Multimed Tools Appl (2013) 62:633–658
DOI 10.1007/s11042-011-0864-4

A case study of user immersion-based systematic design for serious heritage games

Shengnan Chen · Zhigeng Pan · Mingmin Zhang · Huaqing Shen

Published online: 2 September 2011

Abstract Modern digital technologies support the preservation and transfer of cultural heritage information via devices and applications such as digital storage systems, electronic books and virtual museums. Advances in virtual and augmented reality, real-time computer graphics and computer games have made it possible to construct large virtual environments in which users may experience cultural heritage through a variety of interactions and immersions. Thus, an emerging problem is to implement an appropriate systematic design method for achieving various types of entertainment, learning and information transfer. This paper proposes two important design factors that impact on user immersion in serious heritage games: user interface space volume and subsystem sequence. The impact of the two factors on

S. Chen · Z. Pan (✉) · M. Zhang
State Key Lab of CAD & CG, Zhejiang University,
Hangzhou, 310027, People's Republic of China
e-mail: zhigengpan@gmail.com

S. Chen
e-mail: chenshengnan@cad.zju.edu.cn

M. Zhang
e-mail: zmm@cad.zju.edu.cn

S. Chen
Zhejiang Textile & Fashion College, Ningbo,
315000, People's Republic of China

Z. Pan
Digital Media & HCI Research Center, Hangzhou Normal University,
Hangzhou, 310012, People's Republic of China

H. Shen
Art Department, Zhejiang University, Hangzhou,
310027, People's Republic of China
e-mail: digimanshq@126.com

proposed systematic design methods was investigated through comparative studies by implementing a serious heritage game system on three different platforms.

Keywords Serious heritage game · User immersion · The Jing-Hang Grand Canal · User interface space volume · Subsystem sequence · Systematic design

1 Introduction

Large quantities of cultural heritage have been handed down from generation to generation throughout human history. However some artworks have either disappeared or been destroyed by the rise and fall of human societies, natural disasters or degradation with the passage of time. A pressing worldwide problem is how to design novel methods to preserve or exhibit cultural heritage information. In the last decade, cultural heritage preservation and transmission significantly benefited from the rapid development of the Internet, high-performance computer graphics hardware and software, model construction devices, data acquisition, and applications. What do these technological advances and their utility in cultural heritage mean for users beyond simply increasing the quantity of information that can be viewed?

This study explores optimization of serious heritage games from the user perspective. Two design factors that impact on user immersion, user interface space volume and subsystem sequence, were investigated to determine their impact on the user's learning outcome and entertainment level for a serious heritage game. The study was further approached from a systematic design perspective. The systematic design analysis was based on comparative studies of experimental user tests of a serious heritage game system, which was implemented on three different platforms. Following each user's experience with the game system, user tests were administered for measuring their learning outcome and entertainment level. Finally, the system optimization methods for serious heritage games were discussed according to the test results.

2 Related work

Studies of cultural heritage have been attempted in digital preservations [15, 19], online exhibitions [8, 20], virtual explorations [9, 25], and serious games [27]. These previous works improved the steps of cultural heritage preservations worldwide. Anderson et al. surveyed the theories, methods and technologies used in serious heritage games [2]. He also provided an overview of the existing literature relevant to the use of games to support cultural heritage purposes such as teaching, learning and enhancing museum visits. However, Champion argued that when digital places representing the past are constructed using media such as game engines, designers may be susceptible to the lure of technology and forget to concentrate on enhancing the user experience. Therefore, the learning outcome gained from using computer games is particularly dangerous in terms of the objectives of virtual heritage where there are several important issues in the creation, construction or revocation of places of cultural significance. He suggested that computer games offer particular advantages over traditional virtual environment technology, but that their typical modes of interaction must be re-examined, especially in relation to the notion of place [12]. Champion suggested certain techniques from game design that can be applied to cultural heritage virtual environments [11]. Champion also reviewed the types of virtual heritage evaluation and related case studies. He further pointed out that work remains to be done on evaluation of virtual heritage and cultural learning such as how cultural information can be best interactively experienced and learned, and how to determine the capability of a virtual heritage environment to provide a cultural learning experience [13]. Jacobson et al. presented a virtual heritage learning game of Gates of Horus [26] based on the previous project of Virtual Egyptian Temple [27]. The game Gates of Horus provides players the opportunity to work through the interactive narrative and strive towards goals which matter in the context of the content itself. It attempts to further combine narrative and content to balance the learning gained from user experiences and objectives of virtual heritage in computer games. Champion and Jacobson presented four types of interactive environments, and explored ways to extend gaming beyond the limitations of the PC desktop interface. The working prototypes were considered successful in engaging the students with the interface possibilities and interaction issues of unconventional game design [14].

Immersion is a powerful experience of gaming, and has been considered as an important issue of interaction by gamers, designers, and researchers [10]. Immersion is the subjective impression that one is participating in a comprehensive, realistic experience [36], and the extent to which a person's cognitive and perceptual systems are tricked into believing they are somewhere other than their physical location [33]. Immersion in a digital experience involves the willing suspension of disbelief and the design of immersive learning experiences that induce this disbelief by drawing upon sensory, action and symbolic factors [18]. Previous research on immersion has been scattered in several different areas such as virtual learning [28], game research [29], heritage study [1], and interface design [32]. Swing attempted to add immersion to a collaborative tool in a 3D world where each user was represented with an avatar [37]. Tallyn et al. explored enhancement of user immersion from an alternative approach in which participants in the virtual world such as game simulation of a large online community improvised events by embodiment of reporting agents [38]. Handron and Jacobson presented their work in the immersive Earth Theater at Carnegie Museum of Natural History which uses CaveUT and the unreal engine for real time virtual tours as part of public and educational programming. They employed an immersive space by making use of the curvature of the Earth Theater and a tour guide which interacts with the audience while navigating through virtual space using a wireless control device [21]. Bonis et al. presented a content personalization platform for virtual museums, which is based on a semantic description of content and on information implicitly collected about the users through their interactions with the museum [6]. Apostolellis and Daradoumis investigated the potential learning benefit of integrating audience interaction with gaming environments in the immersive space of a dome theater [3].

Brown and Cairns first described the term “immersion” based on the experiences of gamers. They proposed a definition that immersion may be used to describe the degree of involvement with a game, and the barriers to immersion act to determine the level of involvement with a game. They presented three stages of involvement in a game according to different barriers: engagement, engrossment and total immersion [10]. Jacobson explored whether students benefited from an immersive panoramic display in heritage learning that is visually complex and information-rich. He executed experiments of learning experiences of middle-school students in the Virtual Egyptian Temple [27] and Gates of Horus [26], and concluded that the immersive display provides better supports for learning activities in virtual heritage [23]. Jacobson also investigated the immersive displays of the digital dome and desktop computer and presented evidence that visually immersive displays could improve learning in virtual educational applications [24]. Dede designed the Alien Contact! Curriculum to teach math and literacy skills to middle- and high-school students. He concluded that immersion can foster learning experiences and draw on a powerful pedagogy through multiple perspectives, and lesser degrees of immersion can still provide situated learning. He pointed out that further design-based research is needed to determine the degree of immersion necessary for achieving various types of engagement and learning [17].

The current study approaches the evaluation and optimization of serious heritage games by a systematic design method which is based on user immersion. Two design factors that impact on user immersion, user interface space volume and subsystem sequence, were considered in conducting the systematic design analysis. Experiments of user interface space volume were based on Jacobson's prior research [23], and a subsystem sequence study for supporting the systematic design was further attempted. No prior studies are known to have been conducted for evaluating and optimizing serious heritage games from the systematic design approach based on user immersion. The current study emphasizes the preliminary nature of these concepts and highlights the associated assumptions, pitfalls and challenges. In particular, this study is based on a utilitarian view of systematic design, where usability and benefits are assessed purely from the user's perspective. Wider issues of optimization, such as the intrinsic value of immersion and the evaluation issues associated with technical support to enhance user immersion degrees were not considered in this study. These issues, while impossible to quantify in usability terms, are clearly fundamental to the serious heritage game implementations. The analyses presented herein are meant to complement, not replace, more profound considerations of technical applications.

3 Terminology

Entertainment level The degree to which the users have been entertained by playing the game.

Learning outcome The learning benefit that the users achieved from the serious heritage game including the knowledge and practical experiences.

Subsystem The main parts that make up the integrated serious heritage game system. In the experimental system of this study, there are three subsystems: Part A Introduction Subsystem, Part B Landscape Subsystem, Part C Virtual Experience Subsystem. These three subsystems are designed with focus on the three different user immersion levels engagement, engrossment and total immersion, respectively (Fig. 3).

Subsystem sequence The order of which the subsystems are arranged in an integrated serious heritage game system.

System content The information types which make up the integrated game system, such as liberal art, history, landscapes and other large scale constructions, or complex engineering systems with advanced technological features and many user controls.

System content scale The percentage that each of the different types of system contents contribute to the composition of a fully integrated serious heritage game system.

System goal Two aspects from the user perspective, learning and entertaining, were defined to be the main system goals in this study for the serious heritage games.

User immersion level The degree of involvement with a game. The three different user immersion levels in this study are engagement, engrossment and total immersion [10].

User interface space volume The size of user interface space, such as a standard PC screen in the lab or a large screen in the museum.

4 Experimental design

This study explored how the systematic design parameters impacted an effective implementation of a serious heritage game system. The goal of this experiment was to investigate how the two design factors, user interface space volume and subsystem sequence, influenced the user's learning outcome and entertainment level in the Jing-Hang Grand Canal Serious Heritage Game which was implemented on three different platforms: lab, museum and online.

The experiment was designed as follows:

(1) The Jing-Hang Grand Canal was chosen to be implemented as an experimental serious heritage game system, and was designed with three distributed subsystems which corresponded to different user immersion levels.
(2) The Jing-Hang Grand Canal Serious Heritage Game was implemented on three different platforms: lab, museum and online. The lab platform was constructed with a standard PC screen, representing a smaller user interface space volume. The online platform also utilized a PC screen. The museum platform was constructed with a large screen of enhanced user interface space volume which is much larger than the other two platforms. For the online platform, in particular, the three subsystems were arranged in different order for various users to facilitate an investigation about the impact of subsystem sequences on the user's experience in the serious heritage game.
(3) Three groups of participants were recruited. One group experienced the game on a standard PC screen with the lab platform. The second group experienced the game with the large screen museum platform. The third group experienced the game via the online platform, also by PC screen, but with different subsystem sequences.

(4) After each user's experience with the game system, experimental user tests were administered for measuring their learning outcome and entertainment level.
(5) The learning outcome and entertainment level test results of the three groups of users who played the game were compared. The comparative studies had two goals. The first goal was to determine how the user interface space volume affected the user's learning outcome and entertainment level in a serious heritage game by comparing the user test results of lab and museum platforms. The second goal was to investigate how the subsystem sequence impacted on the integrated system of a serious heritage game by comparing the user test results of different sequence groups using the online platform.
(6) The impact of the two factors on proposed experimental system was further approached from a systematic design perspective, and the system optimization methods for serious heritage games were discussed based on the experimental system.

5 The Jing-Hang Grand Canal Serious Heritage Game

The Jing-Hang Grand Canal is one of the longest water transportation systems in Chinese history [31]. "Jing-Hang" is an abbreviation of two cities, Peking and Hangzhou. The canal crosses half of China, starting from Peking and ending in Hangzhou, for a total length of roughly 1,100 miles (Fig. 1). The oldest parts of the canal date back to the fifth century B.C. and different parts of it were finally

Fig. 1 A map showing the Jing-Hang Grand Canal and cultural heritage sites in nearby cities

Fig. 2 A dynamic artistic illustration in the serious heritage game: when the user clicks on a city's name, cultural heritage sites related to that city will be displayed

connected during the Sui Dynasty (581–618 A.D.). This canal had political and economic significance, which linked the old military and political centers of northern China to the granaries of the south [16]. Today, the canal continues to be utilized for shipping and irrigation.

The Jing-Hang Grand Canal represents a remarkable achievement of imperial Chinese hydraulic engineering and presents a popular serious heritage game resource to the public. Architectural and cultural environments along the canal significantly vary due to regional differences. Figure 1 provides a map of the canal featuring cultural heritage sites in nearby cities. These cities' culture, architecture, commerce, and even legends are closely related to the canal.

This serious heritage game introduces the geography, folk culture, and historical events of several sites along the Jing-Hang Grand Canal in a storytelling manner. The game was implemented to promote the cultural learning of the Jing-Hang Grand Canal for the public, especially for the youth. Figure 2 is a screenshot of dynamic artistic illustrations from this serious heritage game, in which the fish swims from Peking to Hangzhou, with the cities' locations and names jumping out as the fish passes them.

5.1 System framework

The Jing-Hang Grand Canal Serious Heritage Game has three main subsystems (Fig. 3). "Introduction subsystem" (Part A) outlines the folk culture along the canal and shows cultural heritage sites in the ancient cities by animation clips. Part A also shows the water transportation system of the canal spreading from Hangzhou to Peking. "Landscape subsystem" (Part B) introduces the master cultural heritage sites of the cities along the canal, which were shown by the users' interactions with panoramas. "Virtual experience subsystem" (Part C) allows users to experience culture, history, art, and stories related to the canal by virtual navigation.

Each of the three subsystems offers the users different degrees of immersion [10] (Fig. 3). Part A, as an initial engagement stage, storytelling approach and animation clip facilitates the user entrance into the cultural experience. It allows users to become familiar with the canal in an interesting and dynamic way. Part B offers

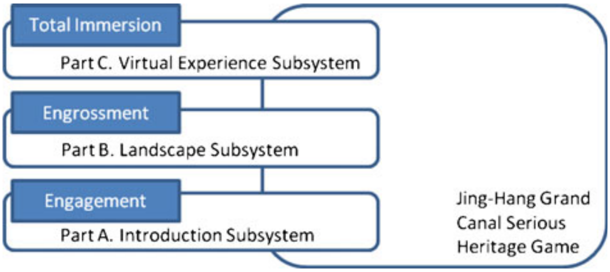


Fig. 3 System framework of the Jing-Hang Grand Canal Serious Heritage Game

users the ability to interact with panoramas as an engrossment stage. Part C provides for user interactions by certain gestures, thus allowing users to interactively explore the objectives of the game and obtain a total immersion stage according to their individual interests.

5.2 System implementation

In order to explore the influence of user interface space volume and subsystem sequence, the Jing-Hang Grand Canal Serious Heritage Game was constructed on three different platforms: lab, museum and online. Specific computer techniques were employed for the system implementation of this game (Table 1). The first five techniques in Table 1 were used in the basic implementation. Additionally, image-based animation, personalized 3D avatar construction and gesture-based interaction were used in the implementation of each of the three platforms while the large-screen projection was specifically employed for the museum platform.

5.2.1 Image-based animation

In order to illustrate a busy scene on the wharf beside the canal, image-based animation [34] was employed to combine 3D objects with 2D background (Fig. 4). This technique improves the real-time rendering speed and harmonizes the locomotive 3D objects on a 2D background picture, thus making the scene more alive. First, a professional artisan was invited to repaint the painting of "Qingming Festival by The Riverside", maintaining the details from the original artwork. Second, 11 discrete parts of the painting were selected to be the main spots where the storylines occur

Table 1 Computer techniques used to construct the Jing-Hang Grand Canal Serious Heritage Game

Technique	Utilization
2D flash	User interface design
Panorama	Presenting real scenes with multiple photos
3D modeling	Depicting pagodas and other objects
3D animation	Illustrating the water transportation process
VRML	Navigation in the virtual canal
Image-based animation	Illustrating scenes along the canal
Large-screen projection	Projecting the scene onto a large screen
Personalized 3D avatar	Connecting users and virtual environment
Gesture-based interaction	Interaction between users and the system

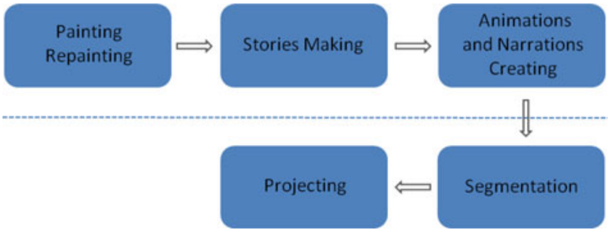


Fig. 4 Process of incorporating image-based animation

and, consequently, a script comprising 11 distinct scenarios was created. Third, a Tour into Picture method [22] was used to create animations and narrations to enable the viewpoint to move back and forth. The inanimate objects were translated and rotated while skeleton-based characters were applied to objects representing humans and animals (Fig. 5). As the final step, textures, lights and shadows were created and imposed on the scenes.

5.2.2 Large-screen projection

A large-screen projection was implemented at the Jing-Hang Grand Canal Museum in order to provide users with an alternative interface from the typical PC screen. A projection measuring 4.0 m × 35.5 m (height × length) was arranged (Fig. 6) to enhance user immersion into the Jing-Hang Grand Canal Serious Heritage Game. The view depicted the panoramic scene along the Jing-Hang Grand Canal with larger user interface space volume. Users could virtually navigate in the large screen by dynamically interacting with the virtual character.

C/S architecture was used in this projection system (Fig. 7). Each frame was segmented into 30 tiles in the PC server, and each segmented tile was transmitted to the corresponding client PC through synchronous switching. Each client PC was connected to a projector which renders and projects one tile to the proper position on the large screen.

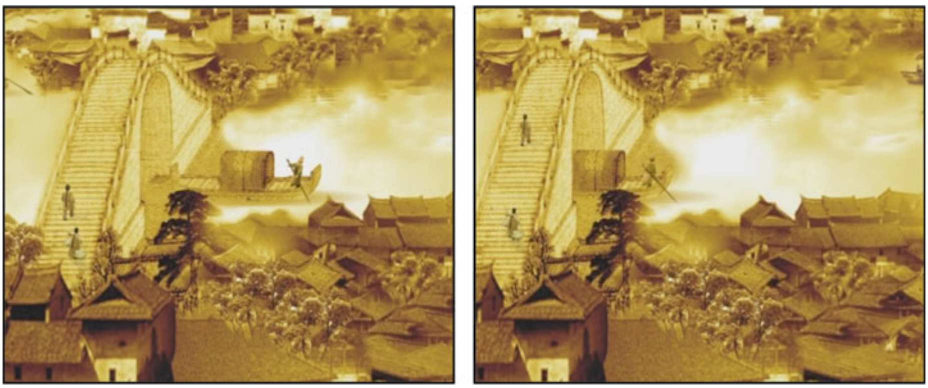


Fig. 5 Two screenshots from the animated painting that depict moving boats and men

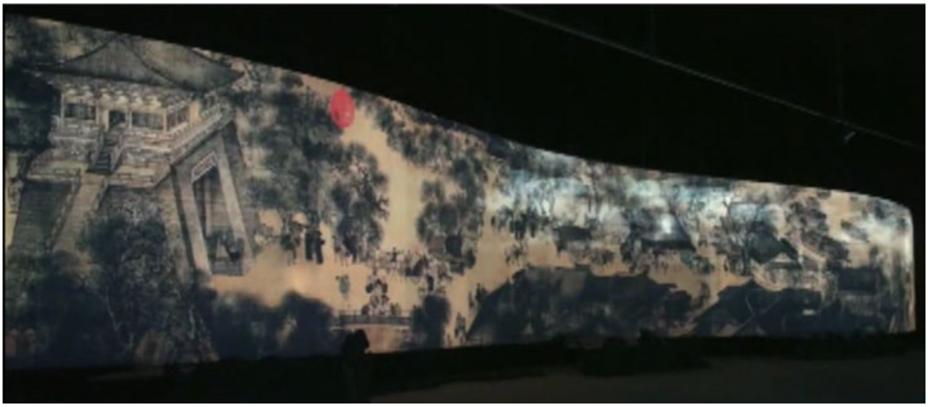


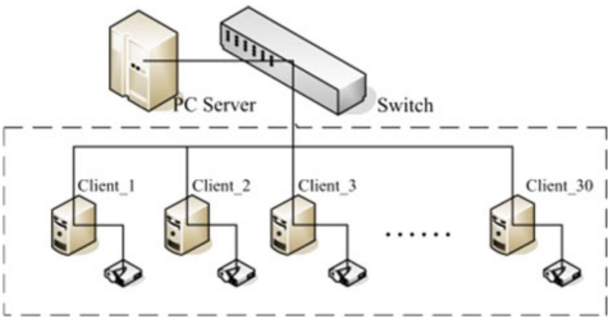
Fig. 6 A view of the large-screen projection

5.2.3 Personalized 3D avatar construction

A personalized 3D avatar was employed into the Jing-Hang Grand Canal Serious Heritage Game to enhance user immersion. The avatar was personalized with a photo-based 3D face model construction method (Fig. 8). This method included two steps: first, extracting the characteristics from the user's photo, and second, reconstructing the face model according to extracted characteristics. For a new input image, the face region was detected first. This was followed by searching for the feature points in a local area through rotation and scaling operations to determine the actual feature points that were closest to the provided points in the template. For the grid deformation, a RBF-based (Radial Basis Function) interpolation method was employed [40].

The architecture of the virtual character interaction involved four parts: virtual environment, avatar-based interface, user information database, and navigation component (Fig. 9). Users were empowered to customize and manipulate their avatar. The avatar can walk to virtual objects of user interest, as well as observe the objects or trigger an interaction process. Furthermore, the avatar may receive feedback generated from the task implementation.

Fig. 7 Large-screen projection method



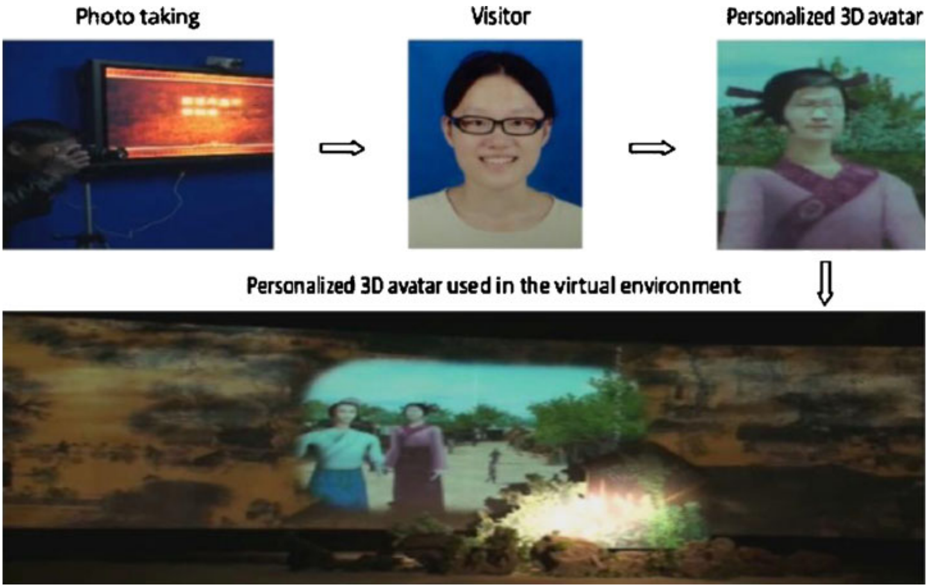
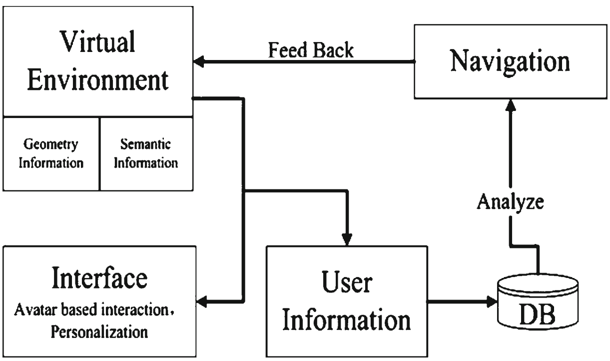


Fig. 8 Photo-based 3D face model construction method

5.2.4 Gesture-based interaction

A robust real-time hand tracking and hand posture recognition method was employed for the Jing-Hang Grand Canal Serious Heritage Game. This method allowed the user to interact with their customized avatar by natural gestures, observe specific models and navigate in the virtual constructions. There were two challenges in posture recognitions in the interaction of this game. The first challenge was to locate the hand accurately and recognize posture correctly within a cluttered background. The hand location and posture recognition were greatly influenced by a complex background. The second challenge was to properly model the scale-invariance and rotation-invariance problems in hand posture recognition. A hand posture which requires a specific scale or angle creates an uncomfortable feel for the users.

Fig. 9 The architecture of the virtual character interaction



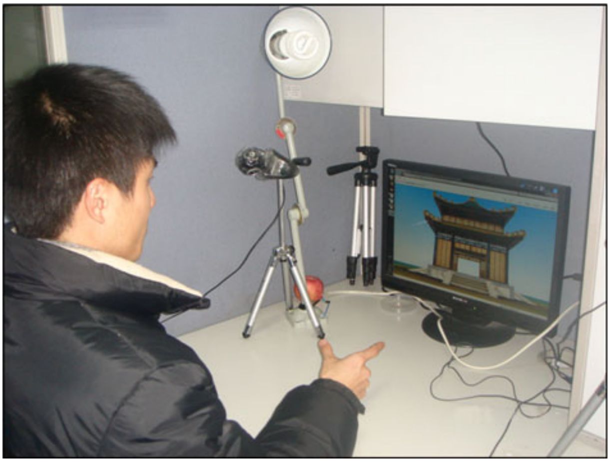


Fig. 10 A participant navigating in a virtual construction by gestures on the lab platform of the game

Due to these issues and difficulties for posture recognitions, the algorithm was generally separated into several steps. Initially, a MCT-based (modified census transform) method [30] with high detection rate was utilized to detect the hand for triggering the system for the first frame. The second step utilized a multi-cue hand tracking algorithm [35] based on velocity weighted features and color cue for the following frames. The multi-cue hand tracking algorithm was applied to track the hand robustly with a single camera and distinguish it from the complex background. This algorithm provided control with large space, including objects of skin color, due to its high detection rate. Therefore, the hand could be located accurately within each frame of a cluttered background. The first two steps resolved the first challenge. In the third step, the hand was segmented using a Bayesian skin-color model [39] and

Fig. 11 A participant interacting by gestures with a boat in which he is interested to obtain more details on the museum platform of the game

the hand tracking result. Finally hand posture was recognized by the feature based on density distribution. This method effectively enforced robustness of scale-invariance and rotation-invariance in hand posture recognition.

This gesture-based interaction allowed users to observe objects, change their viewpoints and navigate through constructions by gestures (Fig. 10). They could also interact with their interested objects by gestures to explore the detail information (Fig. 11). This application provided users with much more natural interactions which helped to enhance their immersion in the serious heritage game.

6 Comparative studies

6.1 Methodology

Comparative studies were used to evaluate the serious heritage game from the user perspective. To estimate the learning outcome and entertainment level of the serious heritage game, the comparative studies were approached from three steps. First, a 5-point Likert scale measurement [5] questionnaire was designed to evaluate users' entertainment level for the serious heritage game. In the current work, the questionnaire asked the participants to rate, "How much were you entertained by this game? What was the entertainment value of each subsystem?" Entertainment

Fig. 12 A screenshot of the first item in the learning outcome user test: Users select the correct answer from two choices

levels of the three subsystems with different immersion stages, and also of the entire game system, were ascertained.

The second step was to execute a user test through interactive computer simulations to investigate the participant's learning outcome from the serious heritage game. Learning outcome was evaluated from the mean score of each participant's test result. There were three items in this user test, all of which use Flash animation. The test scores were calculated referring to the user's learning outcome in each subsystem. In the first test item, users answered the questions about the Jing-Hang Grand Canal's general information (Fig. 12). They attempted to select the correct answer from two choices and submitted their result. This test item measured their learning outcome from Part A of the serious heritage game. The second test item simulated loading grain onto boats and imparts general knowledge of buoyancy (Fig. 13). Users selected different weights of grain to load. The boat's waterline changed as the loaded grain's weight changed. This test item measured the user's ability to calculate the correct weight that can be loaded and determine a suitable loading strategy. The score was generated according to the valid load. In the third test item, users attempted to maneuver a boat through different lock gates (Fig. 14). The frequency of correct manipulations and misapplications was generated to a final score. The second and third test items measured the user's learning outcome from Parts B and C.

The third step of the comparative studies analyzed user test data pertaining to how the two design factors, user interface space volume and subsystem sequence,

Fig. 13 A screenshot of the second item in the learning outcome user test: Users attempt to load grain onto the boat

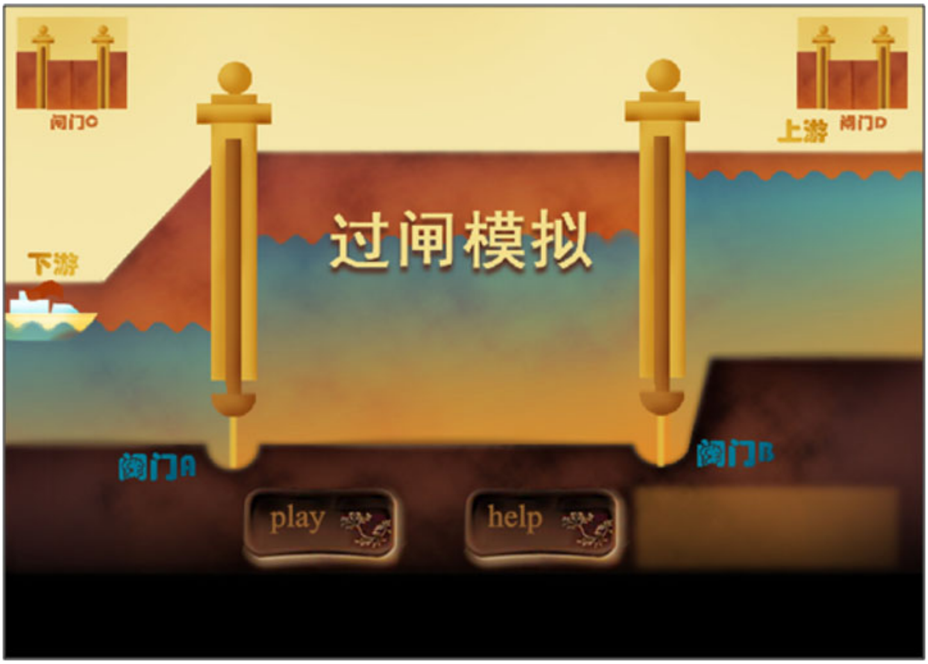


Fig. 14 A screenshot of the third item in the learning outcome user test: users attempt to maneuver a boat through the lock gates

impacted serious heritage games. The analysis also considered how to arrange these two design factors appropriately for systematic design to achieve the expected results, and determine the internal relationships of the system content, goal and application.

6.2 Experiments

6.2.1 Lab platform study

Participants Fifteen volunteers (16–19 years old) were selected from grade two of high school. They received two course validation stamps for their participations.

Procedure Participants experienced the Jing-Hang Grand Canal Serious Heritage Game in the lab using a PC with screen size of 22 inches and resolution of 1,680 × 1,050. A web camera platform was set up for enabling the participant to interact with the game. Participants were given a brief description about the serious game system before their experience. Words such as "learning", "test" and "score" were avoided in descriptions to prevent cognitive interference with the sense making process [7].

Qualitative interviews were conducted after each participant's game experience. The interviews were designed to motivate the participants to recall their experience with the game and to investigate other possible impact factors for serious heritage games. The main questions in these interviews included: Which part do you think you involved most? How? Which parts do you like most and least? Would you like to experience this type of games again in the future?

Following the qualitative interview, each participant was provided with a User Entertainment Level questionnaire. Entertainment levels were deemed to be “extremely entertained” as full-credit of value 5, “fully entertained” as 4, “moderately entertained” as 3, “mildly entertained” as 2, and “not at all entertained” as 1 [4].

Finally, a computer simulation user test about the knowledge of the Jing-Hang Grand Canal was provided to each participant (Figs. 12, 13 and 14). Each participant had twenty minutes to complete the test. The test score was generated automatically when it was finished. Each subsystem score was recorded separately and a total score was calculated, the “Total” is for the total learning outcome from the integrated game, which is the sum of the learning outcome from the three subsystems (Parts A–C) as:

$$\text{Part A}_{(30)} + \text{Part B}_{(30)} + \text{Part C}_{(40)} = \text{Total}_{(100)} \tag{1}$$

Data collection A database was constructed including each participant’s interview reply, entertainment levels and test scores. Three values were catalogued by tagging the platform type and participant number: Platform type—participant number {[answers: keywords of participant’s answers in the short interview]; [entertainment levels: Parts A—C, the entire system]; [test scores: Parts A–C, Total]}.

6.2.2 Museum platform study

Participants Seventeen participants (14–19 years old) participated in this study. Each of them received a gift notebook as a compensation for their time.

Procedure A large-screen projection was constructed for the Jing-Hang Grand Canal Serious Heritage Game as the museum platform. This provided an alternative enhanced user interface space volume apart from the typical PC screen. Therefore, the comparative studies for different user interface space volumes could be analyzed from the users’ test results.

Museum visitors were observed who were estimated to be within the ages of 14–18, and indicated an interest in the large screen. Potential participants were monitored for their performance in experiencing the system.

After their experience, potential participants were approached and briefly introduced to this research project. If they agreed to participate, a further interview was conducted. Participants were asked to complete a User Entertainment Level questionnaire, and were also provided twenty minutes to complete the same computer simulation user test in a laptop PC that was given to the participants in the lab platform study.

Data collection The information data for each participant in the museum platform study were recorded using the same database format as in the lab platform study.

6.2.3 Online platform study

Participants Twenty-six participants (17–21 years old) were recruited from the local area school system. They received monetary compensation for their time.

Procedure There are three subsystems in the Jing-Hang Grand Canal Serious Heritage Game (Fig. 3). These three subsystems were defined as three immersion degrees [10]. A random control was applied to arrange subsystems in six different sequences. Each participant was randomly given one of the six sequences. They were first shown a short introduction page before entering the game. After the introduction, they click an Enter button and proceed into the game where they could spend any time they want during their experience. After participants confirmed to quit from the game, they were directed to a page to enter their answers for the qualitative interview. The same User Entertainment Level questionnaire and computer simulation user test were provided as in the lab and museum platform studies. They had twenty minutes to complete the test. Participants received their scores immediately.

Data collection The sequence information was recorded in each test and archived with the participant's test results into the database. Remaining values were kept in predefined order, same as the lab and museum platform studies. After these three studies, a document for each participant's data was prepared. The documents were correlated to their experimental data, and also included each participant's general information such as age, gender and preference.

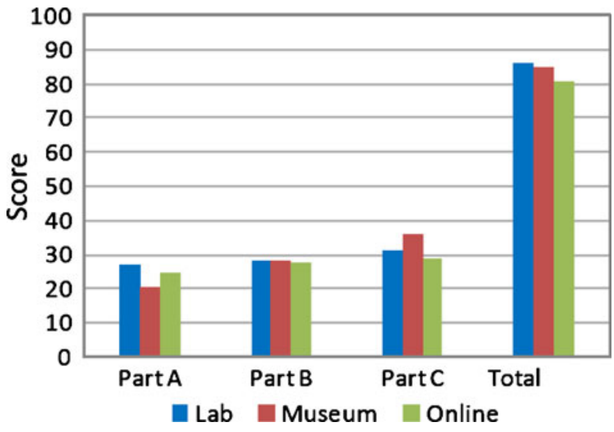
7 Results and discussion

The following systematic design analysis incorporated two factors that impact on user immersion: the user interface space volume and subsystem sequences. The comparative studies estimated the integrative quality of a serious heritage game from the user's perspective in learning and entertainment. The participant scores were compared using data from the three different platform studies and, additionally, the data from the six different subsystem sequences conducted in the online platform study. This evaluation asked which factors impacted, positively or negatively, on the learning outcome of serious heritage games, as well as how the factors made an impact. Participant entertainment levels were also compared within the above conditions and the evaluation asked how these factors impacted on the entertainment facet, which is as equally significant as learning to pursue a successful serious heritage game.

7.1 User interface space volume

The user interface space volume and learning outcome were positively correlated in practical parts; however negatively correlated in general heritage information transfer. In Part A, which indicates the general information of the Jing-Hang Grand Canal that was presented mainly via texts, images, videos and simple interactions, participants received considerably higher scores on the lab and online platforms compared to the museum platform. Nevertheless, in Part C, which is a practical subsystem with rich interactions and navigations implemented, the participants received higher scores on the museum platform than the other two platforms (Fig. 15).The sample standard deviation of the total mean scores was 4.89, 4.51 and 4.43 for the lab, museum and online platforms, respectively (Fig. 16). The standard deviations, although similar in magnitude, appear to be trending to a common value as the sample size increases. The largest standard deviation, 4.89, was realized for the lab

Fig. 15 Mean scores of the participants for the three platform studies



study of 15 users. Whereas, the smallest standard deviation, 4.43, was realized for the online study of 26 users.

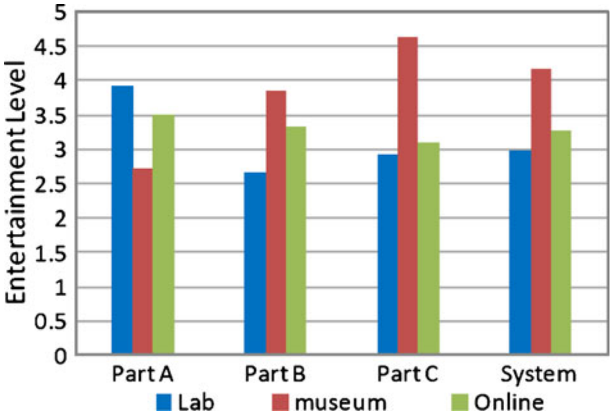
However, user interface space volume did not have a significant relationship with the learning outcome of the entire game system. In the lab platform study, of which the Jing-Hang Grand Canal Serious Heritage Game was implemented on a PC screen, participants received the highest mean total score. While in the museum platform study, of which participants experienced the large interface space volume, the mean total score was higher than the online platform study but lower than the lab platform study (Fig. 15). Based upon the mean scores of entire system, space volume does not crucially impact learning effect of the entire serious heritage game when the game was constructed from several subsystems with both general heritage information parts and practical interaction parts. Therefore, in order to obtain higher learning outcomes from the entire game system, the user interface space volume should be designed according to the content scale of general heritage information parts and practical interaction parts.

Increasing space volume was found to be significant for obtaining a higher entertainment level of the users for serious heritage games. Both from the participant

Fig. 16 The sample standard deviation of the total mean scores of the participants for the three platform studies

	Lab	Museum	Online
Min Score	78.7	77.9	71.9
Max Score	93.5	94.3	88.3
Mean Score	86.2	84.9	80.7
Standard Deviation	4.89	4.51	4.43

Fig. 17 Mean entertainment levels of the participants for the three platform studies



interviews and entertainment level data, the space volume was important to users' enjoyment (Fig. 17). "When I stand in front of the large display, I feel myself absorbed into the situation, feel like a visitor in landscape tour", one of the participants told in the museum platform study. "I didn't remember detail information as working in front of a computer, but I feel it interesting, I would like to try it again." Larger space volume improved more on the user entertainment level of the system yet less on the learning outcome. Therefore, when greater user entertainment is particularly required, enhancing the user interface space volume is highly recommended. If a serious heritage game aims to focus more on the user entertainment aspect, applying a larger user interface is encouraged to enhance game playfulness and users' entertainment level.

7.2 Subsystem sequence

The same quantities of participant scores were randomly selected, the total scores of four participants were selected for the data analysis for each subsystem sequence (24 participants). The scores of the extra two participants were not selected so as to maintain an equal number of subjects for each subsystem sequence evaluation (4 each). Different subsystem sequences resulted in different learning outcomes (Fig. 18). Participants received higher scores when each subsystem was arranged in ascending order by immersion degrees. In other words, participants posted higher scores within the system in which they were guided by gradual involvement.

Different arrangements of subsystem sequences also resulted in different entertainment levels (Fig. 19). The analysis indicated that the participants' score and entertainment level are positively correlated. When participants achieved greater enjoyment about the game, they received higher scores.

The results of the analysis emphasize several issues that may arise when arranging subsystem sequences in a serious heritage game system. First, according to the user preference, when they were not interested in the general impression of the game they will not even try to continue. Second, as the immersion degree increased, the controls and feedback needed to be appropriately correlated in a step-by-step manner so that users can successfully manage the main controls and feel confident to continue. Third, users needed a period of time to concentrate their attention into the game.

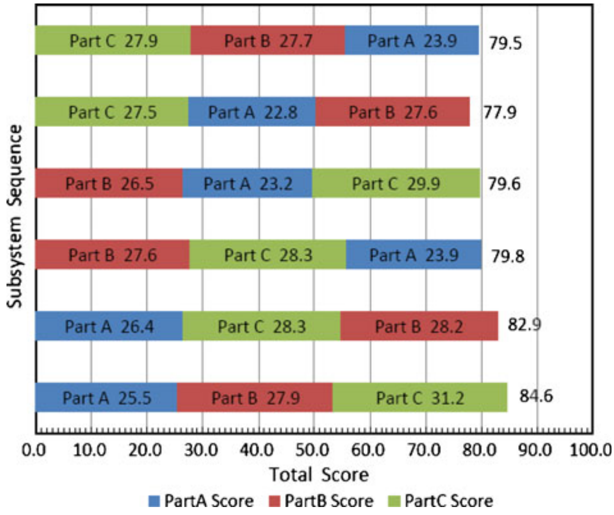


Fig. 18 Mean scores of the participants for the different subsystem sequences

The request of attention also became greater according to the immersion degree. After the users became acquainted with the game content, and succeeded to manage the controls, they felt more at ease and able to concentrate on the game and an increase in learning outcome was realized. Finally, the systematic design for serious heritage games needed to consider the game goals as well as the immersion degree sequence of subsystems. For a serious heritage game, which requires higher user performance, it was more important to present general heritage information in the first stage. The participants posted the lowest mean score for the subsystem sequence

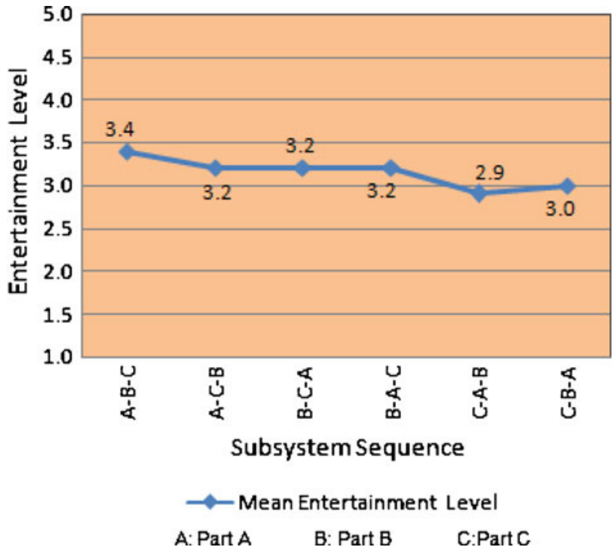


Fig. 19 Mean entertainment levels of the participants for the different subsystem sequences

C-A-B for which the immersion stages sequences were total immersion, engagement and engrossment (Fig. 18). One of the reasons was that the system was composed in a subsystem sequence of which Part A, the basic engagement stage, appeared after the highest immersive stage, which caused participants' unawareness of necessary involvement and information during their practical experiences.

Therefore, it was important to design the serious heritage game with a subsystem sequence that provided a step-by-step increase to the immersion degree level that encouraged users to manage the system well and increase their learning achievement. It was also important to provide users with basic and general information before immersing them into the game. The immersion sequence influenced users' understanding about each section (Fig. 18). When Part C, the section with the highest immersion degree, was given at the beginning of the system, participants found it difficult to become involved. One of the participants complained, "I didn't really see the point; I don't know how to manage the system." In order to reduce the difficulties to enter a stage of total immersion degree, participants needed to gradually invest time, information and attention.

However, entertainment level was also linked with factors other than the sequence of subsystems with different immersion degrees. One possible case was if the game content was well known to all, then users might not be pleased to wait for a long time to become more immersed, or they were impatient to wait until the ground stages were completed. In this case, it would be better to jump into a deeper immersive section than to hold the users back. Another possible case was since the entertainment level was a relative value, when users were asked to undertake the game in a specific lab environment, their anticipation for the experience was much higher than those in a common and easygoing situation. Thus while the action was undertaken at similar level, they achieved different entertainment levels. Models of human behavior that could drive attention changes could not be incorporated into this study and, therefore, entertainment level through feeling or experience could not be altered. This made it difficult to calculate marginal values and, thus, the analysis was constrained to arithmetical means based on total values, which may be misleading when applied to sequence arrangement decisions on serious heritage games. More research into this aspect of user entertainment evaluation is needed.

8 Conclusions and future work

Immersion is not just a way to interact, it has unique properties for determining how users work and think. A better understanding of the user immersion and how to manipulate a systematic design based on it could lead to better progress in serious heritage games. The more that a serious heritage game is based on systematic design strategies that "combine actional, symbolic, and sensory, the greater the user's suspension of disbelief that she or he is 'inside' a digitally enhanced setting" [17].

This study was focused on two design factors that impact on user immersion, and explored different avenues about how systematic design parameters could impact an effective implementation of a serious heritage game system. The result indicated that a large interface of user immersion is not a necessary requirement to achieve learning or entertainment under certain conditions. When collecting the user test data, not all of the information was fit for being transformed into a large immersive environment with plenty of practical interactions and navigations. Referring to the content of general heritage information such as liberal art or history (poems or other exact information), it is more acceptable to transfer the information in a direct and exact visual manner regardless of user interface space volume. For landscapes or other large scale constructions, such as changing the view point in a panorama or a virtual navigation, additional interactions and a larger user interface space volume are proposed. For complex engineering systems with advanced technological features and many user controls, a design with larger user interface and higher immersion degree is recommended to fully command the users' attention and provide a better practical experience.

Another exploration was how to appropriately arrange the sequence of subsystems which are with different immersion degrees in a serious heritage game. According to the study, the subsystem sequence had certain effects on some aspects of the user experience; moreover, an appropriate arrangement of subsystem sequences will successfully support a particular system outcome in both learning and entertainment respects. There is not a confirmed "good" sequence which fits for any system, but different choices for a better sequence according to the main motivation of the system implementation may be warranted. Therefore, it is important to make the expectations of a system clear as an initial step of systematic design. A limited factor analysis with the online platform study data was conducted in this work, which informed about the appropriate sequence of subsystems when the serious heritage game was implemented on a certain platform. However, due to the measurement difficulties in the mentioned issues that may arise and influence the serious heritage game, the sequence study demands further development.

Although user interface space volume and subsystem sequence can help to inform systematic design efforts for serious heritage games from the aspects of user immersion, it is not sufficient to motivate all of the system implementation. In the current analyses, only two impact factors provided by different platforms could be considered. Values associated with psychology, human behavior or social communication could not be quantified. The current evaluation for serious heritage games are, therefore, only a lower bound and might be significantly higher after more complete investigational data are provided by researchers in related areas.

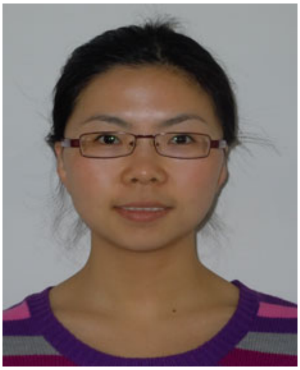
This study was carried out by implementing the Jing-Hang Grand Canal Serious Heritage Game on the three different platforms, however, further investigations need to be undertaken with multiple game systems and larger experimental sample population in order to verify these stated results are also can be utilized in various serious heritage game applications. Additional questions remain warranting future research. How are the subsystem sequence and integrated outcome of the serious heritage games correlated in a universal respect? How does personal information such as age and gender effect on the immersion preference in serious heritage games? Are there any specific design requests according to the age or gender differences? How does a collaborative environment affect user immersion and, furthermore, affect the integrated outcome of serious heritage games?

Acknowledgements The authors gratefully acknowledge the generous contributions to this project from the study participants, the Crystal Company in Shanghai and colleagues of the State Key Lab of CAD & CG.

References

1. Affleck J, Kvan T (2008) A virtual community as the context for discursive interpretation: a role in cultural heritage engagement. Int J Herit Stud 14(3):268–280
2. Anderson EF, McLoughlin L, Liarokapis F, Peters C, Petridis P, de Freitas S (2010) Developing serious games for cultural heritage: a state-of-the-art review. In: Virtual reality, pp 1–21
3. Apostolellis P, Daradoumis T (2010) Audience interactivity as leverage for effective learning in gaming environments for dome theaters. In: Sustaining TEL: from innovation to learning and practice, pp 451–456
4. Ary D, Jacobs LC, Razavieh A, Sorensen C (2009) Introduction to research in education. Wadsworth, Belmont
5. Bond TG, Fox CM (2003) Applying the Rasch model: fundamental measurement in the human sciences. J Educ Meas 40(2):185–187
6. Bonis B, Stamos J, Vosinakis S, Andreou I, Panayiotopoulos T (2009) A platform for virtual museums with personalized content. Multimedia Tools Appl 42(2):139–159
7. Boren T, Ramey J (2000) Thinking aloud: reconciling theory and practice. IEEE Trans Prof Commun 43(3):261–278
8. Bowen JP, Filippini-Fantoni S (2004) Personalization and the web from a museum perspective. In: Museums and the web, pp 63–78
9. Brewster SA (2005) The impact of haptic touching technology on cultural applications. In: Digital applications for cultural heritage institutions, pp 273–284
10. Brown E, Cairns P (2004) A grounded investigation of game immersion. In: CHI'04 extended abstracts on human factors in computing systems. ACM, New York, pp 1297–1300
11. Champion E (2003) Applying game design theory to virtual heritage environments. In: Proceedings of the 1st international conference on computer graphics and interactive techniques in Australasia and South East Asia. ACM, New York, pp 273–274
12. Champion E (2008) Otherness of place: game-based interaction and learning in virtual heritage projects. Int J Herit Stud 14(3):210–228
13. Champion E (2011) Evaluating virtual heritage. In: Playing with the past, pp 177–199
14. Champion E, Jacobson J (2008) Sharing the magic circle with spatially inclusive games. In: ACM SIGGRAPH ASIA 2008 educators programme. ACM, New York, p 9
15. Charles Olson's Melville project. Retrieved from http://charlesolson.uconn.edu/Works_in_the_Collection/Melville_Project/index.htm
16. Chen Q (2005) The Grand Canal—on the protection of canal culture. J Hangzhou Teach Coll 3:1–5
17. Dede C (2009) Immersive interfaces for engagement and learning. Science 323(5910): 66–69
18. Dede C, Salzman M, Loftin RB, Ash K (2000) The design of immersive virtual learning environments: fostering deep understandings of complex scientific knowledge. In: Innovations in science and mathematics education: advanced designs for technologies of learning, pp 361–413
19. Digital collections of the University of South Carolina Libraries. Retrieved from http://www.sc.edu/library/digital/
20. Filippini-Fantoni S (2003) Museums with a personal touch. In: EVA 2003 London conference proceedings, pp 1–10
21. Handron K, Jacobson J (2008) Dome displays for educational games and activities in the museum and on the road. In: Entertainment computing-ICEC 2008: 7th international conference, Pittsburgh, PA, USA, 25–27 September 2008: proceedings. Springer, New York, pp 217–220
22. Horry Y, Anjyo KI, Arai K (1997) Tour into the picture: using a spidery mesh interface to make animation from a single image. In: Proceedings of the 24th annual conference on computer graphics and interactive techniques. ACM Press/Addison-Wesley, New York/Reading, pp 225–232 (1997)
23. Jacobson J (2008) Ancient architecture in virtual reality: does immersion really aid learning. PhD thesis, School of Information Sciences, University of Pittsburgh, (2008)
24. Jacobson J (2010) Digital dome versus desktop computer in a learning game for religious architecture. In: Annual meeting of the American Educational Research Association (AERA), Denver, CO
25. Jacobson J, Lewis M (2005) Game engine virtual reality with CaveUT. Computer 38(4): 79–82
26. Jacobson J, Handron K, Holden L (2009) Narrative and content combine in a learning game for virtual heritage. Distance Educ 9(2):7–26

27. Jacobson J, Holden L, Studios F, Toronto CA (2005) The virtual egyptian temple. In: World conference on educational media, hypermedia & telecommunications (ED-MEDIA), Montreal, Canada, pp 4531–4536
28. Jacobson J, Kelley M, Ellis S, Seethaller L (2005) Immersive displays for education using CaveUT. In: World conference on educational multimedia, hypermedia and telecommunication. AACE, Montreal, pp 4525–4530
29. Jacobson J, Le Renard M, Lugrin JL, Cavazza M (2005) The CaveUT system: immersive entertainment based on a game engine. In: Proceedings of the 2005 ACM SIGCHI international conference on advances in computer entertainment technology. ACM, New York, pp 184–187
30. Just A, Rodriguez Y, Marcel S (2006) Hand posture classification and recognition using the modified census transform. In: Proceedings of the Seventh IEEE international conference on automatic face and gesture recognition (FG'06), University of Southampton, UK, pp 351–356
31. Liu X (2007) The research summary of the canal history of China. Jilin Water Res 9:42–45 (2007)
32. Magnenat-Thalmann N, Kasap Z, Moussa MB (2008) Communicating with a virtual human or a skin-based robot head. In: ACM SIGGRAPH ASIA 2008 courses. ACM, New York, pp 1–7
33. Patrick E, Cosgrove D, Slavkovic A, Rode JA, Verratti T, Chiselko G (2000) Using a large projection screen as an alternative to head-mounted displays for virtual environments. In: Proceedings of the SIGCHI conference on human factors in computing systems. ACM, New York, pp 478–485
34. Pan Z, Liu G, Li Z (2007) Virtual presentation and animation of Qingming Festival by the riverside. In: Proceeding DMAMH '07 proceedings of the second workshop on digital media and its application in museum & heritage. IEEE Computer Society, Washington, DC, USA, pp 102–105
35. Pan Z, Li Y, Zhang M, Sun C, Guo K, Tang X, Zhou SZ (2010) A real-time multi-cue hand tracking algorithm based on computer vision. In: Virtual reality conference (VR), 2010 IEEE. IEEE, Piscataway, pp 219–222
36. Stanney KM (2002) Handbook of virtual environments. Lawrence Erlbaum, Hove
37. Swing E (2000) Adding immersion to collaborative tools. In: Proceedings of the fifth symposium on virtual reality modeling language (Web3D-VRML). ACM, New York, pp 63–68 (2000)
38. Tallyn E, Koleva B, Logan B, Fielding D, Benford S, Gelmini G, Madden N (2005) Embodied reporting agents as an approach to creating narratives from live virtual worlds. In: Virtual storytelling, pp 179–188
39. Weng C, Li Y, Zhang M, Guo K, Tang X, Pan Z (2010) Robust hand posture recognition integrating multi-cue hand tracking. In: Proceedings of the entertainment for education, and 5th international conference on E-learning and games. Springer, New York, pp 497–508 (2010)
40. Zhang M, Xiang N, Wang K, Pan Z, Yuan H, Liu H (2010) Avatar-based intelligent navigation for online Shanghai expo. Int J Virtual Real 9(3):39–45



Shengnan Chen is currently a lecturer in Zhejiang Textile & Fashion College, and working as a Ph.D. candidate in the State Key Lab of CAD & CG, Zhejiang University, Hangzhou, China, under the supervision of Prof. Zhigeng Pan. She received her bachelor's degree in industrial design from Dalian Nationalities University in 2003, and master's degree in art and design from Zhejiang Science and Technology University in 2006. Her research interests include user interface design, virtual museum and multimedia applications in cultural heritage learning.

Zhigeng Pan received his bachelor and master degrees from the Computer Science Department in 1987 and 1990 from Nanjing University, and Ph.D. in 1993 from Zhejiang University, Hangzhou, China. Since 1993, he has been working at the State Key Lab of CAD & CG, Zhejiang University, and served as an associate professor and professor in 1994 and 1996, respectively. He has published more than 100 papers on international journals, national journals and international conferences. His research interests include distributed graphics, virtual reality, multimedia, digital entertainment. He is a member of SIGGRAPH, Eurographics, IEEE, a senior member of the China Image and Graphics Association. He is on the director board of the International Society of VSMM (Virtual System and Multimedia), a member of IFIP Technical Committee on Entertainment Computing (acting as representative from China). Currently, he is the editor-in-chief of The International Journal of Virtual Reality, Co-EiC of LNCS Transactions on Edutainment. He is on the editorial board of International Journal of Image and Graphics, International Journal of CAD/CAM, Journal of Image and Graphics, Journal of CAD/CG, et al. He is the director of the Virtual Reality Committee, China Society of Image and Graphics; he is on the Steering Committee member of VRCAI series conference. He is the organizing committee chair of VRAI'2002, ICIG'2004. He is the program co-chair of EGMM'2004 (Eurographics workshop on Multimedia), the program co-chair of Edutainment'2006, conference co-chair of ICAT'2006 and Edutainment'2008.

Mingmin Zhang is an associate professor of Computer and Engineering Department, Zhejiang University. She got her bachelor degree from Computer Science Department, Nanjing University, and the master and PhD degrees from Computer Science and Engineering Department, Zhejiang University. She has published more than 40 papers on international journals, national journals, and conferences in recent years. She is the co-author of two books related to computer graphics and multimedia. Her research interests include virtual reality & virtual environment, multi-resolution modeling, real-time rendering, distributed VR, Visualization, Multimedia and Image processing.

Huaqing Shen got his bachelor degree in physics from Hangzhou University in 1990, and master degree from The Chinese Academy of Sciences. From 1993 to 2004, he has managed an advertising production agency, and has rich experiences in computer graphic software and advertising planning skills. From 2004 until now, he has been working as an associate professor in School of Arts, Zhejiang University. The works directed by him was nominated as final-selected works in 2004 Annecy Animation Festival, France. He was awarded Gold Panda Prize in 2005 Sichun Television Festival, China. His research interests include digital arts, CG animation, design, multimedia and digital entertainment.