Flexible Learning Itinerary vs. Linear Learning Itinerary

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Abstract

The latest video game and entertainment technology and other technologies are facilitating the development of new and powerful e-Learning systems. In this paper, we present a computer-based game for learning about five historical ages. The objective of the game is to reinforce the events that mark the transition from one historical age to another and the order of the historical ages. Our game incorporates natural human-computer interaction based on video game technology, Frontal Projection, and personalized learning. For personalized learning, a Flexible Learning Itinerary has been included, where the children can decide how to direct the flow of their own learning process. For comparison, a Linear Learning Itinerary has also been included, where the children follow a determined learning flow. A study to compare the two different learning itineraries was carried out. Twenty nine children from 8 to 9 years old participated in the study. The analysis of the pre-tests and the post-tests determined that children learned the contents of a game about historical ages. The results show that there were no statistically significant differences between the two learning itineraries. Therefore, our study reveals the potential of computer-based learning games as a tool in the learning process for both flexible and linear itineraries.

Keywords Computer-based learning, Flexible Learning Itinerary, Natural User Interfaces, Frontal Projection, Kinect

1. INTRODUCTION

There is no single definition for e-Learning. Selim [1] defined e-Learning as the use of modern information and communications technology and computers to deliver instruction, information, and learning content. Arbaugh [2] defined e-Learning as the use of the Internet by users to learn specific content. For Stockley [3], e-Learning involves the use of a computer or electronic device (e.g. a mobile phone) in some way to provide educational training, or learning material. e-Learning is not only about training and instruction, it is also about learning that is customized to individual needs and should be flexible and interactive. e-Learning systems cover a large variety of technology-based applications such as computer-based learning, virtual classrooms, digital collaboration, or web-based learning. A definition that is closely related to these ideas is personalized learning, which includes personalized material, personalized objectives, and personalized processes [4]. Flexible learning itineraries are also related to this personalization. A learning itinerary guides how students learn the content. Therefore, it implies a way to organize the learning sequence. It responds to the need of guiding students through the content, processes, and activities. With respect to the organization of the learning sequence, the elaboration theory [5] justifies the importance of sequencing content and teaching-learning activities in two fundamental analyses: the first is the representation of the organizing content, and, the second, the different development levels for structuring the learning sequence [6]. From this definition of learning itinerary, a first classification based on the freedom provided to the users leads to two different itineraries: Linear Learning Itineraries (LLI) and Flexible Learning Itineraries (FLI). LLI are normally guided itineraries where the path is determined completely by the system. These types of itineraries can be seen as a collection of small pieces of information that are sequentially interconnected with each other as shown in Figure 1a. On the other hand, FLI offers users the chance to choose what the next step is in their learning

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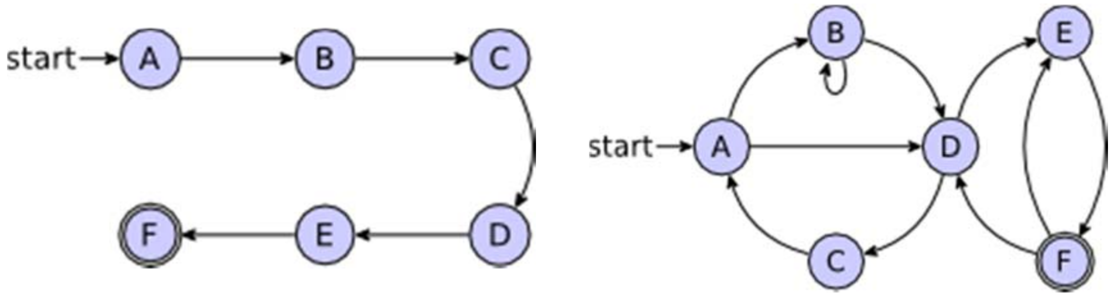
process by changing the path, which is determined completely by the user. These itineraries may have different degrees of freedom depending on how they are designed. They can be viewed as a collection of small information units that are interconnected as a directed graph, which is shown in Figure 1b.



a) Linear learning itinerary b) Flexible learning itinerary

Figure 1: Different learning itineraries

Nowadays, the ability to provide more and better content and the use of the latest video game and entertainment technology suggest new challenges in the development of e-Learning systems. In this paper, we present a novel computer-based game for learning about five historical ages that incorporates natural human-computer interaction based on video game technology. The objective of the game is to reinforce the events that mark the transition from one historical age to another and the order of the historical ages. The contents are integrated in two different versions, one that uses a LLI and another that uses a FLI. These versions include the possibility to continue the learning in different sessions (different hours and days). A study to evaluate the two versions was conducted. The questionnaires used in this study were web-based. The main objective of this study was to find out which of the two learning itineraries provides greater learning improvement. Our hypothesis is that the children will acquire more knowledge while playing with the Flexible Learning Itinerary. Some of the reasons that support our hypothesis are the following:

- When playing with FLI, the children can choose the next historical age they want to learn.
- Each child decides the itinerary that he/she wishes to follow.
- The children can repeat the historical ages as many times as they want. If they do not want to learn about a historical age, they can choose to ignore it.

The rest of the paper is structured as follows. Section 2 mentions previous related research. Section 3 presents the developments involved in the work, and Section 4 describes the study carried out. Section 5 analyzes the results. Section 6 presents some discussion, and, finally, section 7 presents our conclusions.

2. BACKGROUND

2.1. Learning itineraries

The contents of e-Learning games are commonly developed using game technology and design principles whose primary purpose is to educate while entertaining the user. The use of game technology for learning purposes has been widely used, and its suitability for education has been supported by several previous works. For example, Virvou et al. [7] evaluated an Intelligent Tutoring system as a virtual reality educational game, demonstrating that games of this kind can be very motivating while improving the learning effects on students; Mumtaz [8] studied the nature and experiences of children's computer use at home and school, where she found out that 77% of them used computers every day for playing video games; Ebner and Holzinger [9] designed an online game for higher education that is related to the Theory of Structures in Civil Engineering. A playful approach achieves software that is more motivating and engaging. Moreover, the level of interactivity of the materials is attached to the guidelines set out in the design phase. These guidelines will determine the learning itineraries. As mentioned in the introduction section, two types of learning itineraries have been defined: LLI and FLI. LLI are commonly used in educational environments or for educational purposes and represent the traditional approach for learning itineraries. The alternative to this traditional choice are FLI, which have both advantages and disadvantages when compared to LLI. An important advantage of FLI is that it allows students to adapt the itinerary to their own profile. Thus, several studies have focused on interpersonal differences [10] and field dependence [11]. Pask [12] pointed out the individual capacity to switch from one strategy to another in order to adapt the prevailing conditions. Also, FLI have a greater capacity to adjust to users by being able to adapt the itinerary to the individual features and preferences of the student. The main disadvantage of FLI is that students may follow an incomplete or even incorrect itinerary. This can be on their own initiative, by mistake, or disorientation. Therefore, an appropriate design of the itinerary is particularly important in order to prevent these problems.

Previous experiences by researchers have focused on the benefits of integrating technology to give greater freedom to students in the learning process. Some initial experiments of applying technology to provide students with freedom in their learning itineraries include the use of hypermedia. Hypermedia is an extension of hypertext, which integrates multimedia elements to create a set of information items that are usually not offered linearly. As Grabinger [13] affirmed, the major benefit of the hypermedia approach in learning environments may be that learners are invited to express their ideas and prior concepts and externalize them with hypermedia tools. Leclercq and colleagues carried out experiments that are related to hypermedia in the learning field [14] [15]. Leclercq and Pierret [14] developed software based on hypermedia to respect both interpersonal and intrapersonal variation in learning strategies. Leclercq and Gilles [15] also reviewed how hypermedia can enhance educational assessment. They concluded that these strategies of flexible learning increase the autonomy of the learners, which in turn increases their metacognitive activity. Adaptive hypermedia [16] adds new possibilities to the development of interactive learning systems. Adaptive hypermedia systems create a model with the features of each individual user (knowledge, preferences, …) in order to adapt the system to the needs of each learner. Adaptive hypermedia and the introduction of the web have promoted the development of educational hypermedia systems such as ELM-ART [17], 2L670 [18] and InterBook [19]. These systems have been used in several experimental studies: for WWW-based tutoring systems [20]; for designing hypermedia architectures consisting of Java servlets [21]; or for creating tools for development adaptive courseware [22]. These studies confirm the suitability of these learning strategies.

2.2. Interactive tables

Our system incorporates multiple user interaction that is similar to interactive tables. The system integrates frontal projection with Microsoft Kinect to achieve this multiple user interaction. Other authors use similar visualization and/or interaction systems, but they combine different technologies. In 2001, Dietz et al. [23] presented DiamondTouch, which integrates a multi-user touch technology. This technology detects multiple and simultaneous touches and also indentifies which user is touching each point. The system works by transmitting signals that are capacitively coupled through the users and chairs, allowing user identification at each touch. DiamondTouch has been used in several studies [24] [25] [26]. In 2006, Jordà et al. [27] presented the reacTable at the SIGGRAPH conference. The reacTable is a tabletop tangible user interface that was developed to be used as an electronic multi-user musical instrument. It is based on a translucent round table that has a camera placed beneath it that analyzes the table's surface, tracking the position, orientation and type of objects on the surface. In 2010, Weiss et al. [28] presented an interactive tabletop that allows interaction with complex physical controls. These authors use electromagnetic actuation techniques beneath the table to carry out the interaction. One of the drawbacks is the limited size of the display (24"), which limits the multi-user approach. Recently, in 2013, Kubicki et al. [29] developed an interactive table (TangiSense) that is designed for interaction with several people in a simultaneous and collaborative way. They also integrated tangible objects that can be identified in the context thanks to RFID technology.

Several contributions have demonstrated the potential of interactive tables: they promote playfulness [30] [31], increase awareness [32], and are enjoyable to use [33]. In the education field, these tables are especially suitable for learning purposes; for example, Numbernet, developed by Hatch et al.'s, an application in which a group of children use multi-touch technology to learn mathematics [34]. Digital Mysteries, created by Kharrufa et al., which is a collaborative learning application for school children [35]. Piper and Hollan compared the affordances of presenting educational material on a tabletop display and presenting the same material using traditional paper [36]. Falcão and Price studied collaborative activity on a tangible tabletop to learn about the physics of light [37]. Finally, we would like to highlight that some authors have already pointed out that one of the most promising uses of these interfaces is to assist learning through exploration [38].

2.3. Serious games

Since playing games has been demonstrated to be highly related to learning, several models have been developed to identify the learning outcomes that can be achieved by playing digital games [39]. As Garris et al. [40] stated, the user gets hooked on cognitive processes that are triggered that have been proven to be beneficial for learning. Besides, games are extensively accepted by new generations of users. This generation is commonly referred to as the "gamer generation" [41], "digital natives" [42], or the "net generation" [43]. Another important item is that the effectiveness of game-based learning greatly depends on the acceptance by classroom teachers [44]. Girard et al. [45] reviewed the results of experimental studies that were designed to examine the effectiveness of serious games on the learning and engagement of players. They concluded that serious games might be powerful tools for learning; however, there are very few empirical studies that investigate the effectiveness of serious games in learning. One of the goals of this work is to reduce the dearth of studies in this area. Nevertheless, some previous works can be cited such as the work of Papastergiou [46], where she developed and used two similar applications (a gaming one, and a non-gaming one) in order to compare them. The two applications were designed with the goal of introducing students to basic computer memory concepts. Her results showed that the students that had used the gaming application performed significantly better than those that had used the non-gaming one. Beale et al. [47] used a game to learn about cancer, and they found better performance in the group that played the game when compared with a control group that did not play the game. Mayer et al. [48] presented the design and evaluation of a gaming-scenario experiment for the exploration of development planning in an urban network. The results showed that the gaming-scenario approach generated new and critical insights in development planning. Guillén-Nieto and Aleson-Carbonell [49] developed a serious game to teach intercultural business communication between Spaniards and Britons. This study showed that there were statistically significant differences between the pre- and post- knowledge tests. This means that, as a result of playing the communication game, the students improved their intercultural learning; Facer et al. [50] reported a study to explore how using mobile technologies can create a powerful and engaging learning experience. They stated that gamers are expert when they control their own learning alongside more knowledgeable peers, and children as gamers are more likely to learn effectively by acting as mentors to novice learners. Furió et al. [51] combined mobile technology with augmented reality by developing a game where children could learn about multiculturalism, tolerance, and solidarity by transmitting knowledge about three of the world's poorest continents (Africa, Asia, and Central and South America). They carried out a study to determine whether the mobile game had better learning outcomes than a traditional game. They concluded that for learning outcomes, the results did not show significant differences between the two methods. Furió et al. [52] also developed another augmented reality mobile game where the children could learn about the water cycle, water composition, and water pollution in a way similar to the way they studied them in school. They compared the same game on two different devices, an iPhone and a Tablet PC. From the results, they observed that the different characteristics (screen size and weight) of the devices did not influence the children's acquired knowledge, engagement, satisfaction, ease of use, or AR experience. Suh et al. [53] investigated the effectiveness of MMORPG-based instruction in elementary English education. Their findings suggest that games of this kind may be useful for improving the English abilities of students who study English as a second language. The students who used the game showed higher scores in listening, writing, and reading than those who learned with face-to-face instruction.

3. MATERIALS AND METHODS

To simulate a tactile screen, it was necessary to develop some custom hardware and software. This section describes the custom hardware and software that were used.

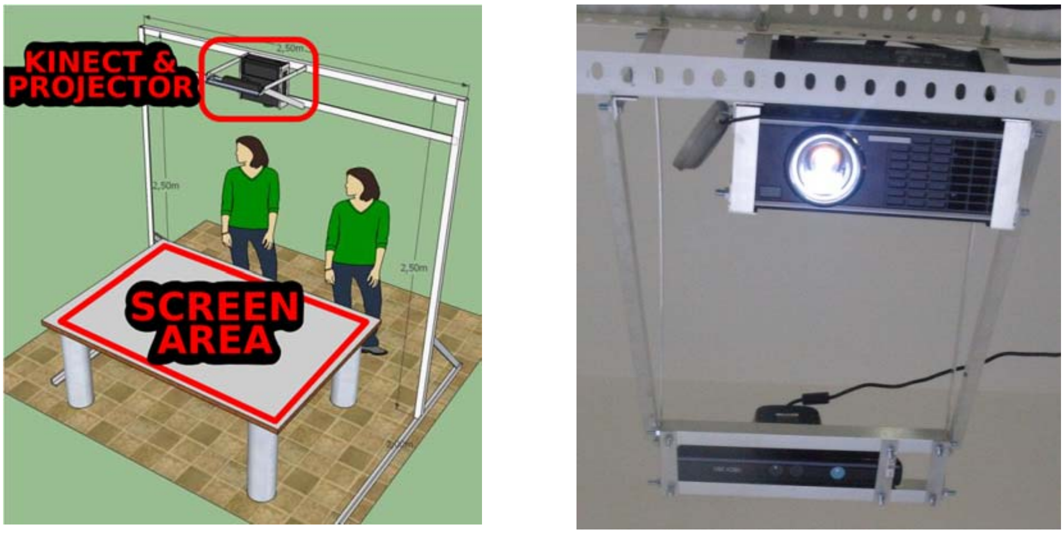
3.1. Hardware

The game was run on an HP Pavillion PC, with an Intel® Core™ i7-2600 CPU @ 3.40GHz working with a NVIDIA GeForce GT 545 graphic chipset. To simulate that tactile screen, a sort throw projector and a white table were required. The projector was an InFocus IN1503. This model can produce a brightness of

3000 ANSI lumens using a resolution of 1280×800 pixels. In addition, this projector can generate an image of 177×111cm at a throw distance of 140cm.

The screen area was a normal table, which was covered with a piece of cardboard. Its size and its color were optimal for projection. To achieve the user interaction, the Microsoft Kinect device was used. It was located next to the projector to capture the projected area where the game would be carried out. The Kinect device had to capture the entire size of the screen, or at least the cardboard area. For this task, the Kinect had to be located above the table (Figure 2). Therefore, the steel support shown in Figure 2 was built taking the following aspects into account:

- The field of view of the Kinect cameras and the field of view of the projector were different. To resolve this issue, the Kinect device was located a little bit higher than the projector in order to be able to capture the entire area.
- Since the projector device might occlude a part of the captured image if the Kinect device was too close to it, we moved the Kinect device a few centimeters.



a) Configuration schema

b) Detail of the aluminum support, seen from the children’s position.

Figure 2: Structure built

3.2. Software

The game was implemented by integrating several libraries and technologies, as shown in Figure 3. The level structure and the state machine that defined the main behavior of the game were written entirely in C# using the XNA framework. This framework provided useful functions for our game. Several of these functions were able to manage audio and video, playing sounds and displaying images. The scene graph provided by GoblinXNA library was used to display the 3D scene and the different models of the different historical ages. This library simplified the game architecture and reduced the time needed for coding the application.

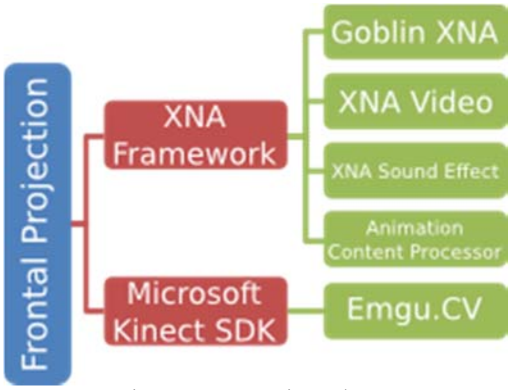


Figure 3: Integration schema

To retrieve the information from the Kinect sensors, the Microsoft Kinect SDK for Windows was used. Images from both cameras (color and depth) could be retrieved from the Kinect using the functions of this SDK. The information about players and their position (skeleton joints) could also be retrieved. Nevertheless, in our architecture, since the Kinect device was pointed at the floor capturing the hands of the children and this feature only works properly if the entire body of the user is shown, the skeleton tracking feature was disabled. It was necessary to include the graphics manipulation library Emgu.CV to track the hands of the children. This library allows the images captured by the Kinect device to be processed in an efficient way and extracts the relevant information from them. To track the position of the hands, a process was needed to create a drag and drop level. To calculate this information, the following procedure was followed:

1. A threshold for the current depth image was calculated.
2. The image was then eroded. This allowed the white pixels corresponding to noise on the capture to be removed.
3. The system searched for blobs on the image.
4. If a blob collided with the screen border, it was considered to be a valid hand candidate.
5. We assumed that the furthest point on the screen border where the blob collided was the end of the fingertips of the hand.
6. If there were hand candidates that were very close to each other, we assumed that all of these points belong to the same hand. If there were more hand candidates at a further distance from each other, we assumed that they were different hands.

Once the depth image and the hand positions were calculated, the equivalences between the cameras and the screen area had to be calculated. This allowed us to determine if a real object or a hand was over another object displayed on the screen area. These equivalences depended on the relative positions of the cardboard, the projector and the Kinect. Therefore, a Calibration Utility was developed using the same tools mentioned above. This tool allowed the user to manually select the rectangle areas of each image (screen and camera captures) that corresponded to the cardboard. The rectangles obtained were serialized in an XML file that was loaded into the game application. To make the system less sensitive to changes, the distances defined on the application must be relative to the screen surface and not relative to the Kinect sensor. To do this, the application captured the first fifteen frames of one execution and calculated a depth image as the mean for each pixel. This image was subtracted from each frame captured after this initialization process. The result is a black image where grey shadows are objects over the table.

3.3. Game design

Several design theories and guidelines such as the Constructivism learning theory [54] have been considered for the design of our game. As a computer-supported group-based learning system, we also designed the game taking into account the approach proposed by Strijbos et al. [55]. The design guidelines for collaborative classroom games proposed by Villalta et al. [56] were also taken into account.

However, the DPE framework [57] had a great influence on our design. In this paper, we focus on this framework and how it influenced our design.

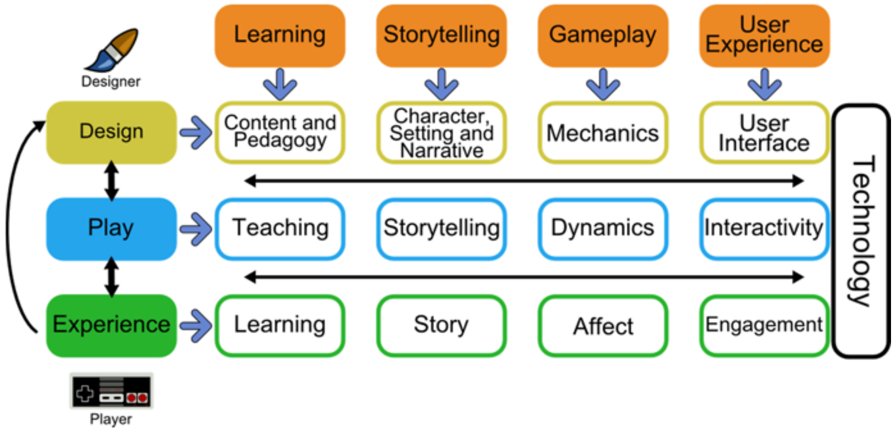


Figure 4: Expanded DPE Framework

The DPE framework (Figure 4) was created as an extension of the MDA framework [58] to address the needs of serious games design for learning. The MDA framework focuses on the design of games for entertainment. Both frameworks take into account the relationship between the designer and the player. The DPE framework layers are the following:

- The learning layer. Our design defines the content, the pedagogy and a set of learning outcomes, i.e., the knowledge that is transmitted by playing the game. The main purpose of the game was to help and motivate children to learn about the main historical periods of the time line. The contents of the game were based on the textbooks that children use in the classroom, which are determined by the primary education law of Spain. The periods of history used in this game were: Prehistory, Ancient Times, the Middle Ages, the Early Modern Period, and the Contemporary Period.
- The storytelling layer. It creates a story to transmit content. In our history game, there is one character, the avatar guide, which guides the children during the game. With his narrative, the avatar transports the children to other historical ages so that they can think and act as if they were there (e.g., painting in a Prehistoric cave).
- The gameplay layer. It defines what the player does in the game. The gameplay layer is composed of mechanics, dynamics, and affects. The mechanics are the rules that define the functionality of the game, what the player can do, and the player's challenges and goals. The dynamics are the resulting behavior when the rules are instantiated over time with the player's interactions. The affects are the resulting experiences or emotions that are induced in the player. As Hunicke et al. [58] indicated, the gameplay layer most closely resembles the original MDA framework, but with a change in terminology (specially, the change of aesthetics by affect). At first (from a player's perspective), the game can be considered as fun or not fun. However, several researchers have tried to identify the specific aspects that create a fun experience. For example, Hunicke et al. [58] identified eight kinds of fun as aesthetic goals. Heeter et al. [59] proposed sixteen forms of fun that include the following: beauty, immersion, intellectual problem-solving, competition, social interaction, comedy, thrill of danger, physical activity, love, creation, power, discovery, advancement and completion, application of an ability, altruism, and learning. Of the goals on Heeter et al.'s list, we consider that our game contemplates the following nine aesthetic goals: beauty, immersion, competition, social interaction, physical activity, creation, discovery, advancement and completion, and learning. With regard to the rules, there are two types of interaction depending on the mini-game that the children were playing: Press button and Drag & drop. In the first type of interaction (Press button), the possible answers to a question are on the table as buttons and the children have to choose the right one (Figure 5). The children have to consecutively select the correct answers to the questions that the avatar asks. When the children have answered all the questions correctly, the game continues to the next mini-game. When the children select an incorrect choice, the button turns from yellow to red; if they select the correct answer, the button turns from yellow to green. In the second type of interaction (Drag & drop), there are several drop areas on the table and their corresponding images. Using their hands, the children have to drag the images that are projected on the table and drop them into their drop area. Each element that the children can interact with is placed near the bottom of the table so that the

children can easily reach the buttons or the draggable images. Figure 6 shows the placement of these elements. Once all of the mini-games of a historical age are done, the game presents the next historical age and its first mini-game. As the game advances through all of the historical ages, a time line that is placed in the upper part of the screen indicates the current historical age that the children are in (see the top of Figure 6 where the current historical age is Ancient Times). According to the theory of flow of Csíkszentmihályi [60], in order to achieve a state of flow, the level of challenge must match the players' abilities as their skills increase. If the challenge is too ambitious, the player could become frustrated and might give up. If the challenge is too small, the player could quickly become bored and might quit playing. In our game we achieve this balance by establishing the most appropriate age range. Another form of gameplay balancing from the theory of flow is related to the frequency of rewards given to the player. In our game, we have incorporated this gameplay balancing by showing the historical ages that the children have successfully passed in the time line.

- The user experience layer. The user interface represents the mode of communication between the player and the game. As Hunicke et al. [58] indicated, the ultimate goal of the designer is to develop a game that immerses the players in the game world and engages them in the play experience. Good user interfaces should be transparent, in other words, the players should not have to focus their attention on how to play the game but rather focus on the gameplay, the storytelling, and the learning experience. This was one of our main goals in designing the game. In our game, the player does not have to wear extraneous devices such as headgear or special glasses and the interaction is achieved using natural gestures (the player only has to touch the table). Therefore, in our game, the players' attention is on the gameplay and the learning experience. In order to ensure that the children listen to the entire audio and video explanations, the interaction is disabled during the explanation so that the children cannot select elements or drag objects.

3.4. Description of the game

Two modes were defined for the game. In the first mode, the children could choose the order of the historical ages; they could repeat the historical ages twice or they could even omit some of them (Flexible Learning Itinerary). In the second mode, the children played the game in the real chronological order, from Prehistory to the Contemporary Period (Linear Learning Itinerary). The flowchart of the mini-games that made up the LLI is shown in Figure 7. The steps of the LLI were the following:

1) The children heard the voice of an avatar introducing them to the game. This avatar guided them throughout the game.
2) The children had to select the first historical age from the time line, Prehistory. To choose it, the children had to cover the button with one hand in the position shown in Figure 5. After a video explanation of Prehistory, they played two mini-games from this time period; the first consisted of finding some cave paintings and using the colours that the cavemen used for that purpose. In the second mini-game, the children had to select a colour and leave an imprint of the shape of their hand in the cave.
3) The children had to select the next historical age the same way as before; this time, it was for Ancient Times. In this mini-game, the children had to reconstruct a Roman city by placing an amphitheatre, an aqueduct, a Roman circus, and a Roman road in it. Afterwards, the avatar asked them some questions about the use of the buildings they had just used to construct the Roman city.
4) The children had to select the next historical age (the Middle Ages). Here, the children had to build a medieval castle by correctly answering the questions the avatar asked. By choosing the correct answer, one more piece of the castle was added to the structure. At the end, the whole castle was visible and the children could go on to the next historical age.
5) The children had to select the next historical age (the Early Modern Period), where they had to find the objects that Christopher Columbus used in his journeys to discover the American continent. This task was completed by finding a compass, a map, and an astrolabe.
6) The children reached the final historical age (and last stage) of the game, the Contemporary Period. Instead of a mini-game, there was a video explanation that provided the explanation for this period.
7) The children had to complete a puzzle that recreated the time line by simply moving their hands. Once this puzzle was complete, the avatar told them that they had reached the end of the game.

Figure 5: Two children playing with the Prehistory mini-game

Figure 6: Ancient Times mini-game

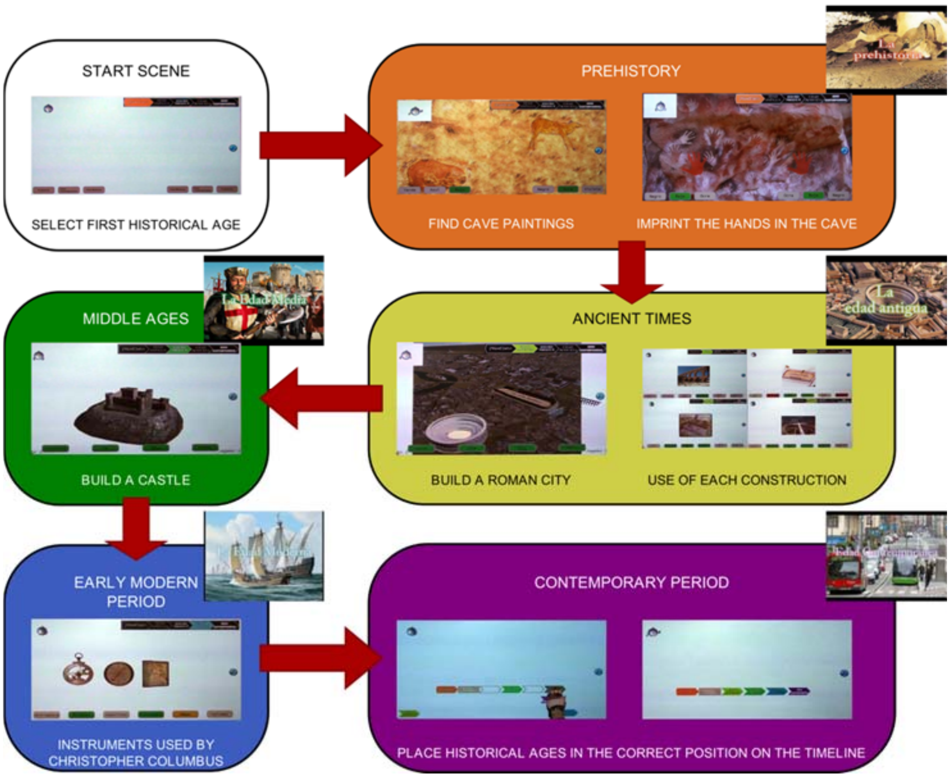


Figure 7: Flowchart of the mini-games that are integrated into the game of history

4. DESCRIPTION OF THE STUDY

This section presents the characteristics of the children that played the game, the measurements that were used during the experiment, and the steps that were followed.

4.1. Participants

We had a total of 29 children playing the game. There were 19 boys (65.52%) and 10 girls (34.48%). They were between eight and nine years old and they had already finished the third grade of primary education. The mean age was 8.62 ± 0.49 years old. The children were attending three different summer schools in Valencia, Spain.

4.2. Measurements

Two questionnaires in a web-based form were designed and used to determine the knowledge that the children acquired during the game (Table 9) as well as their satisfaction and level of interaction (Table

10). The knowledge questionnaire consisted of thirteen questions about the contents that the children learn while playing with the game. By comparing the answers given in the pretest by the children in the pretest with the answers given in the post-test (which had the same thirteen questions), we were able to determine whether or not there had been an increase in knowledge. The satisfaction and interaction questionnaire consisted of eleven questions. The questionnaires were filled out individually for both playing modes (LLI and FLI).

4.3. Procedure

The games were played in pairs of one boy and one girl, two boys or two girls. The participants were assigned to one of the following two groups:

- Group A: Participants that played a linear learning itinerary, where the flow of the game was guided by the game itself.
- Group B: Participants that played a flexible learning itinerary, where the children chose the historical period they wanted to play next.

Figure 8 shows the procedure of the two groups graphically. The protocol used is given as follows:

1. A pair of children from Group A or a pair of children from Group B filled out the pre-test questionnaire (PreLinear for Group A and PreFlexible for Group B).
2. These children played the game.
3. They filled out the post-test questionnaire on-line (PosLinear for Group A and PosFlexible for Group B).

Since the questionnaires were filled out on-line, the answers were automatically stored in a remote database.

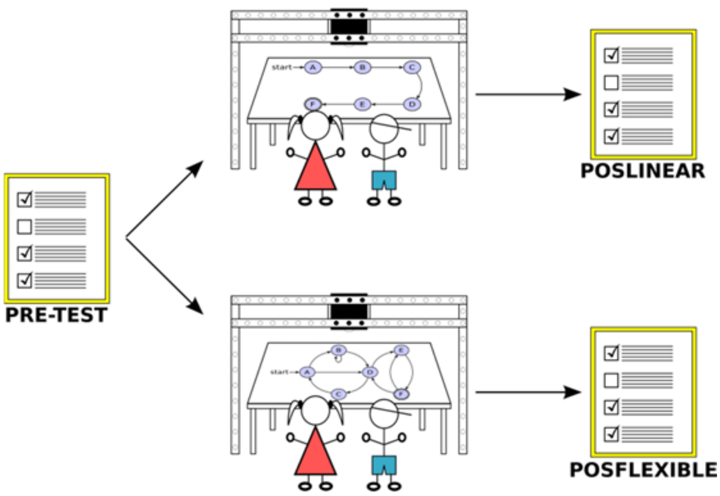


Figure 8: Study procedure

5. RESULTS

All the data retrieved in the questionnaires were analyzed with the statistical open source toolkit *R*.

5.1. Learning outcomes

To measure how much the children learned, the *knowledge* variable was analyzed. This was done by analyzing the answers to questions Q1 to Q13 in Table 9 before playing (Pre-test) and after playing (Post-test). Several *t*-tests were performed to determine if there were statistically significant differences in the knowledge acquired. Figure 9 shows the box plot for the scores before and after playing. A high predominance of correct answers after playing the first game (PosLinear and PosFlexible) over the pre-test (PreLinear and PreFlexible) can be observed.

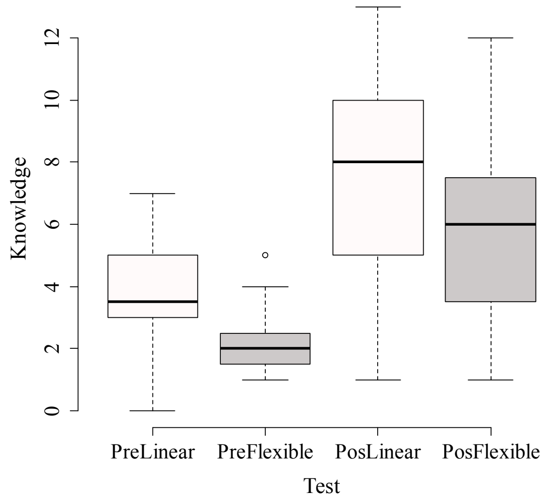


Figure 9: Scores of the knowledge variable in questionnaires before and after playing with the linear or flexible itineraries

All *t*-tests are shown in the format: *(statistic [degrees of freedom], p-value, Cohen's d)*, and ** indicates some statistical significance at level α=0.05. First, to determine if there was a statistically significant difference between the initial knowledge in both pre-tests, an unpaired *t*-test was performed between PreLinear (3.61 ± 1.89) and PreFlexible (2.27 ± 1.21) ($t[27] = 2.03$, $p = 0.053$, Cohen's $d = 0.78$). No statistically significant differences were found. From a paired *t*-test, the scores of the knowledge variable between PreLinear (3.61 ± 1.89) and PosLinear (7.44 ± 3.22) showed statistically significant differences ($t[17] = -6.21$, $p < 0.001$**, Cohen's $d = -1.46$). Another paired *t*-test between the PreFlexible (2.27 ± 1.21) and the PosFlexible (6.18 ± 3.46) questionnaires revealed statistically significant differences ($t[10] = -3.67$, $p = 0.004$**, Cohen's $d = -1.11$). Finally, in order to determine whether or not there was a statistically significant difference between the acquired knowledge in the two groups, another unpaired *t*-test was performed between the knowledge in PosLinear (7.44 ± 3.22) and the knowledge in PosFlexible (6.18 ± 3.46) ($t[27] = 0.96$, $p = 0.345$, Cohen's $d = 0.37$). This showed that the knowledge retrieved while playing the linear mode was not significantly greater than the knowledge acquired while playing the flexible mode. To complete the analysis and to determine the questions that had statistically significant differences, several *t*-tests were performed for each question between PreLinear – PosLinear (Table 1), PreFlexible – PosFlexible (Table 2), and PosLinear – PosFlexible (Table 3). Table 1 shows that children who played the linear mode acquired significantly more knowledge in questions Q1, Q3, Q5, Q6, Q7, Q11, Q12, and Q13. This can be compared with the results in Table 2 provided by children who played the flexible mode. In this case, questions Q1, Q3, Q5, Q7, and Q12 were the ones with significant differences. Table 3 shows that none of the questions had statistically significant differences when the two modes were compared.

A multifactorial ANOVA test was also performed to take into account several factors simultaneously. The factors of gender, age, and game mode (linear or flexible) were between subjects. The effect size used was the partial Eta-squared (η^2). This analysis is shown in Table 4, where the results show that there were statistically significant differences in the interactions of the gender and age factors, and the interaction of the mode and age factors, with p-values less than 0.07. The effect sizes revealed that the most influential factor was the gender and age interaction with a very large effect size, followed by the mode and age interaction which had a medium effect size.

#	PreLinear	PosLinear	*t*	*p*	Cohen's *d*

Q1	0.22±0.42	0.55±0.50	-2.92	0.010**	-0.69
Q2	0.27±0.45	0.16±0.37	1.00	0.331	0.24
Q3	0.16±0.37	0.72±0.45	-4.61	<0.001**	-1.09
Q4	0.22±0.42	0.33±0.47	-0.70	0.495	-0.16
Q5	0.27±0.45	0.66±0.47	-3.29	0.004**	-0.78
Q6	0.16±0.37	0.44±0.50	-2.56	0.020**	-0.60
Q7	0.05±0.23	0.44±0.50	-2.72	0.015**	-0.64
Q8	0.77±0.42	0.61±0.49	1.37	0.187	0.32
Q9	0.72±0.45	0.83±0.37	-1.00	0.331	-0.24
Q10	0.55±0.50	0.77±0.42	-1.17	0.260	-0.27
Q11	0.00±0.00	0.66±0.47	-5.83	<0.001**	-1.37
Q12	0.11±0.31	0.66±0.47	-4.61	<0.001**	-1.09
Q13	0.05±0.23	0.55±0.50	-4.12	<0.001**	-0.97

Table 1: Means and standard deviations of questions for PreLinear and PosLinear, *t*-test analysis, and Cohen's *d*. d.f. = 17

#	PreFlexible	PosFlexible	*t*	*p*	Cohen's *d*
Q1	0.09±0.29	0.72±0.45	-4.18	0.002**	-1.26
Q2	0.00±0.00	0.09±0.29	-1.00	0.341	-0.30
Q3	0.09±0.29	0.63±0.48	-3.46	0.006**	-1.04
Q4	0.09±0.29	0.27±0.45	-1.00	0.341	-0.30
Q5	0.00±0.00	0.54±0.50	-3.46	0.006**	-1.04
Q6	0.09±0.29	0.18±0.39	-0.56	0.588	-0.17
Q7	0.00±0.00	0.45±0.50	-2.89	0.016**	-0.87
Q8	0.81±0.39	0.63±0.48	1.00	0.341	0.30
Q9	0.63±0.48	0.63±0.48	0.00	1.00	0.00
Q10	0.36±0.48	0.45±0.50	-0.56	0.588	-0.17
Q11	0.09±0.29	0.45±0.50	-1.79	0.104	-0.54
Q12	0.00±0.00	0.81±0.39	-6.71	<0.001**	-2.02
Q13	0.00±0.00	0.27±0.45	-1.94	0.082	-0.58

Table 2: Means and standard deviations of questions for PreFlexible and PosFlexible, *t*-test analysis, and Cohen's *d*. d.f. = 10

#	PosLinear	PosFlexible	*t*	*p*	Cohen's *d*
Q1	0.55±0.50	0.72±0.45	-0.91	0.373	-0.35
Q2	0.16±0.37	0.09±0.29	0.56	0.582	0.21
Q3	0.72±0.45	0.63±0.48	0.47	0.642	0.18
Q4	0.33±0.47	0.27±0.45	0.33	0.743	0.13
Q5	0.66±0.47	0.54±0.50	0.63	0.531	0.24
Q6	0.44±0.50	0.18±0.39	1.45	0.160	0.55
Q7	0.44±0.50	0.45±0.50	-0.05	0.960	-0.02
Q8	0.61±0.49	0.63±0.48	-0.13	0.897	-0.05
Q9	0.83±0.37	0.63±0.48	1.19	0.244	0.46
Q10	0.77±0.42	0.45±0.50	1.82	0.080	0.70
Q11	0.66±0.47	0.45±0.50	1.11	0.277	0.42
Q12	0.66±0.47	0.81±0.39	-0.87	0.394	-0.33
Q13	0.55±0.50	0.27±0.45	1.49	0.147	0.57

Table 3: Means and standard deviations of questions for PosLinear and PosFlexible, *t*-test analysis, and Cohen's *d*. d.f. = 27

Factor	d.f.	*F*	*p*	*partial* η^2
Gender	1	0.03	0.85	0.001
Age	1	0.10	0.74	0.004
Mode(Linear/Flexible)	1	1.40	0.24	0.062
Gender:Age	1	5.93	0.02**	0.220
Mode:Age	1	3.40	0.07**	0.139
Other interactions	1	<0.90	>0.35	<0.04

Table 4: Multifactorial ANOVA for the knowledge variable. N = 29

Figure 10 shows the interaction plot between gender and the two modes of playing, indicating that boys acquired more knowledge than girls playing the linear mode and the same knowledge playing the flexible mode. Figure 11 shows the interaction plot between gender and age, indicating that 8-year-old boys acquired more knowledge than girls, but 9-year-old boys acquired less.

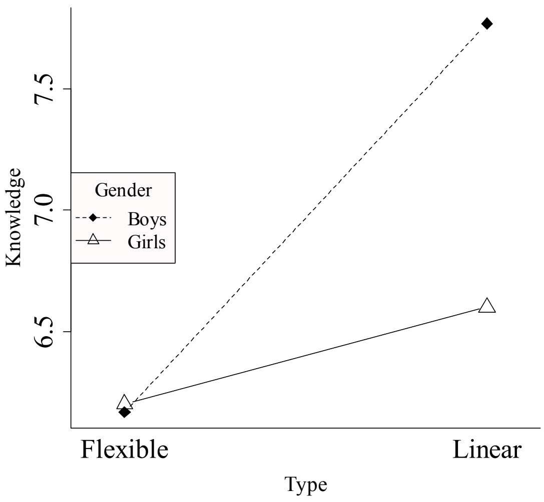


Figure 10: Interaction by gender for each mode

Figure 11: Interaction by gender for each age

5.2. Satisfaction and interaction outcomes

To determine the satisfaction outcomes, the children were asked the questions Q14 to Q24 that are shown in Table 10. The children's satisfaction was quite favorable, as the results in Table 5 show. Most of the children stated that they had a very good time playing the game (Q14). In addition, the children gave an average score of 9.14 ± 1.83 when asked to score the game (Q23). We asked the children to rate the difficulty of the game from one to five (Q16), with one being great difficulty and five being the easiest. Of the 29 children who played the game, eleven children said that the game was easy by giving a score of four points, eight children said that the game was of normal difficulty (3 points), six children chose very easy as their option (5 points), three children chose "hard" (2 points), and only one child chose "very hard" (1 point). The average obtained with this data was 3.62 ± 1.05 points. Therefore, this result indicates that the children's opinion was that the game was "easy". The children also liked the avatar. They gave it an average score of 3.90 ± 1.29 points out of five (Q20). They also thought that the avatar was helpful during the game. They gave a score 4.07 ± 1.07 points out of five (Q21). The rest of the results are shown in Table 5.

#	Bounds	Mean	Answer
Q14	[1-5]	4.83±0.38	Very good
Q15	[1-5]	4.44±0.97	To several friends.
Q16	[1-5]	3.62±1.05	Easy
Q17	[1-5]	4.39±0.69	Good
Q18	[1-5]	4.22±0.85	Easy
Q19	[1-5]	4.52±0.74	A lot
Q20	[1-5]	3.90±1.29	Enough
Q21	[1-5]	4.07±1.07	A lot
Q22	[1-5]	4.34±0.94	A lot
Q23	[1-10]	9.14±1.83	Very good

Table 5: Satisfaction and interaction question results

To determine if there were statistically significant differences between the two game modes with respect to the satisfaction questions, an unpaired *t*-test was performed. Table 6 shows the results of the test. Statistically significant differences were only found for Q15 (where the children were asked about recommending the game to friends) and for Q20 (where the children were asked about liking the avatar character). For the two questions, the children who played the Flexible Learning Itinerary scored these questions higher.

#	Linear	Flexible	t	d.f.	p	Cohen's d
Q14	4.78±0.42	4.91±0.29	-0.89	27	0.382	-0.34
Q15	4.12±1.08	5.00±0.00	-2.49	25	0.020**	-0.99
Q16	3.89±0.74	3.18±1.27	1.83	27	0.078	0.70
Q17	4.41±0.69	4.36±0.64	0.18	26	0.860	0.07
Q18	4.35±0.76	4.00±0.89	1.05	25	0.305	0.42
Q19	4.50±0.76	4.55±0.50	-0.16	27	0.876	-0.06
Q20	3.50±1.34	4.55±0.78	-2.27	27	0.032**	-0.87
Q21	4.00±1.00	4.18±1.11	-0.44	27	0.664	-0.17
Q22	4.44±0.68	4.18±1.19	0.73	27	0.474	0.28
Q23	9.28±1.04	8.91±2.57	0.52	27	0.607	0.20

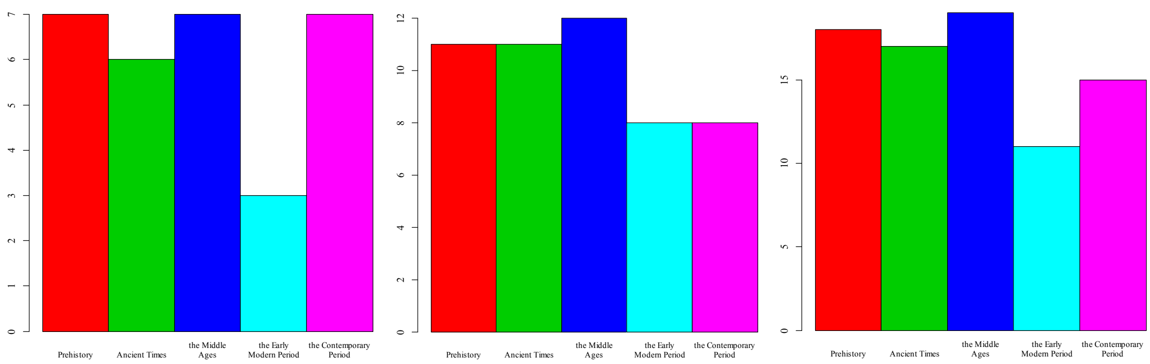
Table 6: Means and standard deviations for satisfaction questions, t-test analysis, and Cohen's d

To analyze the satisfaction variable, a multifactorial ANOVA test was performed. Table 7 shows the results. Statistically significant differences were found in the interaction between Game Mode and Age factors, and in the interaction among Gender, Game Mode, and Age factors.

Factor	d.f.	F	p	partial η^2
Gender	1	2.86	0.105	0.120
Age	1	0.23	0.629	0.011
Mode(Linear/Flexible)	1	0.08	0.780	0.003
Gender:Age	1	0.82	0.375	0.037
Mode:Age	1	3.62	0.070**	0.147
Gender:Mode	1	0.26	0.610	0.012
Gender:Mode:Age	1	3.28	0.084**	0.135

Table 7: Multifactorial ANOVA for the satisfaction variable. N = 29

For Q24, which asked to children about the mini-games they liked the most, a vote count was performed. The children could vote for more than one mini-game. When the results between the children who played the FLI mode and the children who played the LLI mode are compared, some differences can be observed, as shown in the bar plots in Figure 12. Children from FLI preferred Prehistory, the Middle Ages, and the Contemporary Period the most (7 votes). However, children from LLI preferred the Middle Ages the most (12 votes). When all the votes are considered, the most preferred age was the Middle Ages (19 votes). Therefore, the three plots show that the Middle Ages was the favorite.



a) Flexible Learning Itinerary b) Linear Learning Itinerary c) Both learning itineraries taken into account

Figure 12: Comparative frequencies of the mini-games the children liked the most. The votes are shown on the y-axis (ordinate)

A Chi-squared test was performed to analyze the children's preferred mini-game. Table 8 shows the results of the test. These results show that there were no statistically significant differences between the two learning itineraries. The Prehistory, the Ancient Times, and the Middle Ages mini-games were the most voted in the two groups (LLI and FLI) for the preferred mini-game.

Age	Linear	Flexible	χ^2	*p*	*V*
Pre.	1	1	0.00	1.000	0.03
Anc.	1	1	0.00	1.000	0.06
Mid.	1	1	0.00	1.000	0.03
Mod.	0	0	0.28	0.596	0.17
Cont.	0	1	0.39	0.535	0.19

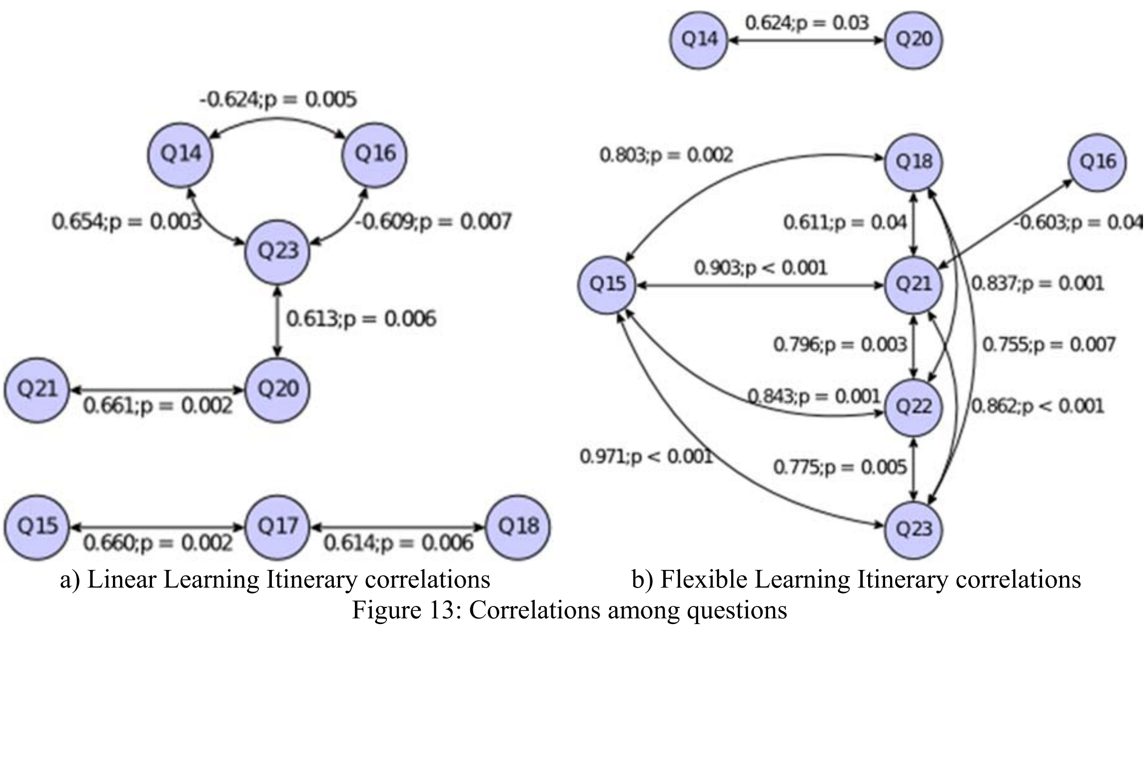
Table 8: Modes of the preferred mini-game, Chi-squared analysis, and Cramer's *V*. d.f. = 1. N = 29

5.3. Correlation analysis

A correlation analysis was performed to determine if there was a correlation among any of the questions. Some correlations were found when the two groups were analyzed together. There were correlations found between Q15 (Recommend the game to friends) and Q23 (Score the game) (0.639, $p < 0.001$), between Q18 (Difficulty of selecting the answers) and Q22 (How much the children learned) (0.691, $p < 0.001$), between Q21 (Did the avatar help) and Q22 (0.654, $p < 0.001$), between Q21 and Q23 (0.673, $p < 0.001$), and between Q22 and Q23 (0.681, $p < 0.001$). When the groups were analyzed separately, we found different correlations (Figure 13a Figure 13b).

When groups formed only by boys and groups formed only by girls were analyzed separately, there were different correlation results. In the group of boys, the correlations found were between Q14 and Q20 (0.614, $p = 0.005$), between Q15 and Q18 (0.648, $p = 0.002$), between Q15 and Q23 (0.664, $p = 0.001$), between Q18 and Q22 (0.809, $p < 0.001$), between Q21 and Q22 (0.714, $p < 0.001$), between Q21 and Q23 (0.737, $p < 0.001$), and between Q22 and Q23 (0.722, $p < 0.001$). In the group of girls, fewer correlations were found. These correlations were between Q17 and Q19 (-0.699, $p = 0.024$), and between Q17 and Q23 (0.620, $p = 0.05$).

When groups organized by age were analyzed separately, in the group of 8-year-old children, the correlations were between Q15 and Q20 (0.703, $p = 0.015$), between Q17 and Q18 (0.600, $p = 0.05$), and between Q20 and Q21 (0.679, $p = 0.02$). In the group of 9-year-old children, there were correlations between Q15 and Q23 (0.683, $p = 0.001$), between Q18 and Q22 (0.754, $p < 0.001$), between Q21 and Q22 (0.719, $p < 0.001$), between Q21 and Q23 (0.819, $p < 0.001$), and between Q22 and Q23 (0.755, $p < 0.001$).



a) Linear Learning Itinerary correlations b) Flexible Learning Itinerary correlations

Figure 13: Correlations among questions

6. DISCUSSION

From the results, it can be observed that the children learned while playing with the two modes, with statistically significant differences between the levels of knowledge before and after playing the game. This implies that the game is suitable for the transmission of knowledge. This result is in line with previous works that have demonstrated this trend using new technologies [51] [52]. Different arguments have been offered to justify this trend. One of them is that video games promote a positive attitude towards learning [61], especially due to their motivational nature [46] [62] [63]. Other authors have also attributed positive learning effects to video games [64].

However, there were no statistically significant differences between playing with the flexible mode or the linear mode. In our hypothesis, we predicted that the children would acquire more knowledge by playing with the Flexible learning Itinerary because they could decide how to learn the different historical ages. These results did not corroborate our hypothesis. Although unexpected, this is a good result because it implies that children can learn using the two modes without having statistically significant differences in the acquired knowledge. However, we still believe that the flexible mode is an alternative mode that some individuals might prefer over the linear mode, especially when other groups are considered such as young people or adults. Another factor that we also think has influenced this result is the limited time of use by each child and the pressure of participating in a study. Thus, we consider that a study with more freedom would benefit the flexible itinerary.

The analysis also revealed that boys improved their knowledge quite a bit more than girls, mainly while playing with the linear learning itinerary. From our point of view, and in line with previous studies (e.g. [65]), this greater improvement in boys could be related to the fact that more boys play video games than girls, and for longer periods of time. For example, a study carried out by Bonanno et al. [65] revealed that male junior college students were far more likely than females to play video games, and males also played for longer periods of time than females (more than double). However, more studies should be carried out to verify this trend.

In the analysis for satisfaction and interaction, there were only statistically significant differences for Q15 (recommending the game to friends) and Q20 (liking the avatar) between the two modes. This result indicates that there were no statistically significant differences for the rest of the questions. If these questions are considered, the children perceived the game as easy to use. This is also a good result because one of the recommendations for a good interface is be easy to use. Several authors have considered usability or perceived ease of use as an important technical factor that affects educational effectiveness [66] [67]. Also, Sun et al. [68] pointed out that learning systems that are easy to use help students to focus their attention on the learning content, and they are more motivated to learn. Therefore, according to the above-mentioned suggestions, our game in the two modes does help students focus their attention on the learning content.

With regard to the most preferred mini-games, the Middle Ages with the medieval castle was the most highly rated historical age. Prehistory was the second most highly rated. The least preferred mini-game was the Early Modern Period. Our explanation for this result is that the Middle Ages and Prehistory were the two periods that had the most animations, and the children had to interact with them. In addition, the rotating 3D model of the medieval castle greatly attracted the children's attention. The Early Modern Period and the Contemporary Period were the two periods in which the contents were mainly transmitted using videos and with little interaction. The children scored the Contemporary Period higher because it is the period that they are most familiar with. From these results, our recommendation is to transmit the content using more interactive material and using fewer videos.

7. CONCLUSIONS

In this paper, we present a new configuration to improve learning environments using natural user interfaces combined with a frontal projection system. A computer-based learning game with two itinerary modes was developed. We performed a study to determine whether playing with the linear or flexible itinerary affected several aspects. To our knowledge, this is the first time a work with these characteristics has been presented. From the learning outcomes, we would like to highlight that the children acquired new knowledge and that the flexible and the linear modes facilitated an increase in knowledge. Therefore, our study reveals the potential of computer-based learning games as a tool in the learning process, in both flexible and linear itinerary modes.

With regard to the use of games of this kind in a real class, it could be a great addition to the traditional learning process because the contents are extracted from the textbooks used in the classroom. In addition, the cost of building the structure is minimal, and the devices used (like a computer and a projector) are normally found in the classroom, except for the Kinect. Nevertheless, the Kinect is also a cheap device with a cost that is similar to a normal web camera. One drawback for classroom use is that the number of children that could use the system at the same time is limited. In its current configuration, two children can play at the same time, but other children could be placed around the system. We think that around 10 or 12 children can stay around the system and learn at the same time. In fact, this is a study that we are planning to carry out.

Our system is based on interactive tables and, as previous authors said, interaction using interactive tables of this type can promote playfulness [30] [31] and are enjoyable to use [33]. This is an important factor that helps children improve their knowledge while having fun. It is also much better for retaining the knowledge acquired, as several authors affirm [69] [70].

For future work, the game could be enhanced by adding more interactive material for the periods in which the content is now mainly transmitted using videos. The system could be used in a mobile device such as a tablet. Both the stationary system and the mobile system are valid. In this paper, we have only compared two modes, but other comparisons are also possible; for example, using a control group in which the children learn the time line using traditional learning. As pointed out in the discussion, another possible study could be to repeat the study by allowing the children more freedom in the flexible itinerary in which it could be possible to learn a period of history in different sessions and whenever the children wanted. Another study could be carried out to determine the benefits of the stationary system and the mobile system. The flexible itinerary allows the children to personalize their learning, but it could be taken further to make the game more customizable, for example, adapting the game difficulty for students in lower, mid and higher grades of primary education. With these studies, it would be possible to determine in which contexts FLI are more suitable than LLI. For the evaluation, the questionnaires could be filled out using the same interface on which the children played the game. Finally, we believe that video game technology, and personalized learning environments could be combined to developed new and powerful e-Learning systems.

Acknowledgements

- This work was funded by the Spanish APRENDRA project (TIN2009-14319-C02-01).
- We would like to thank the following for their contributions:
  - The "Escola d'Estiu" and especially Juan Cano, Miguelón Giménez, and Javier Irimia. The other two Summer Schools that participated in this study. This work would not have been possible without their collaboration.
  - Ignacio Seguí, Encarna Torres, Juan Martínez, and M. José Vicent for their help.
  - The children's parents who signed the agreement to allow their children to participate in the study.
  - The children who participated in the study.
  - The ETSInf for letting us use its facilities during the testing phase.

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Appendix

This appendix presents all the questionnaires that were used in this experiment. The choices to be selected as answers are placed below the questions. The column labeled with # shows the question numbering.

A.1 Learning questions

To measure the knowledge acquired before and after playing the game, the children were asked the following questions.

#	Question
Q1	Which of the following figures did the cavemen paint in the caves? a) Houses b) Deers c) Bisons d) Boats e) Hands f) Carts
Q2	Tell the name of a cave with cave paintings a) Bajamira cave b) Miradentro cave c) Altamira cave d) Cave paintings cave
Q3	Which of the following colours were used for painting in Prehistory? a) Green b) Red c) Violet d) Blue e) Ochre f) Black
Q4	Ancient Times started with the: a) Invention of the wheel b) Invention of writing c) Discovery of America d) Fall of the Roman Empire e) Invention of the compass
Q5	Where did the gladiators and beasts fight? a) Roman circus b) Aqueduct c) Amphitheatre d) Castle
Q6	Which of the following characteristics correspond to Ancient Times? a) Some people lived in castles b) There were aqueducts and amphitheatres c) Mankind started to paint in caves d) The compass was used to navigate.
Q7	What is the name of the fortification in front of the walls of the castle that protected the main door from enemies? a) Moat b) Keep c) Barbican d) Defensive tower
Q8	Which structure surrounds the castle and can be full of water? a) Barbican b) Moat c) Road d) Keep
Q9	What part of the castle did the Castle's Lord and his family live in? a) Keep b) Barbican c) Wall d) Defensive tower
Q10	Which event marked the start of the Early Modern Period? a) The invention of writing b) The discovery of America c) The invention of the mobile phone d) The trip to the moon
Q11	Select the inventions used for sailing in the Early Modern Period a) Compass b) Television c) Astrolabe d) Map e) Mobile phone f) Spaceship
Q12	Place the historical ages in the correct order a) Ancient Times b) Contemporary Period c) Prehistory d) The Early Modern Period e) The Middle Ages

Q13	Place each invention in the correct historical age a) Map b) Mobile phone c) Cave paintings d) Aqueduct e) Castle

Table 9: Learning questions

A.2 Satisfaction questions

To determine their satisfaction, the children were asked the following questions.

#	Question
Q14	How much fun did you have? [1-5]
Q15	Would you recommend this game to friends? [1-5]
Q16	What was the difficulty of the game? [1.Very difficult / 2.Difficult / 3.Regular / 4.Easy / 5.Very easy]
Q17	Did you understand the rules of the game? [1-5]
Q18	Selecting the answers was: [1.Very difficult / 2.Difficult / 3.Regular / 4.Easy / 5.Very easy]
Q19	How much did you like the images in the game? [1-5]
Q20	How much did you like the Clock Avatar (Mr. Tic-Tac)? [1-5]
Q21	How much did Mr. Tic-Tac help you during the game? [1-5]
Q22	How much did you learn during the game? [1-5]
Q23	Score the game from 1 to 10 [1-10]
Q24	Which of all the mini-games did you like the most? [Prehistory / Ancient Times / the Middle Ages / the Early Modern Period / the Contemporary Period]

Table 10: Satisfaction questions