conducted a 7-day follow-up test during the second iteration to examine users' short-term knowledge retention, which provides initial evidence of the game's educational effectiveness beyond immediate gameplay. It is also worth implementing a long-term delayed post-test (e.g., over 1–3 months) across more diverse age groups, such as children and older adults, to further validate and generalize these findings.

The board game was developed for use in museum workshops, but resource limitations present challenges. Implementing board games demands time, staff training, and space, which can be scarce, particularly in smaller or budget-restricted museums. Limited physical space can restrict participant numbers and simultaneous play, complicating integration into museum programs. Additionally, while the game was not explicitly intended to attract visitors to the museum, the spontaneous behavior of users after finishing the activity suggests that it may have inadvertently encouraged participants to seek out and engage with actual artifacts, suggesting the potential for wider application. It remains to be seen how the game will fare in a real-world museum setting, whether as a permanent installation in a lounge area or as a purchasable product. Our observation suggests that while AR technology offers unique benefits such as enhanced visuals, reduced material counts, and interactive features, the impact of perspective-slicing needs to be carefully balanced to avoid disrupting the flow of play. Future iterations could explore ways to minimize these disruptions, possibly through device selection or further integration of digital and physical elements.

VIII. Conclusion

In conclusion, this research highlights the potential of board games as effective edutainment tools in the museum context, effectively combining education and entertainment. By developing and evaluating the *Mu-nopoly* board game on both Card and AR mediums, we showed how the *PLS* framework can guide the design of engaging museum experiences. Our findings suggested that the Card condition of *Mu-nopoly* excels in promoting sensory and imaginative immersion experience, while also promoting a stronger sense of flow. These insights provide valuable design guidelines for enhancing the interactive design of museums for edutainment and provide avenues for future research and applications in the field of cultural heritage.

Acknowledgment

The authors thank the Museum of Wu for the great support in this research and thank all participants for their valuable time and efforts.

References

[1] K. A. Jahangeer and M. N. Ansari, "Role of museums in education," vol. 3, no. 2, pp. 41–43, 2021.

[2] Y. Li, J. Liang, E. Yang, and H.-N. Liang, "User acceptance of 720° virtual tour systems for online museum experiences: Effects of immersion, interaction, and personal innovativeness," in *Interactive Media for Cultural Heritage*, F. Liarokapis, M. Shehade, A. Aristidou, and Y. Chrysanthou, Eds., Cham, Switzerland: Springer Nature, 2025, pp. 129–153.

[3] S. Zhang, M. Ma, Y. Li, K. L. Man, J. Smith, and Y. Yue, "The effects of LLM-empowered chatbots and avatar guides on the engagement, experience, and learning in virtual museums," *Int. J. Human–Computer Interact.*, pp. 1–13, May 2025.

[4] P. Balloffet, F. H. Courvoisier, and J. Lagier, "From museum to amusement park: The opportunities and risks of edutainment," *Int. J. Arts Manage.*, vol. 16, no. 2, pp. 4–18, 2014.

[5] T. Komarac, D. Ozretic-Dosen, and V. Skare, "Managing edutainment and perceived authenticity of museum visitor experience: insights from qualitative study," *Museum Manage. Curatorship*, vol. 35, no. 2, pp. 160–181, 2020.

[6] A. A. U. Kennedy, I. Thacker, B. D. Nye, G. M. Sinatra, W. R. Swartout, and E. Lindsey, "Promoting interest, positive emotions, and knowledge using augmented reality in a museum setting," *Int. J. Sci. Educ., Part B*, vol. 11, no. 3, pp. 242–258, 2021. [Online]. Available: https://doi.org/10.1080/21548455.2021.1946619

[7] D. Michael, N. Pelekanos, I. Chrysanthou, P. Zaharias, L. L. Hadjigavriel, and Y. Chrysanthou, "Comparative study of interactive systems in a museum," in *Proc. Int. Euro-Mediterranean Conf.*, vol. 6436, M. Ioannides, D. Fellner, A. Georgopoulos, and D. G. Hadjimitsis, Eds., Berlin, Heidelberg, Germany: Springer Berlin Heidelberg, 2010, pp. 250–261. [Online]. Available: https://doi.org/10.1007/978-3-642-16873-4_19

[8] K. A. Ayad, "The Role of Edutainment in e-Learning: An Empirical Study," PhD dissertation, Depart. Media Technol., De Montfort Univ., Leicester, U.K., 2011.

[9] W. G. Bowen and J. L. Shulman, *The Game of Life: College Sports and Educational Values*. Princeton, NJ, USA: Princeton Univ. Press, 2011.

[10] D. Buckingham and M. Scanlon, "Parental pedagogies: An analysis of British 'edutainment'magazines for young children," *J. Early Childhood Literacy*, vol. 1, no. 3, pp. 281–299, 2001.

[11] A. Fuchs, C. Pichler-Koban, A. Pitman, W. Elmenreich, and M. Jungmeier, "Games and gamification—new instruments for communicating sustainability," *The Sustainability Communication Reader: A Reflective Compendium*, F. Weder, L. Krainer, and M. Karmasin, Eds., Wiesbaden, Germany: Springer VS, 2021, pp. 221–243.

[12] N. Aksakal, "Theoretical view to the approach of the edutainment," *Procedia Social Behav. Sci.*, vol. 186, pp. 1232–1239, May 2015.

[13] J. Liang, G. Zeng, Y. Li, and Y. Dong, "ARTimeTravel: Understanding spatial changes in heritage sites over time through web-based augmented reality serious games," in *Proc. Extended Abstr. CHI Conf. Human Factors Comput. Syst. (CHI EA)*. New York, NY, USA: Association for Computing Machinery, 2025, doi: https://doi.org/10.1145/3706599.3719904

[14] Y. Li, Y. Li, J. Liang, and H.-N. Liang, "Easy induction: A serious game using participatory design," in *Proc. Int. Conf. Computer-Human Interact. Res. Appl.*, J. Filipe, A. Ghosh, R. O. Prates, B. Horizonte, and L. Zhou, Eds., Cham, Switzerland: Springer, 2023, pp. 192–211.

[15] S. A. Baowidan, "A survey on application of game design element in edutainment," in *Proc. Int. Conf. Human-Computer Interact.*, G. Goos, J. Hartmanis, E. Bertino, W. Gao, B. Steffen, and M. Yung, Eds., Cham, Switzerland: Springer, 2023, pp. 39–50.

[16] N. L. S. Nuraini, P. S. Cholifah, P. Mahanani, W. Oktiningrum, and A. M. Meidina, "Optimizing the learning process in classroom using edutainment," in *Proc. 1st Int. Conf. On Inf. Technol. Educ. (ICITE)*, Industrial Engineering Department, Surabaya, Eds., Indonesia, W. Striełkowski, et al., Eds., Paris, France: Atlantis Press, 2020, pp. 669–672.

[17] N. Mukherjee, "Edutainment," *Int. J. English Learn. Teaching Skills*, vol. 2, no. 1, pp. 1018–1027, 2019.

[18] A. P. Putra, M. Syarifuddin, M. Munzir, M. Asrul, and A. H. Basri, "Education and tourism: Optimizing offline learning through snakes and ladders game at the Islamic tourism study program of IAIN Parepare," *J. Pariwisata Nusantara*, vol. 1, no. 2, pp. 173–182, 2022.

[19] W. Xiang, "Study on the social education of European museums," *Int. J. Educ. Humanities*, vol. 9, no. 1, pp. 120–125, 2023.

[20] T. Nikolic Deric, J. Neyrinck, E. Seghers, and E. Tsakiridis, "*Museums and Intangible Cultural Heritage: Towards a Third Space in the Heritage Sector.*" Vlaanderen, Belgium: Werkplaats immaterieel erfgoed, 2020.

[21] J. Liang, Y. Li, X. Wang, Y. Yao, R. Koeck, and H.-N. Liang, "Artifact^{VM}: Exploring culturally meaningful presentations and user interactions in virtual museums," in *Eur. Assoc. Computer Graph.*, S. Campana, et al., Eds., Eurographics Assoc., 2025.

[22] E. Arbués and C. Naval, "Los museos como espacios sociales de educación," *Estudios Sobre Educacion*, vol. 27, pp. 133–151, Dec. 2014. [Online]. Available: https://doi.org/10.15581/004.27.133-151

[23] National Museum of China, "Education—National Museum of China," 2024. Accessed: Jan. 11, 2026. [Online]. Available: https://en.chnmuseum.cn/education/

[24] The Metropolitan Museum of Art, "Lesson plans—The metropolitan museum of art," 2024. Accessed: Jan. 11, 2026. [Online]. Available: https://www.metmuseum.org/learn/educators/lesson-plans

[25] J. Pallud, "Impact of interactive technologies on stimulating learning experiences in a museum," *Inf. Manage.*, vol. 54, no. 4, pp. 465–478, 2017.

[26] B. Hanussek, "Enhanced exhibitions? Discussing museum apps after a decade of development," *Adv. Archaeological Pract.*, vol. 8, no. 2, pp. 206–212, 2020. [Online]. Available: https://doi.org/10.1017/aap.2020.10

[27] J. Zhao, J. Liang, Y. Li, C. Zhang, and Y. Dong, "Comparing VR and AR in cultural heritage active learning: A study based on the stimulus-organism-response model and the engagement theory," in *Eur. Assoc. Computer Graph.*, S. Campana, et al., Eds., Siena, Italy: Eurographics Assoc., 2025.

[28] Z. Jiang, S. Zhang, Y. Li, K. L. Man, Y. Yue, and J. Smith, "Is VR always a better choice? Investigating the effects of game modes and role-playing on fire escape simulation training," in *Proc. 10th Int. Conf. Virtual Reality*, 2024, pp. 338–346.

[29] N. Xu, Y. Li, X. Wei, L. Xie, L. Yu, and H.-N. Liang, "CubeMuseum AR: A tangible augmented reality interface for cultural heritage learning and museum gifting," *Int. J. Human–Computer Interact.*, vol. 40, no. 6, pp. 1409–1437, 2024.

[30] T. Octavia, et al., "Museum interactive edutainment using mobile phone and QR code," Ph.D. dissertation, Ind. Eng. Dept., Petra Christian Univ., Surabaya, Indonesia, 2019.

[31] X. Xia et al., "Cross-reality interaction and collaboration in museums, education, and rehabilitation," in *Proc. IEEE Int. Symp. Mixed Augmented Reality Adjunct (ISMAR-Adjunct)*, Piscataway, NJ, USA: IEEE Press, 2023, pp. 815–820.

[32] H. Turner, G. Resch, D. Southwick, R. McEwen, A. K. Dubé, and I. Record, "Using 3D printing to enhance understanding and engagement with young audiences: Lessons from workshops in a museum," *Curator: Museum J.*, vol. 60, no. 3, pp. 311–333, 2017.

[33] N. Kara, "A mixed-methods study of cultural heritage learning through playing a serious game," *Int. J. Human–Computer Interact.*, vol. 40, no. 6, pp. 1397–1408, 2024.

[34] K. M. Madsen and R. Krishnasamy, "Our museum game: A collaborative game for user-centered exhibition design," in *Proc. Int. Conf. ArtsIT, Interactivity Game Creation*, A. Brooks and E. I. Brooks, Eds., Cham, Switzerland: Springer, 2019, pp. 427–435.

[35] N. Nordin and W. Omar et al., "Rev-opoly: A study on educational board game with web-based augmented reality," *Asian J. Univ. Educ.*, vol. 18, no. 1, pp. 81–90, 2022.

[36] D. Mina, J. Salah, and S. Abdennadher, "ARcode: Programming for youngsters through AR," in *Methodologies and Intelligent Systems for Technology Enhanced Learning, 11th International Conference*, F. De la Prieta, et al., Eds., Cham, Switzerland: Springer, 2022, pp. 65–74.

[37] L. A. R. S. Prabali and A. I. w I. Y. Sukmana, "Monopoly media: Efforts to increase the activity of elementary school students in learning animals movement organs," *J. Ilmiah Sekolah Dasar*, vol. 5, no. 2, pp. 250–259, 2021. [Online]. Available: https://doi.org/10.23887/jisd.v5i2.35549

[38] E. Klopfer, J. Perry, K. Squire, M.-F. Jan, and C. Steinkuehler, "Mystery at the museum—A collaborative game for museum education," in *Computer Supported Collaborative Learning 2005*, T. Koschmann, Ed., NY, USA: Routledge, 2017, pp. 316–320.

[39] F. Frapolli, A. Brocco, A. Malatras, and B. Hirsbrunner, "Flexible rules: A player oriented board game development framework," in *Proc. 3rd Int. Conf. Advances in Computer-Human Interact.*, Piscataway, NJ, USA: IEEE Press, 2010, pp. 113–118.

[40] W. H. Chou, C. Y. Chen, and Y. B. Lai, "Augmented reality in a monopoly-type game," *Int. J. Advancements Comput. Technol.*, vol. 4, no. 23, pp. 592–599, 2012. [Online]. Available: https://api.semanticscholar.org/CorpusID:62392813

[41] T. Rizov, J. Djokic, and M. Tasevski, "Design of a board game with augmented reality," *FME Trans.*, vol. 47, no. 2, pp. 253–257, 2019.

[42] M. S. dos Santos, M. A. R. Schmitt, A. Peres, and E. B. Reategui, "Conquer the artwork: a board game for teaching history of art," *Educação em Revista*, vol. 36, May 2020, Art. No. e219027.

[43] J. Barreira, M. Bessa, L. C. Pereira, T. Adão, E. Peres, and L. Magalhães, "MOW: Augmented reality game to learn words in different languages. Case study: Learning English names of animals in elementary school," in *Proc. 7th Iberian Conf. Inf. Syst. Technologies (CISTI)*, 2012, pp. 1–6.

[44] Z. Liu, D. Chen, C. Zhang, and J. Yao, "Design of a virtual reality serious game for experiencing the colors of Dunhuang frescoes," *Heritage Sci.*, vol. 12, no. 1, pp. 1–31, 2024.

[45] L. Ye, R. Wang, and J. Zhao, "Enhancing learning performance and motivation of cultural heritage using serious games," *J. Educational Comput. Res.*, vol. 59, no. 2, pp. 287–317, 2021.

[46] B. Plimmer, "Tangible interaction: A case for light-weight tangibles," *Proc. 15th New Zealand Conf. Human-Computer Interact.*, A. Hinze and M. Masoodian, New York, NY, USA: ACM, Mar. 2015, p. 85. [Online]. Available: https://api.semanticscholar.org/CorpusID:6671579

[47] M. Yuna, et al., "Impressing museum visitors by having them answer questions toward the realization of an interactive viewing support system," in *Proc. 12th Int. Conf. Inf. Educ. Technol. (ICIET)*, Piscataway, NJ, USA: IEEE Press, 2024, pp. 137–142.

[48] M. J. Rogerson, M. R. Gibbs, and W. Smith, "Cooperating to compete: the mutuality of cooperation and competition in boardgame play," *Proc. 2018 CHI Conf. Human Factors in Comput. Syst.*, R. L. Mandryk, M. Hancock, M. Perry, and A. L. Cox, Montréal, QC, Canada: ACM, Apr. 2018. [Online]. Available: https://doi.org/10.1145/3173574.3173767

[49] C. Pering, "Pet pals: A game for social mediation," *Proc. Extended Abstr. CHI Conf. Human Factors Comput. Syst. (CHI EA)*, L. Terveen and D. Wixon, Eds., Minneapolis, MN, USA: ACM, Apr. 2002, pp. 778–779. [Online]. Available: https://doi.org/10.1145/506443.506593

[50] S. Nicholson, "Making gameplay matter: Designing modern educational tabletop games," *Knowl. Quest*, vol. 40, no. 1, pp. 60–65, 2011. [Online]. Available: https://api.semanticscholar.org/CorpusID:53456732

[51] J. Brooke, "SUS: A "quick and dirty" usability scale," *Usability Eval. Industry*, vol. 189, no. 3, pp. 189–194, 1996.

[52] M. Schrepp, A. Hinderks, and J. Thomaschewski, "Design and evaluation of a short version of the user experience questionnaire (UEQ-S)," *Int. J. Interactive Multimedia Artif. Intell.*, vol. 4, no. 6, pp. 103–108, 2017.

[53] W. A. IJsselsteijn, Y. A. De Kort, and K. Poels, "*The Game Experience Questionnaire*," Eindhoven, Netherlands: Eindhoven Univ. Technol., 2013.

[54] I. Malegiannaki, T. Daradoumis, and S. Retalis, "Using a story-driven board game to engage students and adults with cultural heritage," *Int. J. Game-Based Learn.*, vol. 11, no. 2, pp. 1–19, 2021.

[55] H. Neale and S. Nichols, "Theme-based content analysis: A flexible method for virtual environment evaluation," *Int. J. Human–Computer Stud.*, vol. 55, no. 2, pp. 167–189, 2001.
[56] B. Laugwitz, T. Held, and M. Schrepp, "Construction and evaluation of a user experience questionnaire," in *HCI and Usability for Education and Work*, A. Holzinger, Ed., Berlin, Heidelberg: Springer, 2008, pp. 63–76.
[57] Q. Liu and C. Sutunyarak, "The impact of immersive technology in museums on visitors' behavioral intention," *Sustainability*, vol. 16, no. 22, 2024, Art. No. 9714.
[58] D. Reinhardt and J. Hurtienne, "The impact of tangible props on gaming performance and experience in gestural interaction," in *Proc. 12th Int. Conf. Tangible, Embedded, Embodied Interaction*, Mar. 2018, pp. 638–646. [Online]. Available: https://doi.org/10.1145/3173225.3173258
[59] A. Kim, H. Bae, and K. Lee, "Effects of tactile perception on emotion and immersion to film viewing in a virtual environment," *Proc. 25th ACM Symp. Virtual Reality Softw. Technol.*, Nov. 2019. [Online]. Available: https://doi.org/10.1145/3359996.3364703

Jiachen Liang received the M.Sc. degree in social computing from Xi'an Jiaotong-Liverpool University (XJTLU), Suzhou, China, in 2023. She is currently working toward the Ph.D. in computer science and software engineering with XJTLU and the University of Liverpool, Liverpool, U.K.

Her research interests include human–computer interaction, cultural heritage, augmented reality, and serious games.

Yue Li (Member, IEEE) received the Ph.D. degree in computer science from the University of Nottingham, Nottingham, U.K., in 2020.

She is an Associate Professor with Xi'an Jiaotong-Liverpool University, Suzhou, China. She leads the Heritage, Edutainment, and Reality Laboratory (HER Lab). Her research interest is in the field of human-computer interaction (HCI), with particular emphasis on virtual reality and augmented reality technologies.

Fanpei Liu is currently working toward the bachelor's degree in data science and big data technology from the Contemporary Entrepreneurialism, School of AI and Advanced Computing, Xi'an Jiaotong-Liverpool University, Suzhou, China.

His research interests include human–computer interaction, augmented reality, and deep learning.

Yu Cheng received the B.Eng. degree in digital media technology from Xi'an Jiaotong-Liverpool University, Suzhou, China, in 2025. He is currently working toward the M.Sc. degree in games engineering with the University of Warwick, Coventry, U.K.

His research interest includes game design and game development.

Richard Koeck received the professional degree in architecture from Germany and the M.Phil. and Ph.D. degrees in architecture and the moving image from the University of Cambridge, Cambridge, U.K., in 2006.

He is a Professor and Chair in Architecture and the Visual Arts with University of Liverpool, School of Architecture, Liverpool, U.K., and is the Director of the Centre for Architecture and the Visual Arts (CAVA). His research interests include three interlocking knowledge domains: space, media, and people.

Hai-Ning Liang received the Ph.D. degree in computer science from the University of Western Ontario, London, Canada.

He is an Associate Professor with the Computational Media and Arts Thrust, Hong Kong University of Science and Technology (Guangzhou), Guangzhou, China. His research interests include human–computer interaction, focusing on the design of novel interaction techniques and applications for virtual/augmented/mixed reality, gaming, and visualization technologies.