Playful interaction for learning collaboratively and individually

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Abstract. Playful interactions facilitate the development of engaging applications for different purposes. This aspect is very important for serious games, and especially when these games are for children. Another aspect to consider is the interaction among children, which could be a great reinforcement in learning environments. Children enjoy playing, and they like playing with other children. This relationship could encourage their motivation and their learning outcomes. In this paper, a playful interaction system for learning about a period of history is presented. The interaction of the system was achieved using natural gestures and the visualization was autostereoscopic. A study was carried out to determine whether their learning outcomes were greater playing collaboratively or playing individually. Forty six children from 7 to 10 years old participated in the study. The analysis of the pre-tests and the post-tests indicate that the children increased their knowledge about historical periods after playing with the two modes. Therefore, the game could be used as an effective transmitter of knowledge both collaboratively and individually. When the post-knowledge scores for the two modes were compared, statistically significant differences were found in favor of the collaborative mode. Therefore, the collaborative mode facilitates learning to a greater extent than the individual mode. The rest of the questions indicated that the children had a lot of fun while playing the game; they found the game easy to play; they would recommend the game to their friends; and they scored the game as a mean of 9.57 over 10. Finally, we believe that the combination of playful interaction and autostereoscopy is an option that should be exploited not only for the development of computer-supported learning systems, but also for the development of systems for different purposes.

Keywords: Playful interactions, Serious games, Collaborative, Autostereoscopy, Natural User Interfaces

1. Introduction

In recent decades, the habits of the society of the industrialized world have changed at every level. Not only has the way in which we communicate with other people changed, but the learning model and the way we solve problems have also changed. In general, most children and young people have been surrounded by technologies since they were born (digital natives [1,2]) and, for them, computers are a daily element in their lives. Hence, there is a need to adapt our learning methods to the new times. The learning model that was valid years ago must now be improved. We currently have playful interactions and advanced display technology to get children's attention and interest. Based on this argument, we have developed a collaborative, computer-based learning system with natural gesture interaction and autostereoscopic visualization. Autostereoscopic visualization generates a 3D perception without the use of special glasses or other headgear. The game focuses on the historical time line that is taught to children that are in the 2nd grade of primary school. The game was also developed with the underlying idea of "edutainment", which means learning while playing. As has been demonstrated in previous studies [3], learning and acquired knowledge can be similar using the new technologies and traditional methods. In addition, the use of these new technologies increases the level of satisfaction of the children [3,4].

The first objective of our work was to develop a game that included playful interaction and autostereoscopic visualization. The second objective was to carry out a study to find out if children had a higher

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increase in knowledge playing collaboratively or individually. To our knowledge, this is the first time that this combination has been used to develop a learning environment for children to compare playing collaboratively or individually. Our main hypothesis is that children will learn more by playing the game in the collaborative mode than in the individual mode. Some of the reasons that support this hypothesis are the following:

- Although both modes use the same game, when playing in the collaborative mode, the children can interact with each other and this can affect their learning outcomes. This argument is in line with previous works that have pointed out that collaborative learning has benefits over individual learning [5,6].
- When playing in the individual mode, the children are not able to interact with anybody and they have to follow the learning process by themselves.

The rest of the paper is structured as follows. Section 2 focuses on the state of the art. Section 3 presents the developments involved in the work, the resources used, the hardware and the software, and the description of the game. Section 4 describes the study carried out, the participants, the measures, and the procedure. Section 5 analyzes the results obtained. Section 6 presents some discussion, and, finally, Section 7 presents the conclusions and future work.

2. Related work

The way in which collaboration influences children is not new and has been addressed from different points of view. Several authors have considered that collaborative learning has benefits over individual learning [5,6]. Johnson and Stanne [5] carried out an experiment with 74 eighth-grade students. They formed three groups: the first group used cooperative learning, the second group used a competitive system, and the third group used individual learning. All the groups had to carry out a computer simulation task. After a period of ten days, the students in the cooperative learning group obtained better learning outcomes and more task-related interactions with other students. Slavin [6] reviewed cooperative learning, concluding that improvement in student achievement depends on the existence of group goals and on individual accountability. Johnson and Johnson [7] found that children that worked in groups retain the knowledge acquired longer than children that worked individually. However, later studies concluded that collaborative learning obtains better results only in certain circumstances related to the size and composition of the group and social status. Pairs seem to be more effective than groups with more members. Also, differences among children in a group should not be too large (low achievers vs. high achievers).

Learning also depends on the task (some tasks are inherently distributed and require coordination and planning, while others are purely procedural and collaboration does not improve results [8]). Doise and Mugny [9] and Blaye [10] considered intelligence and inter-individual coordination for solving problems. They established that cooperation in problem resolution between peers of similar initial performance benefits later individual performance. Instead of focusing on the actions themselves, they focused on interactions with others. Elices *et al.* [11] presented five studies with children between 10 and 13 years old. The children had to carry out a task, either individually or in pairs. Pairs were formed based on the affectivity between students, social context, and previous ability. The results showed that pairs achieve better results than individuals, but only if affectivity was neutral. Friendship and dislike can influence the learning process.

Based on the Cognitive Load Theory (CLT) [12], Kirschner *et al.* [13] established that collaborative learning gets better results at an individual level if the task is complicated. CLT assumes that individual Working Memory (WM) is limited, and, therefore, if members in the group share their WM, they can create a collective WM and are able to carry out complex problems. In that case, group learning performance is higher than individual performance. On the other hand, the creation of this collective memory implies a communication and coordination cost, which means that if the difficulty of the problem to solve is low or the performance is measured based on memory retention, the learning outcomes are better for individuals. In Kirschnet *et al.*'s study, the participants were high-school students and the learning problems were related to the field of biology. However, collaborative learning does not always improve the knowledge acquired at an individual level; even though it does increase motivation [14].

A well-known cooperative learning method is the jigsaw [15], in which students work in small groups. As in a puzzle, each group (piece) is essential in order to solve the problem. No individual can solve the problem alone. Hänze and Berger [14] compared the jigsaw method with the traditional direct instruction method in a real classroom. The participants in the jigsaw method showed greater involvement, motivation, and interest in the topic. Similarly, Kreijns *et al.* [16] observed that the absence of social interaction negatively affects the learning process, and they concluded that the key to the efficiency of collaborative learning is social interaction.

The balance in the participation is also an important aspect to consider. As Bachour *et al*. [17] indicated, if participation is not balanced in a collaborative learning situation, the children who participated less would get worse scores than those who participated more. Dillenbourg [18] argued that there is no guarantee that the learning process will be improved just because the participants work together. Szewkis *et al*. [19] stated that certain conditions must exist in order for the activity to be conducted successfully, such as the existence of a common goal [20], positive interdependence between peers [21], coordination and communication between peers [22], individual accountability [23], awareness of peers' work [24], and joint rewards [25].

Several works on Computer-Based Learning Environments argue that environments of this kind are not always interesting for the children of today. Because of this, in the last few years, new learning tools such as on-line games have been incorporated to increase children's interest, reinforcing their motivation [26–30]. Magnisalis *et al*. [31] did a review of the field (considering 46 papers) to study the impact of Computer-Learning systems on children's learning, concluding that the use of PI-Type systems (the systems that support peer interaction) motivates children and increases collaboration and learning.

Recent studies not only use interactive and collaborative systems, but also add recent technology. Harrington [32] carried out an empirical study with little children to compare learning activities in a virtual environment with a real environment. The activity consisted of a trip through nature using PCs. The results showed that the children who took the Real trip had better scores, but the Virtual trip was useful in situations where a Real trip was not possible and for reinforcing material that was in the curriculum. Marty and Carron [33] developed an on-line collaborative game in which the teachers can observe and monitor the activity. The game consists of a "pedagogical dungeon" with learning activities that are focused on the Operating Systems field, which consists of one or more sub-activities that are associated with each room. The students can move from one room to another by solving activities in an individual or collaborative way. The rooms can have some prerequisites to come in. Throughout the activity session, the teacher can monitor and observe the process of each student and intervene if necessary. The observation was achieved using a 3-phase architecture: first the collecting phase, where relevant traces were identified and collected; the second phase made these traces more explicit and understandable; the final phase consisted of the visualization phase, where visualization techniques were used to reveal any semantics from these traces. The students seemed to get great personal satisfaction. Alem *et al*. [34] developed a mobile game and presented a study involving 28 primary school students in order to explore the extent to which playing alone, collaboration, and competition affect perceived learning. They conclude that competition and collaboration influence perceived learning more than individual play. The main drawback of this study is that they did not determine the increase in knowledge.

Other researchers have used novel devices, like Schneider *et al*. [35] who incorporated tangible interaction in a collaborative learning system. Schneider *et al*. [35] made a comparative study with two groups of logistics students. One group used a multi-touch interface and the other group used a tangible interface. The students worked in pairs and had to analyze several warehouse layouts in terms of space management and efficiency. The results showed that the students who used the tangible interface solved a warehouse design task better than the students that used the multi-touch interface. Chan *et al*. [36] used virtual reality technologies and motion capture to develop a dance training system. Their objective was to implement a self-learning system. This system first showed the user the movements by a professional dancer by rendering a 3D animation with OpenGL. Then, the system tracked the user doing the same movements and compared them with the professional dancer's movements that were stored in the motion database. The results were compared with a control group using self-learning without feedback. They concluded that there was a significant difference between the two groups; in fact, the improvement in the experimental group was greater than in the control group.

3. The game

3.1. Hardware

The system shows an image of the real world mixed with virtual elements such as buttons. To capture the real-world image and the user tracking, we used a Microsoft Kinect device, which captures a 640×480 image. Autostereoscopic rendering was possible by using an XYZ display. The model was XYZ3D8V46, with a size of 46” and full HD resolution (1920×1080 pixels). This display is able to generate eight views using a technology known as LCD/lenticular [37]. Other display technologies are based on GPU [38,39] or parallax barriers [40]. Figure 1 shows the position of the hardware elements relative to the position of the children.

Fig. 1: Two children playing with the game

3.2. Software

We used the *OpenSceneGraph* (OSG) toolkit 3.0.1 to render the 3D models. It is an open-source graphics toolkit. This toolkit is written in Standard C++ and *OpenGL*, which offers high performance at render time when working with the hardware described in section 3.1.

Registration and video capture were achieved using *OpenNI*. This library allows different users to be detected and also returns the position of the possible *SkeletonJoints* of the user (hands, elbows, neck, head centre of mass, etc.). With the *SkeletonJoint* of the hands, it is possible to know if the user is pressing the buttons.

For the autostereoscopic rendering, we used *Mirage SDK* (www.mirage-tech.com). This SDK provides an OSG Node that calculates eight different views. With this node, we can define an OSG scene by adding cameras, 3D models (in format .osg and .osgt), transformation matrices, etc. Finally, this node must be added as the root of the scene graph. Once this scene graph is complete, in a display like the one mentioned above, a 3D sensation can be perceived without using any glasses or external devices. In our case, we integrated this scene graph with the *OpenNI* library (which provides NUI support and video capture from Kinect) and the *Mirage SDK* (which provides the autostereoscopic views).

The captured videos were rendered at the background of the game and had no 3D effect. The explanation videos were rendered full screen in the foreground and had no 3D effect, either. These videos were decoded using the *ffmpeg* library (http://ffmpeg.org) and the *Simple DirectMedia Layer* (SDL) library (http://www.libsdl.org) to synchronize the video files with their audios. All the video files were in .mpg format. The *FMOD* audio library (http://www.fmod.org/) was used to play the audio files. All the audio files were in .wav format. The system was coded in C++. Figure 2 shows the architecture of the system explained above, classifying the three main parts of the system (NUI, Render, and Multimedia); it also shows how OSG is the principal base of the application.

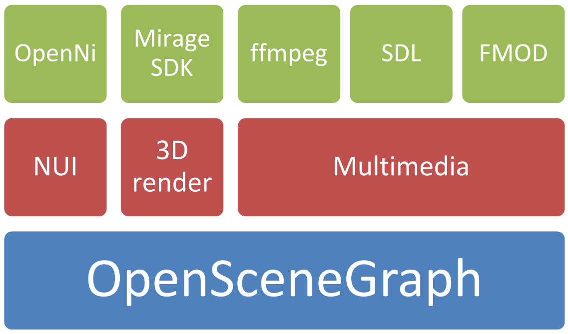


Fig. 2: System architecture

3.3. Game design

The game was developed based on learning theories and pedagogical background. Specifically, we used the experiential learning theory of Constructivism [41,42] for the design of the game. As a computer-supported group-based learning system, we also designed the game taking into account the approach proposed by Strijbos *et al.* [43]. This approach consists of five elements: three elements are shown as dimensions (learning objectives, task type, and level of pre-structuring), and two elements are shown in terms of discrete categories (group size and computer support). We followed the six steps suggested [43] to design our game. These steps are the following:

1) Determine the learning objectives: The learning objectives can range from 'open skills' to 'closed skills'. Open skills are skills such as argumentation and negotiation. Closed skills are relatively fixed skills that can be learned separately. In our game, the skills are closed.
2) Determine the expected (changes in) interaction: focusing on feedback, exchanging ideas or discussion. Our game is focused on exchanging ideas.
3) Select the task type: The Task type can range from 'well-structured tasks' to 'ill-structured tasks'. Well-structured tasks aim to convergence because there is only one correct solution. Ill-structured tasks have a considerable degree of uncertainty regarding the rules and principles that can be applied and often have no clear-cut solution. In our game, the task type is well-structured.
4) Determine whether pre-structuring is needed and how much: The Level of pre-structuring can range from 'high' to 'low'. It addresses the level to which interaction is pre-structured in advance to ensure positive interdependence [44] and individual accountability [45]. Our game has a high level of pre-structuring. The two members have to interact with the system. Half of the interactions with the system and half of the answers to the questions must be performed by each member in order to reach the next level.
5) Determine group size: Group size ranges from couples (two members) to small groups (three to six members) or large groups (seven or more members). In the collaborative version of our game, two children play together. We chose couples or pairs for the following reasons: pairs are the smallest possible social unit; as the size of the group increases, it becomes progressively more difficult to identify the successful components of cooperative learning [46]; the use of larger groups may promote the formation of coalitions. And, therefore, encourage competition rather than cooperation [47].
6) Determine how computer support can be applied (with, at, through): Interaction *with* computers refers to individual student interaction with a computer simulation. Interaction *at* computers represents a group of students interacting with a computer program; it can be either face-to-face or computer-mediated. Interaction *through* computers refers to interaction between group members via networked computers. In our game, the student interaction is at the same time and place (face-to-face) and *at* computer. Each child interacts with the system for half of all interactions required. To choose an answer or option, the children must talk to each other in order to share information and to help each other to achieve the solution.

The design guidelines for classroom collaborative games proposed by Villalta *et al*. [48] were also taken into account to design our game. These design guidelines include the following features for collaborative games:

1) Interactivity and guidance. Our game offers guidance by the avatar guide. The user's interaction with the game is simple and intuitive. It uses natural interaction (gestures without any special hardware).
2) Mechanics linked to learning objectives. In our game, the curricular content is embedded in our game. The success of the game is conditional to understanding its content.
3) Clear narrative. Our game has a base story that allows the immersion of the participants. The narrative is composed of challenges that define collaborative activities in a sequential and precise pattern.
4) Gradual increase in difficulty. This guideline was not taken into account for this version of our game.
5) Teacher mediation during the game. In our game, there is no participation by the teacher because it is a computer-supported learning game.
6) Organization of face-to-face interaction. Our game promotes communication between students. The students must agree with each other before choosing an answer or an element.
7) Mechanics linked to collaboration. In our game collaboration is embedded. Success is conditional to having worked collaboratively.
8) Adequate spatial distribution. Our game distributes elements and activities on the screen in order to take advantage of the available space. The spatial distribution correctly relates aspects of the embedded knowledge to the connection with the real world. In the current version of our game, the player cannot control the camera. However, the elements that require a 360-degree visualization rotate continuously while onscreen.
9) Recognizable elements. In our game, the elements on the screen have distinctive traits that capture

the players' attention. Moreover, the most important elements are displayed with stereoscopy.

10) Accessible language (the text on the screen must have a clear message and be concise and easy to read). In our game, the text only appears in the buttons and in very specific information on the screen. Villalta [48] stated that spoken information should be preferred over written text because it induces less cognitive load. In our game, we include a guide avatar that offers the children audio explanations about the steps to follow.
11) Avoid information overload. Our game avoids information overload by limiting the information on the screen.
12) Action guide. Our game includes educational and playful aspects. It includes a script that specifies action sequences and events that can take place in both the virtual and real world.

In order to evaluate the acquired learning, the game contents needed to be suitable for the children's knowledge. To determine this, we took into account the Royal Decree of the national curricula of Spain. Basic contents of science or history were candidates for our game's main theme. We chose history, since this field is included in the Natural and Social Science subject of Spain.

3.4. Description of the game

In our game, the children assumed the mission of completing a time line for a trip through different historical ages. We emphasized the order of the historical ages in the time line and the events that started and ended each historical age. Once the game had started, the children had to perform some actions in order to complete the current stage. For instance, the children had to build a medieval castle by answering some questions or build a Roman city by selecting certain buildings from this historical age.

The game was divided into a series of mini-games, several of which were designed for each historical age of the time line. There were video and audio explanations at the beginning of the mini-games. These introduced the historical ages to the children. There were also audio explanations transmitted by the avatar guide inside each mini-game to provide more detailed information. The children played the game from Prehistory to the present day.

All the stages of the game had similar features and were developed to be as entertaining as possible. The children had to use their hands to play the games, selecting buttons or searching for images by moving their hands around the active area. As Figure 3 shows, the interaction buttons were located at the sides of the screen due to the position of the children when they are playing and the place where they put their arms in a standing pose. The child on the right side must use his/her right hand, and the child on the left side must use his/her left one. This placement helped the children to interact with the buttons close to them. In the individual mode, the child has to interact alone with the game. In this mode the child has to use both hands to select the buttons on the left/right sides. The children have to interact with the game. In the collaborative mode, in an attempt to balance the participation of the two students, half of the interactions with the game and half of the answers to the questions should be performed by each child in order to reach the next level. If one of the children is much more active than the other, the most active child can have more interactions than the other child. To limit this situation to the maximum, the buttons for each child were on his/her side and one child would have to invade the physical space of the other child in order to perform that selection. In the individual mode, the child has to interact alone with the game.

The game contains seven mini-games distributed in five historical ages: Prehistory, Ancient Times, the Middle Ages, the Early Modern Period, and the Contemporary Period.

Fig. 3: Screenshot of the game showing the 3D buttons

4. Description of the study

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

4.1. Participants

Forty-six children participated in the study. There were 22 boys (47.83%) and 24 girls (52.17%). They were between seven and ten years old, and they had already finished the third grade of primary education. The mean age was 8.52 ± 0.59 years old. The children were attending three different summer schools in Valencia, Spain. Since the children attended summer school they knew each other before the study; however, we did not take into account whether or not they were friends. This aspect could be considered in a future study.

4.2. Measurements

Two questionnaires in a web-based format (PQ1 and PQ2) were used to obtain information from the children. The PQ1 questionnaire, which is related to knowledge, consisted of thirteen questions (Table 6). This questionnaire helped to determine the previous knowledge or the knowledge acquired playing the game. By comparing the answers given by the children before and after playing the game, we were able to determine if there had been an increase in knowledge. The PQ2 questionnaire, which is related to different aspects such as experienced fun, usability, or preferences, consisted of eleven questions (Table 7).

4.3. Procedure

The study lasted over one month (July, 2012). Each child played only one time and only in one day. The entire activity (pre and post questionnaires and game play) lasted 30 minutes. The participants were assigned to one of the following two groups:

- Group A: Participants that played in pairs (couples). These couples were made up of one boy and one girl, two boys, or two girls.
- Group B: Participants that played on their own with no other company than the person monitoring the game.

The person that monitors the activity only guides the children in the steps to follow. In other words, the person tells the children to sit down and to fill out the questionnaires and accompanies the children to the playing area. This person does not interfere during the activity unless the children have interaction problems (do not know how to select the buttons) or technical problems (game failure). Figure 4 shows graphically the procedure for the two groups. The protocol used was the following:

A pair of children from Group A or a child from Group B filled out the pre-test questionnaire (PQ1). Then, these children played with the autostereoscopic game. Afterwards, they filled out the post-test questionnaire on-line (PQ1+PQ2). This process was continuous with no pauses between the pre- and post-phases. All the questionnaires were filled out on-line and individually just before and immediately after playing the game. The children were not helped with the answers. The children could not talk with each other while they were filling out the questionnaires. Since the questionnaires were filled out on-line, the answers were automatically stored in a remote database for later treatment.

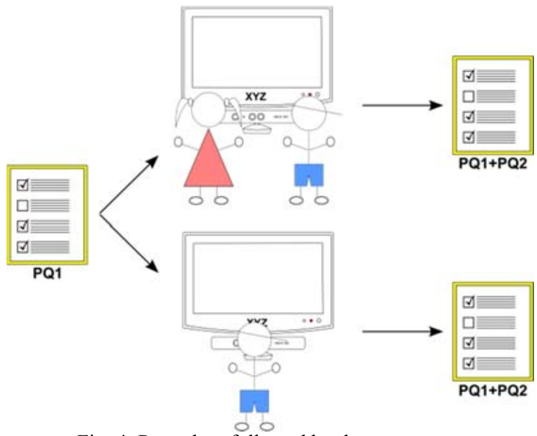


Fig. 4: Procedure followed by the two groups

5. Results

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

5.1. Learning outcomes

In order to measure how much the children learned, the *knowledge* variable was analyzed before playing (Pre-test) and after playing (Post-test). The *knowledge* variable was created to condense the thirteen knowledge questions (Table 6) by counting the number of correct answers. Several *t*-tests were performed to determine if there were statistical differences in the knowledge acquired. Figure 5 shows the box plot for the scores before and after playing. A high dominance of correct answers after playing the game (PosCouple and PosIndiv) over the pre-test (PreCouple and PreIndiv) can be observed.

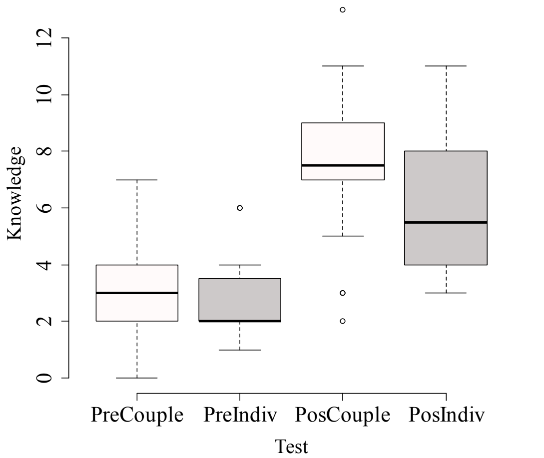


Fig. 5: The scores for the knowledge variable in the questionnaires before and after playing in couples or individually

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 were statistically significant differences between the initial knowledge in both pretests, an unpaired *t*-test was performed between PreCouple (3.00 ± 1.60) and PreIndiv (2.80 ± 1.50) ($t[44] = 0.32$, $p = 0.75$, Cohen's $d = 0.10$) where no statistically significant differences were found. From a paired *t*-test, the scores of the knowledge variable between PreCouple (3.00 ± 1.60) and PosCouple (7.70 ± 2.50) showed statistically significant differences ($t[29] = -10.65$, $p < 0.001$**, Cohen's $d = -1.94$). Another paired *t*-test between the PreIndiv (2.80 ± 1.50) and the PosIndiv (6.00 ± 2.70) questionnaires revealed statistically significant differences ($t[15] = -4.58$, $p < 0.001$**, Cohen's $d = -1.14$). Finally, in order to determine if there were statistically significant differences between the acquired knowledge in the two groups, another unpaired *t*-test was performed between the knowledge in PosCouple (7.70 ± 2.50) and the knowledge in PosIndiv (6.00 ± 2.70) ($t[44] = 2.15$, $p = 0.037$**, Cohen's $d = 0.66$) showing that the knowledge gained while playing in couples was significantly higher than the knowledge acquired while playing alone. To complete the analysis and determine which questions had statistically significant differences, several *t*-tests were performed. For the *t*-test between PreCouple – PosCouple, the children acquired more knowledge in 9 of the 13 questions. For the *t*-test between PreIndiv – PosIndiv, the children acquired more knowledge in 6 of the 13 questions. For the *t*-test between PosCouple – PosIndiv, the children acquired more knowledge in only one question (Q8) playing in pairs.

A multifactorial ANOVA test was also performed to take into consideration several factors simultaneously. The factors of gender, age, and game mode were between subjects. The effect size used was the partial Eta-squared (η^2). This analysis is shown in Table 1, where the results showed that there were statistically significant differences in the gender and age factors, with *p*-values of less than 0.04. The effect sizes revealed that the most influential factor was age (medium-large effect size). This was followed by gender, which also had a medium-large effect size, but it was less than the age factor. A Tukey post-hoc test showed that the acquired knowledge was significantly different between children of ages 8 and 9.

Table 1

Multifactorial ANOVA for the knowledge variable. N = 46

Factor	d.f.	*F*	*p*	*partial* η^2
Gender	1	4.82	0.034**	0.112
Age	3	1.74	0.028**	0.119
Couple / Individual	1	2.09	0.15	0.05
Gender:Age	1	0.91	0.34	0.02
Other Interactions	1	<2.29	>0.13	<0.056

Figure 6 shows the interaction plot between gender and the two modes of playing; it shows that boys acquired more knowledge than girls. Figure 7 shows the interaction plot between gender and age, where it is clearly evident that children in older ages had higher scores than younger children.

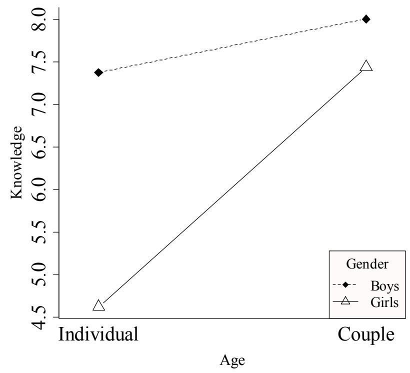


Fig. 6: Knowledge scores by gender and playing mode

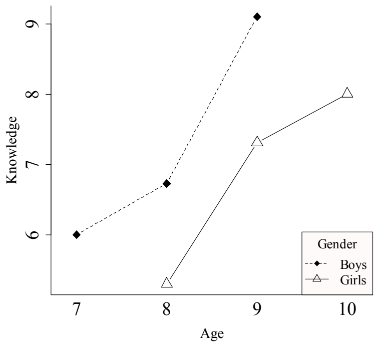


Fig. 7: Knowledge scores by gender and age

5.2. PQ2 outcomes

The aspects not related to knowledge were determined by the questions Q14 to Q24 shown in Table 7. Their analysis is shown in Table 2. As Q14 shows, most of the children stated that they had a lot of fun while playing the game. Moreover, the children scored the game with 9.57 over 10 (Q23). We also asked the children to rate how difficult the game was (Q16); the results indicated that they found the game easy to play. The questions about the avatar (Q20 and Q21) were also scored highly; most of the children liked the avatar and they also thought that the avatar helped them a lot during the game.

To determine if there were statistically significant differences between the two game modes with respect to PQ2 questions, a *t*-test analysis was performed.

Table 3 shows the results of this test. Statistically significant differences were only found in Q18, where the children were asked about the difficulty of selecting the answers. As the results indicate, the children who played the collaborative mode found it easier to select the answers than the children who played the individual mode.

Table 2

PQ2 results

#	Bounds	Mean	Answer
Q14	[1-5]	4.85±0.36	Very much
Q15	[1-5]	3.47±0.69	To several friends.
Q16	[1-5]	3.96±0.78	Easy
Q17	[1-5]	4.63±0.53	Good
Q18	[1-5]	4.02±0.82	Easy
Q19	[1-5]	4.67±0.51	A lot
Q20	[1-5]	4.48±0.83	A lot
Q21	[1-5]	4.22±0.83	A lot
Q22	[1-5]	4.46±0.71	A lot
Q23	[1-10]	9.57±0.77	Very good

Table 3

Means and standard deviations for PQ2, *t*-test analysis, and Cohen's *d*. d.f. = 44

#	Collaborative	Individual	*t*	*p*	*d*
Q14	4.83±0.38	4.87±0.34	-0.37	0.72	-0.11
Q15	4.40±0.77	4.60±0.51	-0.91	0.37	-0.29
Q16	4.06±0.58	3.75±1.10	1.31	0.20	0.41
Q17	4.70±0.47	4.5±0.63	1.22	0.23	0.38
Q18	4.20±0.73	3.60±1.10	2.24	0.03**	0.71
Q19	4.66±0.55	4.68±0.48	-0.13	0.90	-0.04
Q20	4.53±0.68	4.37±1.10	0.61	0.55	0.19
Q21	4.16±0.99	4.31±0.48	-0.56	0.58	-0.17
Q22	4.40±0.67	4.56±0.81	-0.72	0.47	-0.22
Q23	9.56±0.73	9.56±0.89	0.02	0.99	0.01

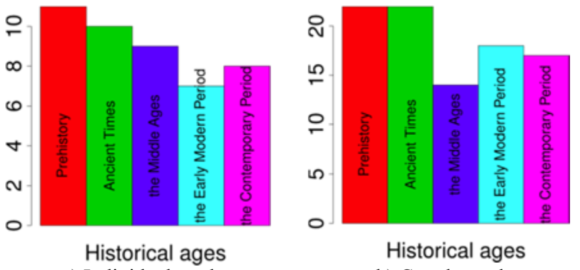
In order to have a global score for the questions included in the PQ2 questionnaire, we used a new variable, called *satisfaction*. This variable consists of the sum of all the values of questions Q14 - Q23 given by each child. To analyze the *satisfaction* variable, a multifactorial ANOVA test was performed. Table 4 shows the results. In this case, no statistically significant differences were found between the different factors.

Table 4

Multifactorial ANOVA for the satisfaction variable. N = 46

Factor	d.f.	*F*	*p*	*partial* η^2
Gender	1	0.003	0.95	0.0001
Age	3	0.88	0.459	0.068
Couple / Individual	1	1.82	0.185	0.048
Gender:Age	1	0.66	0.419	0.018
Other interactions	1	<1.51	>0.22	<0.04

For Q24, which asked the 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 individual mode and the children who played in couples are compared, some differences can be observed as shown in the bar plots in Figure 8. The preferred historical ages were Prehistory and Ancient Times.



a) Individual mode b) Couple mode

Fig. 8: Comparative frequencies of the mini-games that the children liked the most.

A Chi-squared test was performed to analyze the children's preferred mini-game. Table 5 shows the results of this test. These results show that there were no statistically significant differences between the two game modes. The Prehistory and the Ancient Times mini-games were the most voted as the preferred mini-games in the two groups (collaborative and individual).

Table 5

Modes of the preferred mini-game, Chi-squared analysis and Cramer's V

Age	Collab.	Indiv.	χ^2	d.f.	N	p	V
Pre.	1	1	0.00	1	46	1.00	0.05
Anc.	1	1	0.18	1	46	0.67	0.11
Mid.	0	1	0.10	1	46	0.76	0.09
Mod.	1	0	0.55	1	46	0.46	0.16
Cont.	1	0	0.01	1	46	0.90	0.06

5.3. Correlation analysis

An analysis was performed to determine if there was a correlation among any of the questions. When analyzing the two groups together, a correlation between Q20 (avatar) and Q23 (score the game) was found (0.667, $p < 0.001$). This means that the avatar character was an important factor in the children liking the game. When analyzing the groups separately, the same correlation was found in the individual group. All the correlations found for the individual group are shown in Figure 9. From these results, we can state that the level of fun the children had while playing the game is related to the score they gave to the game. We can also affirm that the more they learned, the more fun they had. It can also be observed that the avatar plays an important role, since there is a high correlation with the score that the children gave the game.

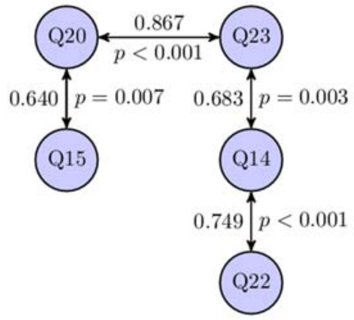


Fig. 9: Correlations in the individual group

When considering groups formed only by boys and groups formed only by girls separately, there were different correlation results. In the group of boys, there was a correlation between Q15 and Q23 (0.648, $p = 0.001$). For the group of girls, the correlations found are shown in Figure 10. It can be observed that the score (Q23) is directly related to the children's perception of having learned (Q22), having liked the images (Q19) and the avatar (Q20), and children's perception that the avatar had helped (Q21).

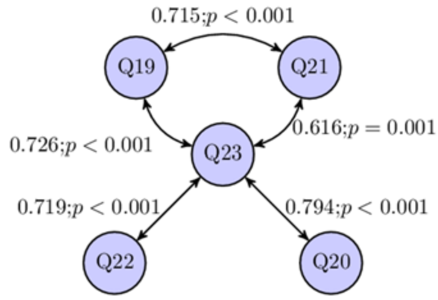


Fig. 10: Correlations in the group of girls

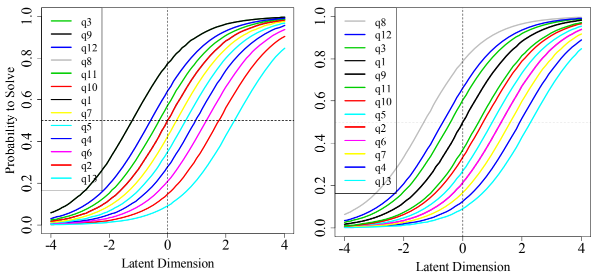
When considering groups organized by age separately, in the group of 8-year-old children, the strongest correlations were between Q20 and Q23 (0.574, $p = 0.006$), and between Q20 and Q21 (0.552, $p = 0.009$). For the group of 9-year-olds, the most correlated question was about the fun experienced (Q14). The more fun they had, the more they would recommend the game to friends (0.665, $p < 0.001$), and the more they liked the avatar (0.729, $p < 0.001$).

5.4. Rasch model

In order to complete the analysis, the dichotomous Rasch model proposed by Georg Rasch was used. This model measures a person's latent trait level from a probabilistic perspective [49]. The probability of a user answering a question correctly relies on the user's underlying ability and the difficulty of question [50].

Figure 11 shows the Item Characteristic Curve (ICC) for every question. The latent dimension shows the ability of the children measured in the interval [-4, 4], with 0 being a child with medium ability. The curve indicates the probability that a child of each ability has to correctly answer a question. The dotted lines represent the medium values of each axis (0 for ability and 0.5 for probability). Figure 11a shows the ICC for the group of children who played individually. It can be observed that for the individual group, the hardest question was Q13, where it was necessary for a child to have an ability value of 2 in order to have a probability of 0.5 to answer the question correctly. The easiest questions were Q3 and Q9 (which had the same value), where a child with an ability value of -1 was enough to have a probability of 0.5 to answer correctly. The most balanced question in this group was Q10, which needed an ability of 0 (the medium value) to have a probability of 0.5.

Figure 11b shows the group of children who played collaboratively. The order of the questions changed a little. The hardest question was also Q13, but the easiest one was Q8. The most balanced questions were Q1 and Q9.



a) Individual b) Couple

Fig. 11: Item Characteristic Curve (ICC) for all questions

A graphical model check was also performed, where the questions were grouped by raw scores and the ones which are higher than the mean are separated from the ones which are lower. The red lines represent the confidence bands. The results of the questions for the collaborative group are shown in the graph in Figure 12. In this case, every question was inside the confidence bands, except Q8. This indicates that Q8 is an easy question. In fact, this question was answered correctly by almost every child in the collaborative group. In the individual group, all the questions were inside the confidence bands (not shown in the paper). This result is in line with the result obtained when each knowledge question was analyzed, in which the *t*-test between PosCouple – PosIndiv indicated that the children acquired more knowledge in only one question (Q8).

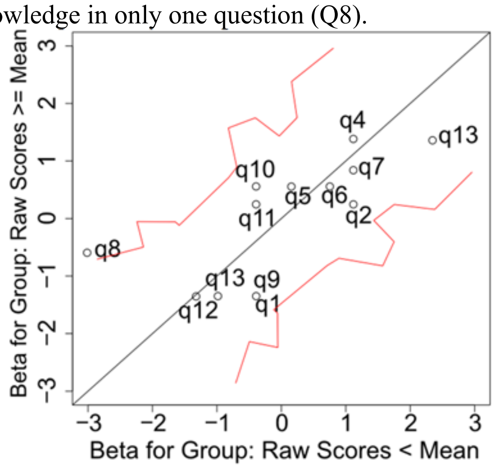


Fig. 12: Graphical model check for the collaborative group

Based on the results of the ICC and the graphical model check, it can be concluded that the questions are appropriate for the assessment of the acquired knowledge for both game modes.

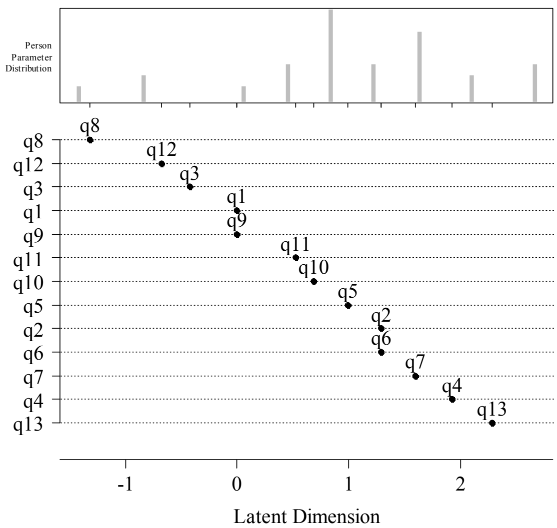


Fig. 13: Person-Item Map for the collaborative group

In order to visually check the children and the questions, a Person-Item Map was plotted, where the estimated ability of the child and question difficulty measures are placed side by side in one vertical dimension. The questions appear in order of difficulty. The Person-Parameter Distribution, which is at the top of the graph, is a distribution of the children's abilities. For the collaborative group, it can be observed in Figure 13 that the hardest question (Q13) was easier than the ability of 10.34% of the children. On the other hand, the easiest question (Q8) was more difficult than the ability of 3.44% of the children. The question in the middle (Q11) was easier than the ability of 75.86% of the children and more difficult than the ability of 24.14%. For the individual group, the hardest question (Q13) was easier than the ability of 6.25% of the children, and the easiest questions (Q3 and Q9) were more difficult than the ability of 18.75% of the children. The question in the middle (Q5) is easier than the ability of 68.75% of the children, and more difficult than the ability of 31.25% of the children.

When the Person Parameter Distribution of the children who played individually and in couples were compared separately, we obtained the distributions shown in Figure 14. In the distribution of children who played collaboratively, most of the values are situated in higher values of ability, between 0 and 2. In contrast, the opposite happens when looking at the distribution of children who played individually, where most of the values are situated in values of less ability. This indicates that the collaborative mode provides more ability to correctly answer the questions.

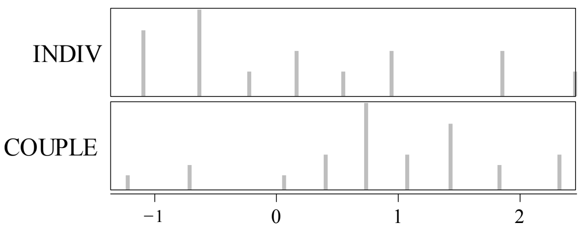


Fig. 14: Comparison of Individual and couple Person Parameter Distribution

The Rasch model is also based on the idea that the conditional maximum likelihood estimation of the item parameters is independent of the actual values of the individual parameters. This means that it can be expected to get the same item parameter estimations from individuals with high raw scores as from individuals with low raw scores; however, this only happens when the model is true. To determine if the model is true, the test proposed by Andersen [51] can be used. This test is based on a comparison between the difficulties estimated from different score groups and over-all estimates, resulting in a conditional likelihood ratio. Andersen stated that 2 times the logarithm of this ratio is χ^2-distributed when the Rasch model is true. In our study, this test offered the values, LR-value = 8.828, df = 12, $p = 0.718$, which fit the χ^2 distribution. Therefore, in our study the Rasch model is true.

6. Discussion

When the answers given by the children before playing the game in the two modes were analyzed, no statistically significant differences were found. This means that the two groups of children had similar knowledge about the topic of the game before playing, which therefore assures the homogeneity of the two groups for the statistical analysis. Nevertheless the samples were checked beforehand to determine that they come from a normal distribution.

Statistically significant differences were found when the knowledge variable of the children before and after playing with the two modes (collaborative and individual) was analyzed. Therefore, it can be concluded that play our historical content game positively affected the learning outcomes of the participants. This indicates that the children remembered quite a lot of the knowledge transmitted in the game. For this reason, we can say that our game has been effective when it comes to transmitting knowledge in the short-term.

When the results obtained after playing the two modes were compared, statistically significant differences were found in favor of the collaborative mode. If the Person Parameter Distribution is taken into account, it also indicates that the collaborative mode provides more ability to correctly answer the questions. In other words, the ability to correctly answer the learning questions was higher in the group of children who played the game collaboratively. Therefore, we can conclude that the collaborative mode facilitates learning to a greater extent than the individual mode.

The results show that the game transmits knowledge effectively both collaboratively and individually. At this point, we would like to highlight that the percentage of correct answers for most of the questions (11 of 13) was higher in the collaborative mode. Since our hypothesis was that the children would learn more by playing the game in the collaborative mode than in the individual mode, our hypothesis has been corroborated. Finally, we believe that this result is very encouraging because it implies that games of these characteristics are suitable for both collaborative and individual learning, and that collaboration positively affects learning outcomes.

In the analyses of other aspects such as experienced fun, usability, or preferences, there were no statistically significant differences for the 10 analyzed questions, except for Q18. The results indicate that the game was easy to use and the children had fun while playing it. Most of the children would recommend the game to their friends and, generally, they scored the game very high. It is also important to have some kind of guide such as the figure of the avatar throughout the game. From the results, we observed that the children valued this character highly. They thought the avatar helped them a lot during the game. The high scores assigned to the questions related to the avatar and the correlations found corroborate the importance of the two design guidelines indicated by Villalta *et al.* [48] (Interactivity and guidance, and accessible language).

We would also like to discuss the ease of use and its implications. Several authors argued that perceived ease of use is an important technical factor that affects educational effectiveness [52–54]. Based on their findings, Sun *et al.* [55] stated 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. Since our game was easy to use, we consider that the game does help students focus their attention on the learning content.

7. Conclusions

The game included playful interaction and autostereoscopic visualization. The game was designed following general learning theories and guidelines for collaborative games, and the mechanics of the game are linked to learning objectives as suggested by Villalta *et al.* [48]. We performed a study to determine whether playing collaboratively or individually affects several aspects. To our knowledge, this is the first time that this combination has been used to develop a learning environment for children that has been compared for playing collaboratively or individually.

The results were very positive for learning in the short-term: the children acquired new knowledge; the collaborative and the individual modes facilitated an improvement in knowledge (the collaborative mode facilitated learning to a greater extent); boys improved their knowledge more than girls; and older children improved their knowledge more than younger children (especially between 9-year-old and 10-year-old children). From the analyses, it is not possible to determine why the boys improved their knowledge more than girls. Further studies should be carried out to study this.

With regard to the use of this game at school, we believe it could be used in class for learning purposes. It could probably be helpful as a reinforcement in learning environments like classrooms. In our opinion, the designed game can be an important educational resource in the classroom because of its close relationship with the content of school curriculum and its highly motivational component as a tool to introduce or reinforce classroom content. However, the use of this technology at school has several drawbacks. First, there is a cost issue because the autostereoscopic displays are quite expensive. Second, the number of children that could use the system at the same time is limited; this is especially true for the autostereoscopic display because the number of users that can have correct depth perception is limited. This limitation is also present for interaction. In the current configuration, the game is for two users. Modifications for more users are possible, but this number is also limited. One possibility to facilitate its introduction in the classroom is to use the TV set, computer monitor or projector that is used normally in the classroom as the visualization device. In this case, the visualization will not be autostereoscopic, but it could still be an adequate system. Nevertheless, a study that compares this new type of visualization with the autostereoscopic display will be required to determine its benefits.

From our work and previous experiences, we consider that playing games using the entire body as controller and an autostereoscopic vision is metaphorically similar to the real-world experience, and it allows a fully playful interaction. In addition, the user has depth perception. With regard to the interaction with the Kinect, some 7-year-old and 8-year-old children had trouble being calibrated by the Kinect sensor due to their short height and the position of the device. To have a larger field of view, two Kinects or the new Kinect (version 2) can be used. The sensor of the new Kinect will theoretically have a wider field of view, going from 57.5º horizontally and 43.5º vertically to 70º horizontally and 60º vertically.

Several authors affirm that entertainment is an important factor that helps to improve learning [56,57]. With systems like ours, children can use new technologies to learn and have fun at the same time.

Nowadays, many video-games use techniques like Natural User Interfaces (e.g., Wii or Kinect) or 3D displays (which are not so common).

For future work, the game could be enhanced by adding other play modes that are not only collaborative but also competitive. In this paper, we have 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, or using a collaborative desktop computer game or a tabletop computer game. According to Bachour *et al*. [17], if participation is not balanced in a collaborative learning situation, the children who participated less would get worse scores than those who participated more. We tried to facilitate this balance. However, a formal study could be carried out to determine the influence of the most active child when they play in pairs/groups. Since the evaluation was made by filling out some on-line questionnaires, making these questionnaires more interactive by using the same devices on which they played the games would make the children more willing to fill them out. Another challenge could be to make the game less linear and predictable. One extension could be to add activities that have a gradual increase in difficulty [48]. Another possible extension could be to add open skills such as learning objectives and ill-structured tasks [43]. The autostereoscopic vision could be improved by displaying the video image in 3D and not just the virtual objects. This can be done by using several cameras to capture the real-world image. Augmented Reality could also be considered [58]. With the emergence of handheld devices with autostereoscopic capabilities (e.g., Nintendo 3DS or LG Optimus 3D), the game could be adapted to these devices and a comparison could be carried out. Finally, considering playful interaction and autostereoscopy, we firmly believe that new games could be developed to support learning not only for children, but also for adults. Moreover, current devices allow the development of serious games with playful interaction for different areas such as healthcare.

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10. APPENDIX

Questionnaire used in the experiment

Table 6

PQ1. Knowledge questions (numbered as in the questionnaires)

#	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) Ocher f) Black
Q4	Ancient Times started with the: a) Invention of wheel b) Invention of writing c) Discovery of America d) Fall of Roman Empire e) Invention of 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) 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 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 history 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 7

PQ2 (numbered as in the questionnaires)

#	**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]