Universidad Politécnica de Valencia

Departamento de Sistemas Informáticos y Computación

Master Thesis

Using Natural User Interfaces to support learning environments

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To my family,
for being always there.

“Hizkuntza bat ez da galtzen ez dakitenek ikasten ez dutelako, dakitenek hitz egiten ez dutelako baizik.”

(“Una lengua no se pierde porque los que no la saben no la estudian, sino porque los que la saben no la utilizan.”)

(“A language is not lost because those who do not know how to speak it do not learn it, it is lost because those who can, do not use it.”)

— Joxean Artze

Abstract

Education is a field of research in which Natural User Interfaces (NUI) have not been exploited. NUI can help in the learning process, specially when using with children. Nowadays, children are growing up playing with computer games, using mobile devices, and other technological devices. New learning methods that use these new technologies can help in the learning process.

In this thesis, a new system that uses NUI for learning about a period of history has been developed. This system uses autostereoscopy that lets the children see themselves as a background in the game, and that renders the elements with 3D sensation without the need for special glasses. This system has been developed from scratch. The Microsoft Kinect is used for interaction.

A study for comparing the autostereoscopic system with a similar frontal projected system was carried out. This study analyzed different aspects such as engagement, increase of knowledge, or preferences. A total of 162 children from 8 to 11 years old participated in the study. From the results, we observed that the different characteristics of the systems did not influence the children's acquired knowledge, engagement, or satisfaction; we also observed that the systems are specially suitable for boys and older children (9-11 years old). There were statistically significant differences for depth perception and presence in which the autostereoscopic system was scored higher. However, of the two systems, the children considered the frontal projection to be easier to use.

Another comparative study was performed to determine the mode in which the children learn more about the topic of the game. The two modes compared were the collaborative mode, where the children played with the game in couples; and the individual mode, where the children played with the game solo. A total of 46 children from 7 to 10 years old participated in this study. From the results, we observed that there were statistically significant differences between playing with the game in the two modes. The children who played with the game in couples in the collaborative mode got better knowledge scores than the children who played with the game individually.

Finally, we would like to highlight that the scores for all the questions were very high. The results from the two studies suggest that games of this kind could be appropriate educational games and that autostereoscopy is a technology to exploit in their development.

Resumen

La educación es un campo de investigación en el que las Interfaces de Usuario Naturales (NUI) no se han explotado demasiado. Las NUI pueden ser útiles en el proceso de aprendizaje, especialmente cuando se trata de niños. A día de hoy, los niños crecen jugando con juegos de ordenador, utilizando dispositivos móviles y otros dispositivos tecnológicos. Con nuevos métodos que utilicen alguna de estas nuevas tecnologías se podría mejorar el proceso de aprendizaje.

En esta tesina se ha desarrollado un nuevo sistema que utiliza la tecnología NUI para aprender sobre un periodo de la historia. Este sistema utiliza la visión autoestereoscópica, la cual permite a los niños verse a ellos mismos en el fondo de pantalla del juego, y que tiene la capacidad de visualizar los elementos del juego con una sensación 3D sin la necesidad de utilizar gafas especiales. Este sistema ha sido desarrollado desde cero como la parte de programación para esta tesina. El dispositivo Microsoft Kinect ha sido utilizado para la interacción.

También se ha llevado a cabo un estudio comparativo con un sistema similar basado en proyección frontal. Este estudio ha tenido en cuenta diferentes aspectos como la satisfacción, cuánto han aprendido mientras jugaban o sus preferencias. Un total de 162 niños de 8 a 11 años han participado en este estudio. Por los resultados, observamos que las diferentes características de los sistemas no han influido en el aprendizaje, en la usabilidad o en la satisfacción; también observamos que los sistemas son especialmente apropiados para chicos y niños mayores (de 9 a 11 años). Se han observado diferencias estadísticamente significativas en la percepción de la profundidad, donde el sistema autoesterescópico fue puntuado mejor. Sin embargo, de los dos sistemas, los niños consideraron que el sistema de proyección frontal era más fácil de manejar.

También se ha realizado otro estudio para determinar el modo con el que los niños pueden aprender el tema del juego a un mayor nivel. Los dos modos comparados han sido el modo colaborativo, en el que los niños jugaban por parejas; y el modo individual, en el que los niños jugaban solos. Un total de 46 niños de 7 a 10 años han participado en este estudio. Por los resultados, observamos que existen diferencias estadísticamente significativas entre jugar al juego de un modo o de otro. Los niños que jugaron al juego en parejas en el modo colaborativo obtuvieron un mejor resultado que los niños que jugaron al juego en el modo

individual.

Finalmente, queremos también señalar que las puntuaciones para todas las preguntas han sido muy altas. Los resultados de estos dos estudios sugieren que los juegos de este tipo pueden ser apropiados para la educación y que la autoestereoscopía es una tecnología a explotar en el desarrollo de juegos educativos.

Acknowledgements

First and foremost I want to thank to my supervisor M. Carmen Juan, her expert guidance, her patience and her stimulating ideas have been the basement onto which this thesis has been built.

Another important ingredient in the realization of this thesis has been the good atmosphere created by my colleagues in the Universidad Politécnica de Valencia: Vicente Broseta, Santiago González, David Furió, Juan Martínez, Flabio Gutiérrez, Gustavo Rovelo, Armando de la Re. Thanks to all of them. They have made me feel as at home.

There have been some other people who, at some way or other, have helped me in this journey but are left unmentioned. I hope I can name them on other occasions.

Finally, thanks to my parents, my sister, my family and friends for their positive attitude, understanding and support. This thesis is dedicated to all of them.

Definitions and abbreviations

Throughout this thesis several terms that have a specific meaning have been used. Following, there is a list of definitions and abbreviations ordered alphabetically.

Augmented Reality (AR) AR is a specific type of Mixed Reality where most of the information is real and virtual objects are coherently located onto the real scene.

Autostereoscopic vision Autostereoscopy is any method of displaying stereoscopic images (adding binocular perception of 3D depth) without the use of special headgear or glasses on the part of the viewer.

Cave Automatic Virtual Environment (CAVE) CAVE is an immersive virtual reality environment where projectors are directed to three, four, five or six of the walls of a room-sized cube.

Head-Mounted Display (HDM) HDM is a device that allows the rendering of computer generated imagery in a display close to the eyes. It can allow the visualization of AR from the user's perspective.

Human-Computer Interaction (HCI) HCI is a very active research area where the interaction with computers is studied, and usually involves highly multidisciplinary studies. It also refers to any kind of possible interaction and communication between a machine and a person.

Mixed Reality (MR) MR refers to the synthesis of virtual and real imagery that creates a combined scene of virtual and real information in any kind of proportion.

Natural User Interfaces (NUI) NUI is the common definition used by designers and developers of human-computer interfaces to refer to a user interface that is effectively invisible, or becomes invisible with successive learned interactions, to its users, and is based on nature or natural elements.

Open Graphics Library (OpenGL) OpenGL is a cross-language, multi-platform API for rendering 2D and 3D computer graphics. The API is typically used to interact with a GPU, to achieve hardware-accelerated rendering.

Open Natural Interaction (OpenNI) OpenNI is a framework that provides a set of open source APIs. These APIs are intended to become a standard for applications to access natural interaction devices.

Open Scene Graph (OSG) OSG is an open source 3D graphics application programming interface, used by application developers in fields such as visual simulation, computer games, virtual reality, scientific visualization and modeling. The toolkit is written in standard C++ using OpenGL.

Radio Frequency Identification (RFI) RFI is the use of a wireless non-contact system that uses radio-frequency electromagnetic fields to transfer data from a tag attached to an object, for the purposes of automatic identification and tracking.

Red Green Blue (RGB) RGB is an additive color model in which red, green, and blue light are added together in various ways to reproduce a broad array of colors.

Software Development Kit (SDK) SDK is typically a set of software development tools that allows for the creation of applications for a certain software package, software framework, hardware platform, computer system, video game console, operating system, or similar platform.

Stereoscopic vision Stereoscopy is a technique for creating or enhancing the illusion of depth in an image by means of stereopsis for binocular vision.

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I

Introduction

Introduction

1

"明人不用细说，响鼓不用重锤。"

(A person of good sense needs no detailed explanation; a resonant drum needs no heavy beating.)

(A buen entendedor, pocas palabras bastan.)

— Chinese proverb

1.1 Motivation

The rapid development of technology has provided a lot of new and advanced systems that were unimaginable six years ago. Nowadays, the use of technological systems is common for daily tasks such as playing at home. Microsoft Kinect has revolutionized the gaming market, and it has also been a revolutionary device for Natural User Interfaces (NUI). Microsoft Kinect consists of two frontal cameras (one is an RGB camera similar to a webcam, and the other is an infrared camera) and one infrared emitter. Microsoft Kinect is widely used in video-games by connecting it to an Xbox console, but this is not its only purpose. The Microsoft Kinect driver, OpenNI, or Libfreenect (the software developed by the OpenKinect community) facilitate the programming of Microsoft Kinect for PCs. These facilities have led the natural user interaction to be incorporated in a large number of different types of applications (Chang et al., 2011b). However, NUI have not been extensively exploited in learning environments. From our point of view, this technology is on the right track for being a good complement to the traditional educational approach.

Nowadays, it is also common to have stereoscopic visualization. This means that a 3D sensation will be perceived by the user. To achieve stereoscopic visualization, three main technologies are used: passive, active, and autostereoscopic. The main difference between active/passive stereoscopy and autostereoscopy is that the autostereoscopic visualization generates the 3D sensation without the use of special glasses or other headgear. There are several previous works related to autostereoscopy (e.g. (Maimone et al., 2012)).

In this thesis, we compare two different systems that use NUI for the same purpose. Comparing two or more systems that are for the same purpose is quite common. The differences between the systems can be, for example, in the visualization (e.g. Juan and Calatrava (2011) compared video see-through and optical see-through HMD systems for the treatment of phobia to small animals). In our systems, the Microsoft Kinect device was used to recognize the user's gestures. The first system consists of a projected surface that is used as an interactive table. The second system uses an autostereoscopic display as the visualization device, and it merges the image from the real world captured by the camera with the virtual elements. Different technologies such as Augmented Reality (AR) have been used to develop educational systems. Taking into account Azuma's definition of AR (Azuma, 1997), our autostereoscopic system cannot be considered an AR system; however, it shows the real world captured by the Kinect camera as the background and mixed virtual elements. The main difference between the two systems is that in the autostereoscopic display the interaction between the user and the system is made by using gestures and selecting the elements that appear on the screen; in the frontal projection system the interaction is achieved on a table. Another difference is that in the autostereoscopic system, the visualization of the models has 3D sensation, and the visualization of the projected system is not stereoscopic. Using the combinations of projected surface + Kinect and autostereoscopic display + Kinect, we designed an educational about historical ages, specifically, five time periods in history (Prehistory, Ancient Times, the Middle Ages, the Early Modern Period and the Contemporary Period). To our knowledge, this is the first study in which a comparison between projected surface + Kinect and autostereoscopic display + Kinect has been presented. The use of history as the subject of a computer game is also novel and has not been considered for the design of games that use new technologies, such as interactive tables, mobile devices, Virtual or AR.

Also, in a second study, we compared two different game modes in order to determine with which of them the children increase more their knowledge about the topic of the game. These modes were the collaborative mode, where the children played with the game in couples, and the individual mode, where the children played with the game solo.

1.2 Scientific goals and research hypotheses

The main objective of this thesis is to determine the goodness of new technologies, such as Natural User Interfaces and autostereoscopy, in a learning environment for children. To achieve this, we have established several goals:

- To develop a video-game that can attract attention from children and engages them.
- To design that video-game with an educational background, letting the children to increase their knowledge about some topics.
- To study the interaction of the children with an autostereoscopic display, comparing it with another display technology like frontal projection.
- To study the interaction of the children with Natural User Interface technology.
- To study the effect on children of a collaborative learning against an individual learning.
- To test the systems with a statistically significant number of children.
- To design some questionnaires capables of retrieve data for analysis.
- To measure learning and satisfaction outcomes from the answers to those questionnaires.
- To provide a thorough statistical analysis of the results.

To achieve these goals, the video-game mentioned above and two different studies had been performed, as detailed next:

1. **Development of a new system that combines autostereoscopy and NUI: The passage of time, learning about different historical periods (The game)**:

   For this goal, a system that combines autostereoscopic technology and NUI for the interaction with the user has been developed from scratch. This developed has been done by using the C++ programming language, OSG for the rendering, and other libraries for video and audio. Also, for the

NUI part, the OpenNI has been used. The autostereoscopic visualization is achieved by using the Mirage SDK[1]. This SDK provides and OSG node that can be inserted in the graph scene and takes charge generating the eight views that the autostereoscopic visualization needs. The game developed consisted of five stages corresponding to five historical ages, and some mini-games inside each stage. When the children arrive at the final stage, they would be able to recreate the time line by ordering every historical age.

2. **Autostereoscopy against Frontal Projection (Study 1)**:

   One of the objectives of this study was to find out which system was most appreciated by the children. The first of our three hypotheses is that the children will prefer the autostereoscopic system over the frontal projection system. The second of our hypotheses is that children will increase their knowledge about the subject treated in the game by using the two systems, and that the autostereoscopic system would lead to greater learning results.

   Some of the reasons that support our hypotheses are the following:

   (a) Although the two systems have the same NUI, the autostereoscopic display provides a 3D sensation that improves the immersion in the game.

   (b) While playing, the children can see themselves inside the game in the display, and this gives them a sensation of prominence that encourages them and, consequently, they are more motivated and involved in the game.

   (c) Since the size of the autostereoscopic display is 46 inches, the fact that the children can play video-games using such a big TV makes a deep impression on them and they are eager to start playing.

   The third hypothesis is that the frontal projection system will be easier to use. Support this hypothesis is that nowadays children are accustomed to using actual gadgets and peripherals that are controlled in the same way, which is much different than using a gesture-oriented autostereoscopic system.

3. **Individual against Collaborative learning (Study 2)**:

   One of the objectives of this study was to find out which method the children acquired a higher increment of knowledge with.

   Our main hypothesis is that the children will learn more by playing the game in the collaborative mode over the individual mode.

   Some of the reasons that support our hypothesis are the following:

[1] www.mirage-tech.com

(a) Although the two modes have the same video-game, when playing in the collaborative mode, the children can interact between themselves, and this can improve their learning outcomes.

(b) When playing in the individual mode, the children are not able to interact with anybody and they have to answer every question.

1.3 Thesis structure

The thesis document is structured as follows:

Chapter 1 introduces the study of the document, including the motivation, the scientific goals, the research hypotheses, and this explanation of the thesis structure.

Chapter 2 shows the state of the art, reviewing the most relevant literature relative to this study in Natural User Interfaces, Autostereoscopic vision, Frontal Projection and learning environments.

Chapter 3 describes the developments of the systems used in this thesis, and the software built to develop the game used.

Chapter 4 describes the first study of the thesis, where the system was built and evaluated with children by using the autostereoscopic system and the frontal projection system used for comparing.

Chapter 5 describes the second study of the thesis, where the system was evaluated by the children in two different ways. Some of them played the game in couples (collaborative version), and, the rest, played the game solo (individual version).

Chapter 6 finalizes the work with the conclusions and future work, and presents the publications derived from this thesis.

In addition to this, there is an Appendix Chapter A that shows the questionnaires that had been used in this study.

II

State of the art

State of the art

2

"To know the road ahead ask those coming back."

—

2.1 Introduction

Nowadays, children are growing up using computer games and other technologies that have changed their preferred leisure styles, their social interaction, and even their learning preferences (Bekebrede et al., 2011). This generation is commonly referred to as the "gamer generation" (Beck and Wade, 2004, 2006), "digital natives" (Prensky, 2001), or the "net generation" (Tapscott, 1998). Several fields have benefited from the incorporation of these new advances. There are works that have studied NUI. For example, Shen et al. (2011) used computer vision to detect hand interaction in an AR environment. As Roman (2010) pointed out in the statement "The mouse's days are numbered", the current trend in new devices, games, and consoles is to get rid of all gamepads, joysticks, and other input methods. Largillier (2011) argued that technologies such as tablet interfaces should evolve with the user.

2.2 Natural User Interfaces

NUI allow users to be the controller themselves by detecting the position of the different parts of their body. According to Fishkin (2004), NUI facilitate the acceptance of an application by users. However, adult people are more reluctant to accept the new advances, and more effort is required to introduce these technologies. For example, the study of Carvalho et al. (2012) presented a multi-touch game that was envisioned to encourage and teach digitally excluded people, as shown in Figure 2.1. From its results, they found that the use of NUI may be beneficial to help overcome some difficulties produced by the digital divide.

(a) First impact of the interface (b) Change in behaviour (c) Teamwork

Figure 2.1: Carvalho et al.'s experiment stages

As mentioned above, NUI are being incorporated in a large number of different types of applications: for physical rehabilitation (Chang et al., 2011b; Lange et al., 2011); for training individuals with cognitive impairments (Chang et al., 2011a); for navigating with Google Earth (Kamel Boulos et al., 2011); for videoconference in which depth perception was added to attendants (DeVincenzi et al., 2011); for transforming a paper based process to a NUI process in a chronic care hospital (Anacleto et al., 2012); 3D imaging for hand gesture recognition (Periverzov and Ilieş, 2012); or interaction with 3D objects from touchscreen inputs like the study of Cohé and Hachet (2012), in which non-technical users tended to interact with the objects by 3D cube manipulations. One of the objectives of their work was to find out the most widely used strategies for manipulating the 3D objects. The hardware used in that study was a TouchCo 13-inch multi-touch surface and an Optima video-projector, which was placed perpendicularly to the table, as shown in Figure 2.2. The users sat in front of the video-projector and were asked to interact with the objects.

2.3 Autostereoscopic systems

Several works can also be cited for autostereoscopy. In 2012, Maimone et al. (2012) presented an enhanced personal autostereoscopic telepresence system us-

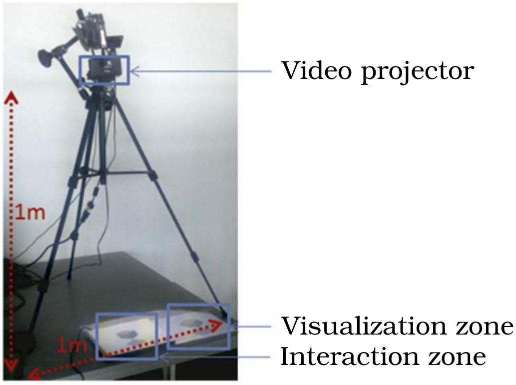
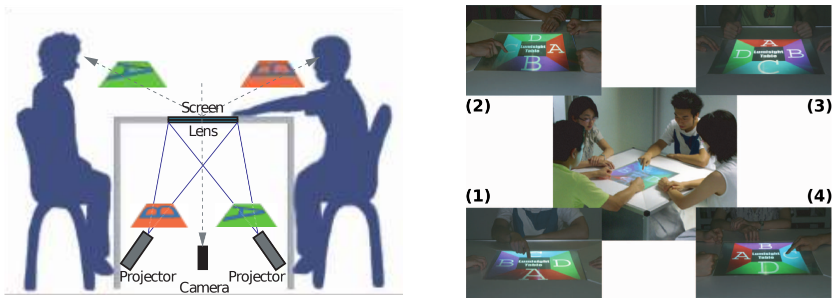


Figure 2.2: Cohe and Hachet's experimental setup

ing depth cameras. Kim et al. (2012) used this technology combined with NUI making an autostereoscopic display for multi-user collaboration. Kim et al.'s study proposed an autostereoscopic platform for sharing visual data with two or more users, which uses two displays. Our proposal shares this use of OpenNI and Kinect. Autostereoscopic systems have also been used for immersion platforms for the World Wide Web as in the work of Nocent et al. (2012) in which tracking devices were used. Taherkhani and Kia (2012) presented an eye-tracking display with autostereoscopy that used a LCD monitor by using the parallax barrier technique, where the two stereo images were rendered on the LCD simultaneously, but in different columns of pixels.

2.4 Frontal Projection systems

Several previous works can also be cited for the frontal projection system. Chan and Lau (2012) presented a CAVE-like system with a projector and some infrared cameras on the ceiling of the CAVE structure. The user held the "Magicpad" in his hands (which mainly consists of one or more flat white surfaces). The user could use an infrared pen for tracking and 3D glasses to look at the Magicpad. Kubicki et al. (2013) presented another work involving interactive tables in which a traffic simulation was developed. A TangiSense interactive table was chosen for this. It is not a tactile table; the interaction is achieved via tangible objects that are placed on the table. It detects overlapping objects by using Radio Frequency Identification (RFID) technology. This technology lets the user handle objects equipped with RFID tags; in this case, for the simulation, these objects were traffic signals. Kakehi et al. (2005) developed an interactive view-dependent tabletop display. It was made up of some cameras and projectors installed under the table, which had a special screen system that allowed multiple images to be projected at the same time without the user having to wear specific devices. This experiment is shown in Figure 2.3.



(a) Overview of the Lumisight Table architecture

(b) Four users' views at the Lumisight Table

Figure 2.3: Kakehi et al.'s interactive view-dependent tabletop display

For entertainment purposes, we find the work of Lam et al. (2006) where a prototype of an AR table was designed for a card game. It consisted of an overhead camera to register card inputs and a plasma display to act as the game board, rendering 3D models and generating sounds. The system was able to recognize player inputs such as pressing command buttons and card inputs. This system needed a calibration process before playing in order to provide a stable environment. According to several works, interactive tables are enjoyable and engaging to use (Rick et al., 2009). They also promote equity of participation (Harris et al., 2009) and encourage learning (Jamil et al., 2011; Pontual and Price, 2009).

This kind of technologies are used too nowadays for music purposes, for instance, as *Tangible music* with the *Reactable* system (Jordà et al., 2007; Kaltenbrunner and Bencina, 2007; Kaltenbrunner, 2009). This is an HCI AR-based interface that they used in their study for producing music; in addition, several musicians had used this system in many concerts.

2.5 Learning environments

Many computer games have been designed with an educational background and for learning purposes, but only few of them perform a deep analysis, as several studies determined (Connolly et al., 2011; Freitas and Campos, 2008; O'Neil et al., 2005). Most of the educational computer games have been developed with no underlying body of research or coherent learning theory (Shaffer et al., 2004). According to Connolly et al. (2007), games-based learning can be defined as the use of computer games-based technology approach to deliver, support, and enhance teaching, learning, assessment and evaluation. Different technologies such as AR have been used to develop educational systems. For example, Construct3D (Kaufmann, 2004) was developed to teach mathematics and geometry. Larsen et al. (Larsen et al., 2005) presented an AR system for learning how to play billiards. The most outstanding characteristic of this system was that the game was played on a real billiard table. Organic chemistry has also been taught using an AR system (Fjeld et al., 2007). In 2009, Wang et al. (Wang et al., 2009) tested three user interface prototypes for learning about heritage temples.

In the *Computer Graphics* research group several AR systems have been developed and tested: a storytelling system (Juan et al., 2008b); a system for learning the interior of the human body (Juan et al., 2008a); systems for learning about endangered animals (Juan et al., 2010b, 2011b), and words (Juan et al., 2010a); or a phone game for learning how to recycle (Juan et al., 2011c). As a result of the APRENDRA project, AR iPhone games for learning multiculturalism, solidarity, and tolerance (Furió et al., 2013b), and the water cycle (Furió et al., 2013a) has also been recently published. These two last games are shown in Figure 2.4.

(a) Child finding an oxygen drop

(b) Non-AR game with the Tablet PC

Figure 2.4: APRENDRA learning games

III

Contributions

Developments

3

"I haven't failed, I've found 10.000 ways that don't work."

— Thomas Alva Edison

3.1 Introduction

In this chapter, the main programming part developed for this thesis is presented. For the autostereoscopic system, detailed information about the hardware and the software used, and how all the technologies that this video-game implies had been integrated is presented.

Also, in this chapter we find the description of the video-game developed and a more detailed explanation of every stage, and the reasons why we chose this topic for develop a game with such as educational background.

3.2 Autostereoscopic system

This system combines autostereoscopic visualization and natural interaction. The real world and users are captured by the camera. This image appears in the background without stereoscopy. The virtual elements are the objects with stereoscopic perception. Therefore, the children could see themselves in the screen. They were able to interact with the game by moving their hands. This interaction was achieved using the Kinect camera, which detects their movements. Figure 3.1 shows a couple of children playing with the autostereoscopic configuration. As Figure 3.4 shows, the autostereoscopic display was placed on a mid-height table which allowed the children to see their entire body on the screen. The Microsoft Kinect was placed in front of the 3D display, which was centered relative to the 3D display. Also, there were two numbered markers at a distance of about 2m. from the display to let the children know the surface area where they should stand.

Figure 3.1: Children playing with the autostereoscopic system.

3.2.1 Hardware

To capture the image of the real world and to track the children's bodies, a Microsoft Kinect device was used, represented in Figure 3.2, which had a camera with a 640×480 pixel image resolution. The autostereoscopic rendering was made possible by using an XYZ display. The specific model was XYZ3D8V46, which had a screen size of 46" and full HD resolution (1920×1080 pixels). This display renders the eight views of the 3D vision. To do this, it uses a technology known as LCD/lenticular (Omura et al., 1998).

3.2.2 Software

The OpenSceneGraph (OSG) toolkit 3.0.1 was used to render the 3D models and the virtual world. It is an open source graphics toolkit that is written in Standard C++ and OpenGL. In OSG the run method calls the main loop. The run method internally calls the frame method which updates the next frame of the graph scene. The problem with this approach is that the behaviour of this loop cannot be modified. To solve this problem, the run method has been replaced by the code shown in Listing 3.1. For our study, with this loop, the scene to render was updated with the children's pose, the sound and the video states.

```
while !done
  update children's pose
  update sound and video
  perform interaction
  frame
end while
```

Listing 3.1: Update main loop

Figure 3.2: Microsoft Xbox Kinect

The autostereoscopic rendering was performed by using the Mirage SDK (http://www.mirage-tech.com). This SDK provides an OSG `Node` that is able to calculate the eight different views needed by the 3D perception. With this node, an OSG scene can be defined by adding cameras, 3D models (in format `.osg` and `.osgt`), transformation matrices, etc... Finally, this node must be established as the root node of the scene graph. Once this scene graph is complete, a 3D perception can be perceived in a display without using any glasses or external devices. Figure 3.3 shows how this integration was achieved.

To render the scene, in our study, the image captured by the camera was shown as a background image in each of the 8 views. To make these 8 views work fluently, the application required the image captured by the Kinect camera to be developed using a separated thread to the update main loop. This process is shown in Listing 3.2. Additionally, each of the 8 views renders the calculated image for each point of view of the 3D models.

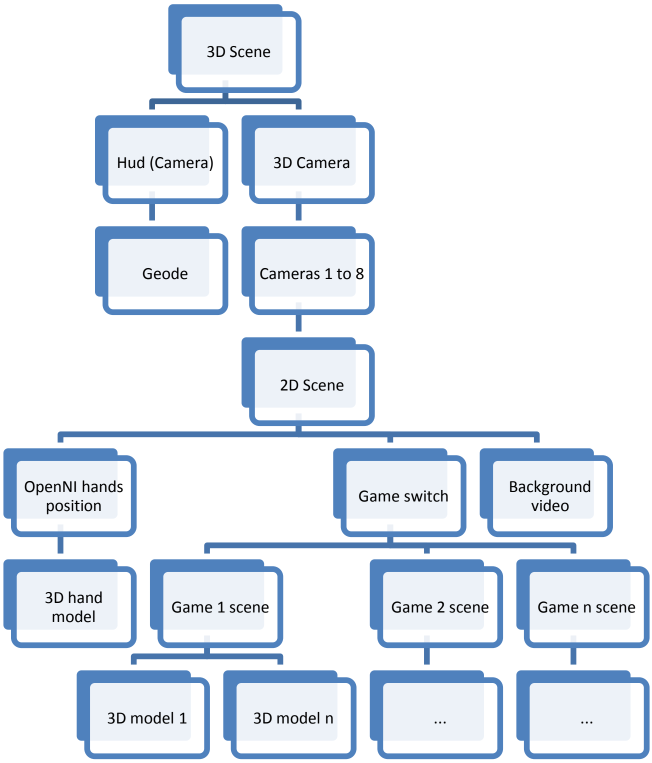


Figure 3.3: OSG graph scene used to create the 3D scene integrating OpenNI with a 3D layer specific for the autostereoscopic display

```
while !done
  disable z-buffer
  get pixel array from Kinect
  texturize quad at bottom
end while
```

Listing 3.2: Separated thread for retrieving the image of the Kinect camera

In our study, OpenNI and the Kinect drivers for Windows were used for registration and video capture. OpenNI allowed different users to be detected and it also returned the position of the possible *SkeletonJoints* of the user (hands, elbows, neck, head centre of mass, etc.). With the *SkeletonJoint* of the hands, it was possible to know whether or not the user was pressing the buttons.

In order to differentiate the users that were playing the game and any other people that could be nearby, the children had to be calibrated by the application. By doing this, the game was able to track and capture only the players' movements and to ignore any other people that were moving inside the game area. The children were calibrated at the beginning of the game after an audio explanation that told the children to adopt the *Psi* pose for a second. Figure 3.4 shows a silhouette of the pose. Its name comes from the resemblance that it has with the greek letter Ψ (Psi). For our development, we integrated this scene graph, the OpenNI library (which provided NUI support and video capture from Kinect), and the Mirage SDK (which provided the autostereoscopic views).

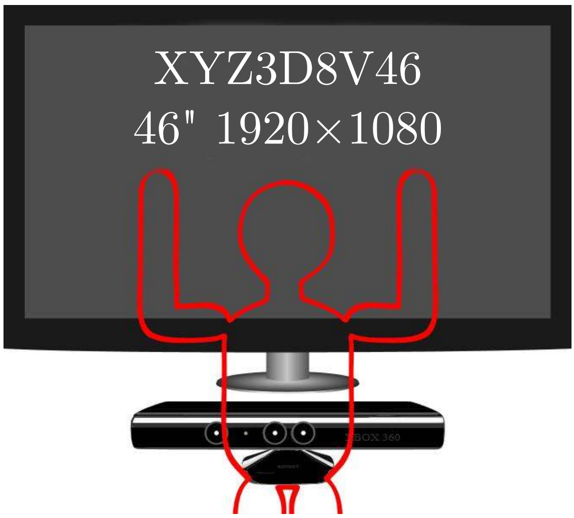
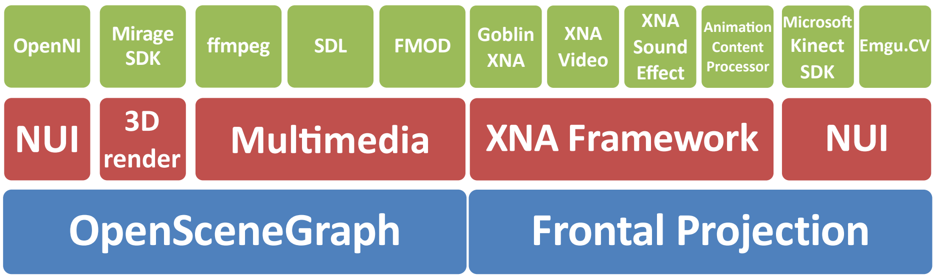


Figure 3.4: Autostereoscopic configuration. 3D display with Kinect and child position

The captured videos were rendered in the background of the game and had no 3D effect. Similarly, the explanation videos were rendered in the first plane in full screen 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`) for synchronizing the video files with their audios. All the video files were in `.mpg` format. Furthermore, the FMOD audio library (`http://www.fmod.org/`) was used to play the audio files. To make this library easier to use, the `Sound` singleton class was developed. In this way, with the help of a few methods from this class, the system was able to preload, load, and play any sound necessary for the correct guidance of the game. The singleton pattern made the code of the `Sound` class easy to be accessed from any part of the code with a really good performance. All the audio files were in `.wav` format. The system was coded in C++. Figure 3.5a shows a hierarchical diagram of the architecture of the autostereoscopic configuration. Aside, Figure 3.5b shows the architecture for the frontal projection system that the autostereoscopic system will be compared with (see Subsection 4.2.2).



(a) Autostereoscopic architecture (b) Frontal Projection architecture

Figure 3.5: Systems architectures comparison

3.2.3 Interaction

Figure 3.6 shows how the buttons were located throughout the game; hand-shaped pointers for hand guidance can also be seen in Figure 3.6a. The avatar that guided the children during the whole game is represented by an alarm clock figure, shown in the upper-left corner. He guided the children telling them what they must do in each part of the mini-games.

For pressing the buttons the children had to locate the hands on the buttons, as shown in Figure 3.6b. In this way, children had to select the options that appeared throughout the whole game.

3.3 The game

To carry out this study, we decided to design and develop a game that incorporates autostereoscopic visualization and Natural User Interfaces in a single game. In this section the design principles, educational background, and a description of its functionalities and stages are explained.

(a) Autostereoscopic configuration (b) Frontal projection

Figure 3.6: Button interaction

3.3.1 Game design

The subject of the game that was chosen was a historical timeline, specifically, five historical ages (Prehistory, Ancient Times, the Middle Ages, the Early Modern Period and the Contemporary Period). Based on their experience, the pedagogues of the research group in charge of the selection of the theme proposed four possibilities. As many works have pointed out (De Freitas and Oliver, 2006; Law et al., 2008) the importance of considering national curricula to develop educational computer games. According to this, the proposals of the game met the requirement that the topic should be one that is included in the primary education law of Spain[1]. The four proposals were:

1. Animals: Vertebrates and their reproduction

2. Animals: Nutrition

3. Plants: Parts, nutrition and their reproduction

4. The passage of time: Learning about different historical periods.

We selected the last proposal, the historical period. The reason for this selection was that in a meeting with the entire research group, the topics related to animals or plants were discarded because they had already been used as topics for different educational games (e.g. endangered animals (Juan et al., 2011a)). To our knowledge, history as a topic has not yet been covered in an educational game with the characteristics of our proposal. The knowledge presented in the game is the same as what the children study at school. This knowledge was

[1] Boletín Oficial del Estado (BOE) http://www.boe.es/boe/dias/2006/12/08/pdfs/A43053-43102.pdf

extracted from books used in the classroom. The primary education law of authors' country divides these contents into three cycles. The first cycle includes basic notions of time (before – after, past – present – future) and time units (day, week, month, year); some events from the past and from the present and their relationship with historic topics appropriate for children; and the use of audio explanations to reconstruct the past. The second cycle contains the use of more time units (decade, century) and initiation to terms like succession, order or simultaneity; learning about ancient societies from daily aspects; recognition and meaning of traditions or historic buildings; and distinguishing the roles of men and women in history. Finally, the third cycle includes topics like data conventions such as (B.C., A.D., age); techniques to locate facts about the past on a timeline and notice the duration, simultaneity and relationships between historic events; characterization of some historical ages (Prehistory, Ancient Times, the Middle Ages, the Early Modern Period, the Contemporary Period) through their lifestyles; important people and events in the history of the authors' country; the use of some historical, geographical or artistic sources for making reports and other historical content; appreciation of men and women as subjects of history.

The developed game is based on the experiential learning theory of Constructivism (Dewey, 1963). According to (Hernandez, 2008), this method implies that the acquisition of knowledge can be focused on carrying out rich, context-based activities. Nowadays, this can be advanced with the use of the new technologies that have emerged in the last few years. These tools offer the students unlimited information immediately and the possibility to control their own learning directions themselves. Hernandez proposed changing the classical paradigm of being in the classroom with the blackboard and chalk and using new ways to introduce new content. Following Hernandez's proposal, other proposals, and our own personal experiences, we developed our game following the experiential learning theory of Constructivism.

In our game, the children assumed the mission of completing the time line by travelling through the different historical ages. We emphasized the order of these ages in the time line and the events that start and end each historical age. Once the game starts, the children had to perform several activities to complete the current stage that corresponds with a time period in history. For example, the children had the experience of finding some cave paintings and colouring them using the colours that were available in prehistory.

3.3.2 Description of the game

The aim of the game is to reinforce the learning of the concept of time line, including its order, and the characteristics of each historical age. The game is divided into a series of mini-games, several of which pertain to each time period on the time line. There are also video and audio explanations at the beginning of the mini-games to introduce the historical ages and to give more detailed information in each mini-game.

In our study, the game had the same stages and order in both the frontal projection and autostereoscopic configurations. The children played the game from Prehistory to the present day. All the mini-games shared some common characteristics. The children had to use their own hands to interact with the games, searching for shapes or pressing buttons by moving their hands to the active area. In the case of frontal projection, the buttons were placed at the bottom of the screen, and, in the autostereoscopic case, they were placed on the sides of the display. The position of the buttons was different in the two configurations since the position of the children and the place where they put their arms in a stand pose were different. The game consisted of seven mini-games distributed into five historical ages: Prehistory, Ancient Times, the Middle Ages, the Early Modern Period, and the Contemporary Period. In the frontal projection configuration, the children could interact with whichever hand they preferred. However, in the case of the autostereoscopic configuration, the child playing on the right had to use his/her right hand, and the child playing on the left had to use his/her left one. This choice helped the children to interact with the buttons that were close to them.

The flowchart of the mini-games that shaped the game is shown in Figure 3.7. At the beginning, the children heard the voice of an avatar introducing them to the game. The avatar guided them through the process of user calibration by adopting the *Psi* pose (Ψ). Once they were ready to start, they had to select the first historical age from the time line, Prehistory, by pressing the correct buttons. 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. When all this was done, they had to select the next historical age the same way as previously; this time, it was the turn 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 game asked them some questions about the use of the buildings they had just used to construct the Roman city. The Roman city stage for the two systems is shown in Figure 3.8, where the button disposition between the two systems is distinguished.

The next historical age was the Middle Ages. Here, the children had to build a medieval castle by correctly answering the questions the game 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, as shown in Figure 3.9, and the children

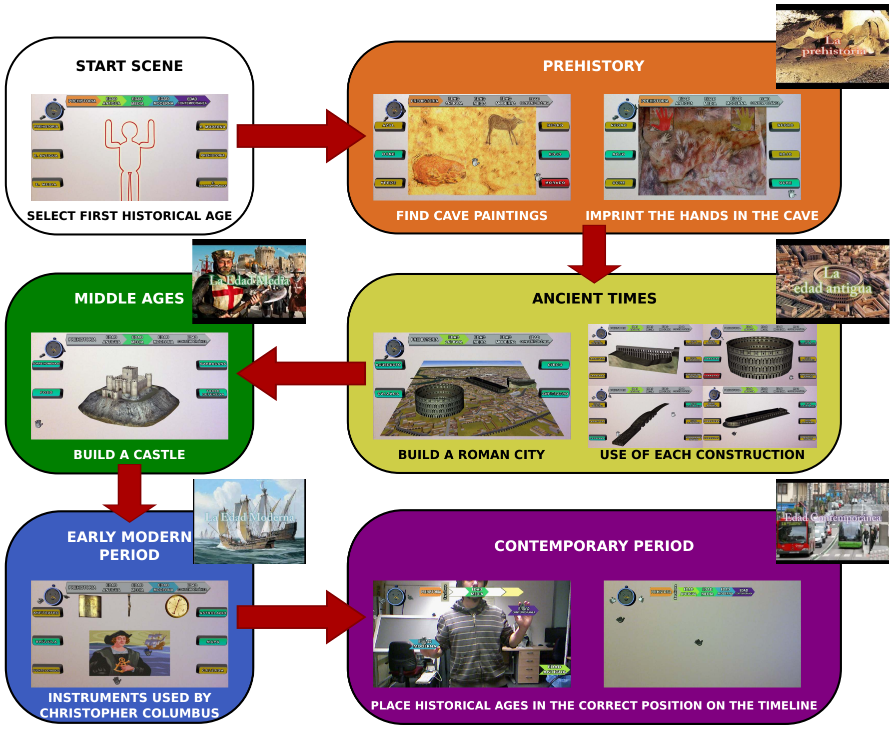
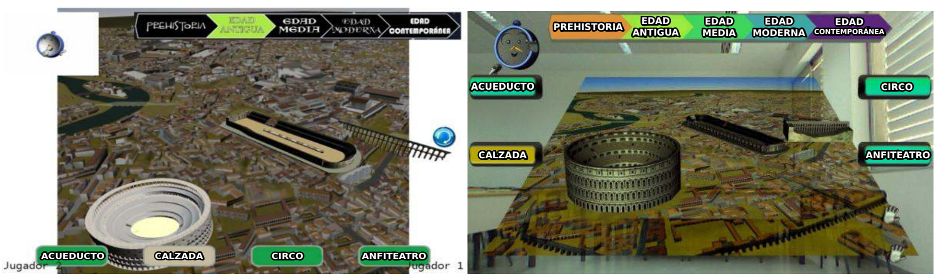


Figure 3.7: Flowchart of the mini-games integrated into the game of history



(a) Frontal Projection (b) Autostereoscopic system

Figure 3.8: Roman city stage and button disposition

could go on to the next historical age. After completing the Middle Ages, the children began 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. When all these objects were found, the children reached the final historical age (and last stage) of the game, the Contemporary Period. In this part of the game, the children had to complete a puzzle that recreated the timeline by moving their hands. Once this puzzle was complete, a final audio speech was played telling them that they had reached the end of the game.

Figure 3.9: Medieval castle completely built

IV

Validation

Study 1: Autostereoscopy against Frontal Projection

4

"Choose a job you love, and you will never have to work a day in your life."

— Confucius

4.1 Introduction

In this chapter a novel study that emphasizes the use of an autostereoscopic display as a complement for learning environments is presented. The autostereoscopic system is compared with a frontal projection system with the very same game developed inside. Both autostereoscopic and frontal projection systems use Natural User Interfaces as input method. One hundred and sixty two children of primary school tested the systems.

4.2 Frontal Projection system

For comparing the autostereoscopic system with another with similar characteristics, a frontal projection system, also developed by the *Computer Graphics* research group, was used. This system works as a tactile screen. To simulate a tactile screen, a Kinect device and a projector were used.

4.2.1 Hardware

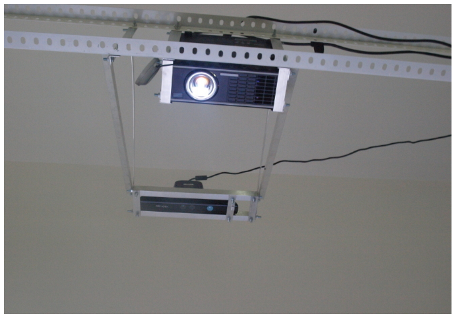
For the user interaction, a Microsoft Kinect device and an InFocus IN1503 short throw projector were used for the projection. This projector could generate an image of 177×111cm. at a throw distance of 140cm. It produced a brightness of 3000 ANSI lumens and had a resolution of 1280×800 pixels. A table covered with a white cardboard was used for the projection area. A steel support was used to place the Kinect device and the projector vertically as shown in Figure 4.1a. The table surface was used for capture and display at the same time. However, since Kinect had to capture at least the entire width of the screen area, a problem arose because the projector and the Kinect were placed together on the metallic support. They cast shadows on the screen or occlude part of the capture area. The solution was to determine the distance required between Kinect and the Projector. Figure 4.1b shows this distance. Notice that the Microsoft Kinect and the projector were not at the same height and were separated from each other. When mounting this configuration, it is necessary to keep this distance in mind in order to obtain concordance between the projected images and the points captured by the Microsoft Kinect.

4.2.2 Software

The programming language that was used to develop the game was C#. We also used the XNA Framework with the official Kinect drivers from Microsoft. This makes the XNA Framework a quick and easy way to develop applications using the Microsoft Kinect device. Emgu.CV which is a computer vision library based on the OpenCV library was used to manipulate complex graphics. This provided several functions that were very useful for hand detection. GoblinXNA was used to display the 3D scene, which provides a scene graph that simplifies the implementation. Figure 3.5b shows a hierarchical diagram of the architecture of the frontal projection configuration.

To calculate the equivalence between camera pixels and screen pixels, the system had to be calibrated. This process had to be performed each time the cardboard position or the size of the table was changed. A second application was developed to perform this calibration. This application facilitated calibration, but

(a) Two children playing with the frontal projection configuration. The steel structure can also be seen



(b) Detail of the aluminum support for the projector and Kinect

Figure 4.1: Image of the frontal projection structure and detail of the projector and kinect

it had to be done manually. In order to define the area to be used as screen we had to use this application.

Commonly, the games that use depth information from Kinect use the distance from the camera to the user's body. Our system required a different distance, which was the distance from the children's hand to the table. To achieve this, a reference image (captured before starting the game) was subtracted from each frame. As a result, the depth image obtained took the floor and the table as a reference instead of the Kinect position.

Our system also required knowing the position of the hands. This was easy using the Microsoft Kinect SDK with the camera in the horizontal position. However, since the Kinect device was pointing to the floor and skeleton detection did not work, we developed manual recognition from scratch. To do this, each frame captured by the depth camera was subtracted from the reference image and a threshold was applied. Each white blob generated by this process was a hand candidate. The last step consisted of checking whether the white blob was an object introduced to the scene (e.g. a box or a child's baseball cap) or if in fact it was a hand. A heuristic was used, if the blob was quite big and had at least one part extended out from the table (an arm), it was considered to be a hand. In this case, the hand position was calculated as the point that was further from the table border and was contained on the blob.

For button interaction, if a hand was close to the table and on the button, the button was considered to be pressed. The button area was partially covered by the hand at a predefined height. Figure 3.6b shows an example of a button being pressed.

4.3 Design of the evaluations

The developed game described in the previous chapter (see section 3.3) was extensively played by a group of children. This section explains in detail the participants, the measurements and the procedure carried out during the evaluations.

4.3.1 Participants

A total of 162 children participated in our study. There were 84 boys (51.85%) and 78 girls (48.15%). They were between seven and eleven years old, and they had already finished their academic course between the second and fifth grades of primary school. The mean age was 8.81 ± 1.03 years old. The children were students from three different summer schools in Valencia.

4.3.2 Measurements

To retrieve data for the analysis, three different questionnaires were used. There was a pre-test questionnaire with only thirteen questions of plain text. The pre-test questionnaire is shown in Table A.1. This test was used to evaluate the children's knowledge before they started playing the games. There was a second post-test questionnaire. This questionnaire had the same thirteen questions from the pre-test, and thirteen additional questions related to different aspects including usability (Table A.2). By comparing the pre-test and this post-test, it was possible to determine if there had been an increase in knowledge. There was a last questionnaire that the children filled out (Table A.2) once they had played with the two system configurations (frontal projection and autostereoscopy). This questionnaire was used to determine which of the two configurations they preferred. This questionnaire had nineteen questions; ten questions obtained information about the last configuration played and the last nine questions compared the two configurations.

4.3.3 Procedure

The participants were assigned to one of the following two groups:

- Group A: Participants that played with the autostereoscopic configuration first and afterwards played with the frontal projection configuration.
- Group B: Participants that played the frontal projection configuration first and afterwards played with the autostereoscopic configuration.

The A and B groups were balanced by grouping the children into pairs (1 boy + 1 girl, 2 boys, 2 girls), with the same number of pairs for each combination. Figure 4.2 shows graphically the procedure for both groups. The following protocol was used:

1. A pair of children filled out the pre-test questionnaire in a web-based form (PreAuto for Group A and PreFrontal for Group B).
2. These children played one configuration (frontal projection or autostereoscopy).
3. Then, they filled out the post-test questionnaire on-line (Pos1Auto for Group A, and Pos1Frontal for Group B).
4. Then, they played a short version of the other configuration. This short version corresponded to the preferred period.
5. Finally, they filled out the final questionnaire (Pos2Auto for Group A, and Pos2Frontal for Group B).

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

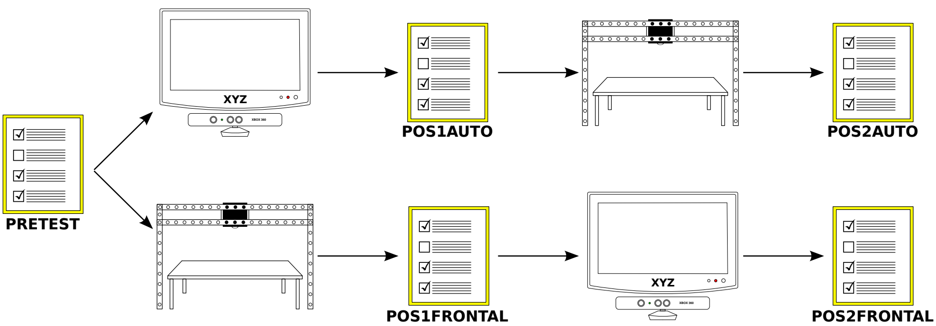


Figure 4.2: Study procedure

4.4 Results

The data from the study were analyzed using the statistical open source toolkit *R*[1] with the *RStudio*[2] IDE. The following facts should be kept in mind regarding

[1]Available at http://www.r-project.org
[2]Available at http://www.rstudio.com

the number of participants and the number of different questions in the questionnaires.

- When completing the on-line questionnaires, the children moved from one question to the next, and the system did not monitor if they had answered all the questions. Therefore, there were children who had not answered all the questions. This means that the number of children who answered each question was not the same.

- We considered the number of participants that used the two systems (one after the other) for the comparison questions. However, there were also participants that only used one of the systems for questions related to usability and knowledge. Therefore, the number of participants was different for several questions.

4.4.1 Learning outcomes

Several *t*-tests were performed to determine if there were statistically significant differences in the knowledge acquired. In these tests, the knowledge variable was analyzed, which took into account all of the knowledge questions (Q1 to Q13 of Pre and Pos1 in Table A.1) and summed up the correct answers. The knowledge variable was compared in the Pre and Pos1 questionnaires. Figure 4.3 shows the box plot for the scores before and after playing with the two systems. A

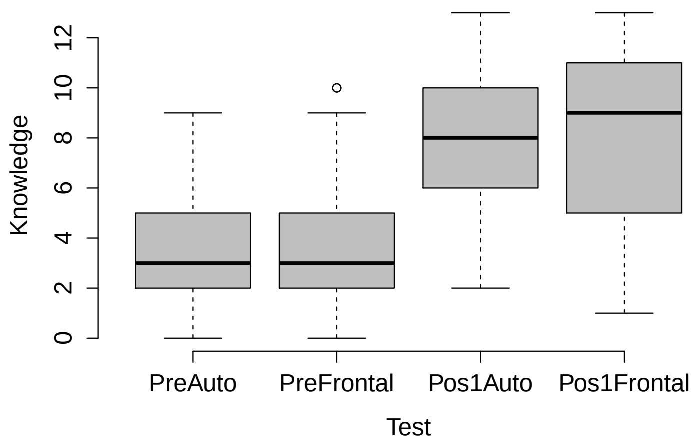


Figure 4.3: Scores of the knowledge variable in the Pre and Pos1 questionnaires for the Autostereoscopic system and for Frontal Projection

high dominance of correct questions after playing the first game (Pos1Auto and

Pos1Frontal) over the pre-test (PreAuto and PreFrontal) can be observed. All t-tests are shown in the format: *(statistic [degrees of freedom], p-value, Cohen's d)*; and ** indicates the statistical significance at level $\alpha = 0.05$. From a paired t-test, the ratings of the knowledge variable between PreAuto (mean 3.41 $\pm$ 1.89) and Pos1Auto (mean 7.81 $\pm$ 2.73) showed that there was a statistically significant difference ($t[80] = -17.62$, $p < 0.001$**, Cohen's $d = -1.96$). Another paired t-test revealed that there was a statistically significant difference between the ratings of the knowledge variable in PreFrontal (mean 3.54 $\pm$ 2.50) and Pos1Frontal (mean 7.91 $\pm$ 3.54) ($t[80] = -14.96$, $p < 0.001$**, Cohen's $d = -1.66$). To determine whether or not there was difference between the initial knowledge of the two groups, two t-test were performed, between the knowledge variable in PreAuto (mean 3.41 $\pm$ 1.89), and the knowledge variable in PreFrontal (mean 3.54 $\pm$ 2.50) ($t[160] = -0.39$, $p = 0.697$, Cohen's $d = -0.06$). These results revealed that there was no statistically significant difference between the knowledge in the two pre-tests. To determine whether or not there was difference between the acquired knowledge in the two groups, a t-test was performed between the knowledge variable in Pos1Auto (mean 7.81 $\pm$ 2.73) and the knowledge variable in Pos1Frontal (7.91 $\pm$ 3.54) ($t[160] = -0.20$, $p = 0.842$, Cohen's $d = -0.03$), which also revealed that there was no statistically significant difference between the acquired knowledge using the two systems. To complete the analysis and to determine in which questions there were statistically significant differences, we performed a paired t-test for each question between Pre and Pos1 for the Autostereoscopic system (shown in Table 4.2). A similar analysis was performed for the Frontal Projection system, in which statistically significant differences were obtained for each question, showed at Table 4.3. A t-test for each knowledge question comparing the acquired knowledge using the two systems revealed that there was only statistically significant difference for Question #1 ($t[160] = -2.69$, $p = 0.008$**, Cohen's $d = -0.42$) where Autostereoscopic got a better score, and for Question #13 ($t[160] = 3.24$, $p = 0.001$**, Cohen's $d = 0.51$) where Frontal Projection got a better score.

A mixed design ANOVA test was also performed to take into consideration several factors simultaneously. The factors of gender, age, and game were between subjects. The effect size used was the generalized Eta-squared (η^2_G) (Olejnik and Algina, 2003), which has been proven to be very suitable for mixed design analyses because it takes into account the repeated measures and the observed and manipulated factors (Bakeman, 2005). The results of the analysis in Table 4.5 show that there were statistically significant differences in the gender and the age factors. The p-values in these cases showed statistically significant differences, and the effect sizes revealed that the most influential factor was age, followed by gender. There was also some interaction between the gender and age factors, but there were no statistically significant differences. A Tukey post-hoc test showed

#	PreAuto	PreFrontal	t	p	Cohen's d
Q1	0.12 ± 0.33	0.21 ± 0.41	-1.48	0.141	-0.23
Q2	0.18 ± 0.39	0.16 ± 0.37	0.41	0.68	0.06
Q3	0.09 ± 0.30	0.15 ± 0.36	-0.95	0.342	-0.15
Q4	0.33 ± 0.47	0.27 ± 0.45	0.85	0.395	0.13
Q5	0.32 ± 0.47	0.26 ± 0.44	0.86	0.389	0.14
Q6	0.26 ± 0.44	0.30 ± 0.46	-0.52	0.601	-0.08
Q7	0.01 ± 0.11	0.07 ± 0.26	-1.94	0.053	-0.31
Q8	0.73 ± 0.45	0.67 ± 0.47	0.85	0.395	0.13
Q9	0.67 ± 0.47	0.56 ± 0.50	1.45	0.148	0.23
Q10	0.36 ± 0.48	0.44 ± 0.50	-1.12	0.264	-0.18
Q11	0.07 ± 0.26	0.08 ± 0.28	-0.29	0.774	-0.05
Q12	0.21 ± 0.41	0.22 ± 0.42	-0.19	0.849	-0.03
Q13	0.03 ± 0.19	0.15 ± 0.36	-2.47	0.014**	-0.39

Table 4.1: Means and standard deviations of questions for the PreAuto and PreFrontal, and t-test analysis. d.f. = 160.

#	PreAuto	Pos1Auto	t	p	Cohen's d
Q1	0.12 ± 0.33	0.75 ± 0.43	-11.09	< 0.001**	-1.23
Q2	0.18 ± 0.39	0.34 ± 0.47	-2.97	< 0.001**	-0.33
Q3	0.09 ± 0.30	0.72 ± 0.44	-10.59	< 0.001**	-1.18
Q4	0.33 ± 0.47	0.39 ± 0.49	-0.96	0.339	-0.11
Q5	0.32 ± 0.47	0.56 ± 0.50	-3.98	< 0.001**	-0.44
Q6	0.26 ± 0.44	0.52 ± 0.50	-4.50	< 0.001**	-0.50
Q7	0.01 ± 0.11	0.47 ± 0.50	-8.20	< 0.001**	-0.91
Q8	0.73 ± 0.45	0.79 ± 0.41	-1.09	0.277	-0.12
Q9	0.67 ± 0.47	0.81 ± 0.39	-2.53	0.01**	-0.28
Q10	0.36 ± 0.48	0.67 ± 0.47	-4.44	< 0.001**	-0.49
Q11	0.07 ± 0.26	0.65 ± 0.48	-10.02	< 0.001**	-1.11
Q12	0.21 ± 0.41	0.80 ± 0.40	-10.27	< 0.001**	-1.14
Q13	0.03 ± 0.19	0.32 ± 0.47	-5.63	< 0.001**	-0.63

Table 4.2: Means and standard deviations of questions for the PreAuto and Pos1Auto, and t-test analysis. d.f. = 80.

that the acquired knowledge was significantly different between children of ages 7 and 9, 7 and 10, 7 and 11, 8 and 9, 8 and 10.

For the acquired knowledge variable, Figure 4.4a shows the interaction plot between gender and the two systems. Boys acquired more knowledge than girls using the two systems. Figure 4.4b shows the interaction plot between gender

#	PreFrontal	Pos1Frontal	t	p	Cohen's d
Q1	0.21 ± 0.41	0.56 ± 0.50	-6.50	$< 0.001^{**}$	-0.72
Q2	0.16 ± 0.37	0.26 ± 0.44	-1.92	0.06	-0.21
Q3	0.15 ± 0.36	0.77 ± 0.43	-11.36	$< 0.001^{**}$	-1.26
Q4	0.27 ± 0.45	0.47 ± 0.50	-2.96	0.004^{**}	-0.33
Q5	0.26 ± 0.44	0.67 ± 0.47	-6.76	$< 0.001^{**}$	-0.75
Q6	0.30 ± 0.46	0.42 ± 0.50	-2.59	0.011^{**}	-0.29
Q7	0.07 ± 0.26	0.53 ± 0.50	-6.70	$< 0.001^{**}$	-0.74
Q8	0.67 ± 0.47	0.74 ± 0.44	-1.18	0.241	-0.13
Q9	0.56 ± 0.50	0.73 ± 0.45	-3.32	0.001^{**}	-0.37
Q10	0.44 ± 0.50	0.77 ± 0.43	-4.91	$< 0.001^{**}$	-0.55
Q11	0.08 ± 0.28	0.74 ± 0.44	-12.31	$< 0.001^{**}$	-1.37
Q12	0.22 ± 0.42	0.70 ± 0.46	-8.22	$< 0.001^{**}$	-0.91
Q13	0.15 ± 0.36	0.57 ± 0.50	-7.61	$< 0.001^{**}$	-0.85

Table 4.3: Means and standard deviations of questions for the PreFrontal and Pos1Frontal, and t-test analysis. d.f. = 80.

#	Pos1Auto	Pos1Frontal	t	p	Cohen's d
Q1	0.75 ± 0.43	0.56 ± 0.50	2.69	0.008^{**}	0.42
Q2	0.34 ± 0.47	0.26 ± 0.44	1.20	0.233	0.19
Q3	0.72 ± 0.44	0.77 ± 0.43	-0.54	0.59	-0.08
Q4	0.39 ± 0.49	0.47 ± 0.50	-0.95	0.344	-0.15
Q5	0.56 ± 0.50	0.67 ± 0.47	-1.45	0.148	-0.23
Q6	0.52 ± 0.50	0.42 ± 0.50	1.26	0.21	0.20
Q7	0.47 ± 0.50	0.53 ± 0.50	-0.78	0.435	-0.12
Q8	0.79 ± 0.41	0.74 ± 0.44	0.74	0.461	0.12
Q9	0.81 ± 0.39	0.73 ± 0.45	1.31	0.192	0.21
Q10	0.67 ± 0.47	0.77 ± 0.43	-1.39	0.165	-0.22
Q11	0.65 ± 0.48	0.74 ± 0.44	-1.20	0.233	-0.19
Q12	0.80 ± 0.40	0.70 ± 0.46	1.46	0.146	0.23
Q13	0.32 ± 0.47	0.57 ± 0.50	-3.24	0.001^{**}	-0.51

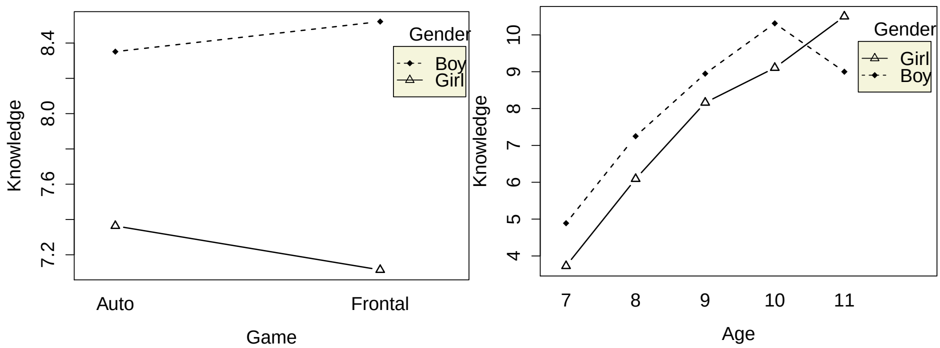
Table 4.4: Means and standard deviations for questions of the Pos1Auto and Pos1Frontal, and t-test analysis. d.f.=160.

and age. From these figures, it can be observed that the score means at older ages were higher than at younger ages with significant differences among the age groups. Also, the knowledge score with the Frontal Projection system was a bit higher than with the Autostereoscopic configuration in the case of boys; in the case of girls the knowledge score was a bit higher with the Autostereosco-

Factor	d.f.	F	p	η_G^2
Gender	1	4.34	0.038**	0.029
Age	4	16.07	< 0.001**	0.308
Game	1	0.0005	0.981	< 0.001
Gender:Age	4	0.22	0.921	0.006
Other interactions	1	< 0.85	> 0.207	< 0.017

Table 4.5: Multifactorial ANOVA for the knowledge variable. $N = 162$

pic configuration, having statistically significant differences between genders as indicated by the above ANOVA analysis.



(a) By system (b) By age

Figure 4.4: Interaction plots for the acquired knowledge.

4.4.2 System comparison outcomes

Several t-tests were performed to determine if there were statistically significant differences in the opinions of the children depending on which game configuration was played first. Table A.2 shows the questions that were used to perform the test (Q14-Q25). The results of these tests are shown in Table 4.6, Table 4.7 and Table 4.8. First, the data of the children that played the autostereoscopic system first versus the children that played the frontal projection system first were analyzed (Table 4.6). The scores of each child playing with one system first and later with the other (Pos1Auto versus Pos2Frontal (Table 4.7), and Pos1Frontal versus Pos2Auto (Table 4.8)) there were also compared. From the analysis of Q14 (how much fun the children had playing the game for the first time), no statistically significant differences were found. Nevertheless, when the same child played first with one of the two games, he/she scored the first time statistically significantly higher than the second time. This result was the same independently of whether the child played with the autostereoscopic configuration first or with frontal projection configuration first. We would like to highlight that the second time they played the game was shorter. The analysis of Q16 (ease of use) for between subjects showed that the children that played with the autostereoscopic system (3.94 ± 0.80) gave a statistically significant higher score to the ease of use than the ones who played with frontal projection (3.74 ± 0.84). However, when a within subjects analysis was performed, the results showed that there was a statistically significant difference in favour of the system played the second time for both the autostereoscopic system and the frontal projection system. Our explanation for these results is that the second time they played, they found the game easier because they had already played before and they already knew what they had to do in the game even though the interaction was not exactly the same. Something similar happened with Q18 (ease of selecting the answers). The first time they played, no statistically significant differences were found; however, the second time they played they gave a statistically significant higher score to the second system used. Q19 asked children if they liked the images shown in the game. The analysis showed that no statistically significant differences were found either between subjects or within subjects. Statistically significant differences were found in the autostereoscopic vision-oriented questions (Q23 and Q24). The analysis of Q23 showed that statistically significant differences were found between subjects for the first time they played in favour of the autostereoscopic system. If the children played the frontal projection first and the autostereoscopic system later, statistically significant differences were also found in favour of the autostereoscopic system. In contrast, playing with the autostereoscopic system first and with frontal projection second, the children scored the autostereoscopic system higher, but this difference was not statistically significant. The analysis of Q24 showed that there were statistically significant differences between and within subjects in favour of the autostereoscopic system. These results reveal that with autostereoscopy the children had the feeling of being able to touch the 3D elements like the medieval castle or the Roman road. Finally, another t-test was made for Q25 which asked the children for a global score for the game from 1 to 10. The results of this question showed that there were no statistically significant differences between subjects. However, when the analysis was within subjects, there was a statistically significant difference in favour of the autostereoscopic system when it was played first. No statistically significant difference was found when the children played with the frontal projection system first.

#	Pos1Auto	Pos1Frontal	t	d.f.	p	Cohen's d
Q14	4.85 ± 0.35	4.79 ± 0.45	1.26	241	0.21	0.16
Q15	4.45 ± 0.69	4.45 ± 0.84	0.01	234	0.99	0.00
Q16	3.94 ± 0.80	3.74 ± 0.84	1.98	240	0.048**	0.25
Q17	4.61 ± 0.57	4.48 ± 0.65	1.66	240	0.10	0.21
Q18	3.98 ± 0.89	4.07 ± 0.92	−0.72	242	0.47	−0.09
Q19	4.63 ± 0.52	4.58 ± 0.72	0.65	242	0.51	0.08
Q22	4.38 ± 0.80	4.42 ± 0.80	−0.30	241	0.7	−0.04
Q23	6.41 ± 1.69	5.16 ± 2.58	4.42	233	< 0.001**	0.58
Q24	4.95 ± 1.97	4.27 ± 2.19	2.50	229	0.01**	0.33
Q25	9.62 ± 0.77	9.45 ± 1.27	1.28	242	0.20	0.16

Table 4.6: Means and standard deviations of questions for the Pos1Auto and Pos1Frontal tests and t-test analysis

#	Pos1Auto	Pos2Frontal	t	d.f.	p	Cohen's d
Q14	4.84 ± 0.37	4.67 ± 0.57	2.38	62	0.02**	0.30
Q15	4.51 ± 0.66	4.42 ± 0.79	1.35	64	0.18	0.17
Q16	4.12 ± 0.62	4.45 ± 0.86	−2.76	65	< 0.01 **	−0.18
Q17	4.69 ± 0.53	4.80 ± 0.44	−1.47	63	0.15	−0.18
Q18	4.15 ± 0.77	4.48 ± 0.66	−3.07	65	0.003**	−0.38
Q19	4.62 ± 0.55	4.62 ± 0.60	0	64	1.00	0.00
Q22	4.29 ± 0.82	4.15 ± 1.01	1.22	65	0.23	0.15
Q23	5.58 ± 1.53	5.14 ± 2.04	1.83	65	0.07	0.23
Q24	4.90 ± 1.97	4.35 ± 2.26	2.16	61	0.03**	0.27
Q25	9.59 ± 0.76	9.20 ± 1.55	2.69	65	< 0.01 **	0.33

Table 4.7: Means and standard deviations of questions for the Pos1Auto and Pos2Frontal tests and t-test analysis

4.4.3 Satisfaction outcomes

In order to measure the satisfaction that the children had while playing the game, several Chi-squared tests were performed for the satisfaction questions. Table A.2 shows the questions that were used to perform the test (Q27-Q34). The results of these tests are shown in Table 4.9. The Chi-squared tests performed revealed that there was a statistically significant difference for Q27 only, which refers to the preference for the system they liked the most. After analyzing the results, we could see that the children tended to choose the system they had used the first time. In this question, 45% of the children preferred both systems, 40% of them preferred the autostereoscopic configuration, 14% chose frontal projection, and

#	Pos1Frontal	Pos2Auto	t	d.f.	p	Cohen's d
Q14	4.88±0.33	4.75±0.51	2.05	58	0.04**	0.27
Q15	4.48±0.80	4.45±0.80	0.36	57	0.72	0.05
Q16	3.84±0.65	4.41±0.80	−4.80	55	< 0.001**	−0.64
Q17	4.54±0.65	4.78±0.42	−2.69	58	< 0.01 **	−0.35
Q18	4.07±0.85	4.38±0.70	−2.99	55	0.004**	−0.40
Q19	4.64±0.61	4.69±0.56	−0.72	58	0.47	−0.09
Q22	4.44±0.79	4.36±0.83	0.82	58	0.42	0.11
Q23	4.68±1.98	6.68±1.80	−3.56	56	< 0.001**	−0.47
Q24	4.41±1.90	5.52±1.87	−4.21	55	< 0.001**	−0.56
Q25	9.56±0.86	9.51±1.15	0.33	58	0.75	0.04

Table 4.8: Means and standard deviations of questions for the Pos1Frontal and Pos2Auto tests and t-test analysis

1% none of them. Several other Chi-squared tests were performed to analyze the interaction with the systems. For ease of use (Q28), the percentages were 41% for frontal projection, 31% for both systems, 27% for autostereoscopy, and 1% for none of them. For comfort (Q29), the results revealed that 36% of the children chose both systems, 35% frontal projection, 28% autostereoscopy, and 1% none of them. For the controlling variable (Q30), the frontal projection offered the best result with 44% of the scores, followed by autostereoscopy with 28%, and both of them with 26% of the scores. Only 2% of them chose none of systems. For Q31 which asked which system had the best-looking images, the results obtained in this question were 42% for autostereoscopy, 31% for both systems, 26% for frontal projection, and 1% for none of them. The Chi-squared test for Q32 (if children would recommend some of the systems to their friends), obtained the results of 67% for both systems, 21% for autostereoscopy, 11% for frontal projection, and 1% for none of them. The question about satisfaction (Q33), which asked about which of the two systems was the most fun, showed 54% for both systems, 31% for autostereoscopy, and 15% for frontal projection. Note that, in this question, none of the children chose the "None of them" choice. Q34 asked the children if they would like to use any of these systems in their classrooms. The results obtained by this question were 45% for both systems, 41% for autostereoscopy, 13% for frontal projection, and 1% for none of them. In order to determine which of all the mini-games was liked the most, Q26 was asked after playing with the game for the first time. In that question, the children could select the mini-games they preferred, and they could select more than one option. The mini-game with the highest score was Prehistory (find cave painting and place an imprint of the shape of your hand in the cave) with 66.39% of votes. The second highest was Ancient Times (construct a Roman city and answer questions about Roman construction) with 55.73%. The next preferred mini-game was the Middle Ages (build a medieval castle) with 53.27%. Following, 47.13% of children selected the Contemporary Period (solve the timeline puzzle) as one of their favourites. Finally, the mini-game with the least votes was the Early Modern Period (find objects used by Christopher Columbus) with 39.75% of votes.

#	Auto	Frontal	χ^2	d.f.	N	p	Cramer's V
Q27	1 Auto	3 Both	8.79	3	128	0.03**	0.26
Q28	2 Frontal	3 Both	2.47	3	127	0.48	0.14
Q29	2 Frontal	3 Both	1.39	3	126	0.71	0.11
Q30	2 Frontal	2 Frontal	4.40	3	126	0.22	0.19
Q31	1 Auto	1 Auto	2.69	3	127	0.44	0.15
Q32	3 Both	3 Both	5.52	3	126	0.14	0.21
Q33	3 Both	3 Both	3.98	2	125	0.14	0.18
Q34	1 Auto	3 Both	2.58	3	127	0.46	0.14

Table 4.9: Modes of questions for the Pos1Auto and Pos1Frontal tests and Chi-squared analysis.

With regard to Q35 (changes in the game), some of the comments included the following: "I wouldn't change anything in the game", "It would be better to have more difficult activities", "The game could be last longer", "To have more topics to learn".

4.4.4 Avatar outcomes

As the guide/avatar is a principal part of the game, two questions were asked to determine the children's opinion about him. These questions followed a Likert scale ranging from 1 to 5 and Chi-squared tests were performed to analyze them. Table 4.10 shows the results of these tests. The first of these two questions was Q20, which asked how much they liked the avatar. The results of the test showed that there were no statistically significant differences for the avatar between subjects. The mean answer of the children for the autostereoscopic system was a little bit higher than the mean for the frontal projection, but there were no statistically significant differences. From the scores, it can be deduced that most of the children liked the avatar character. The second question about the avatar was Q21. It asked how much the avatar helped the children during the game. This test obtained results that showed there were no statistically significant differences between the two configurations. This reveals that the avatar character was helpful for the children while playing the game.

#	Auto	Frontal	χ^2	d.f.	N	p	Cramer's V
Q20	4.46 ± 0.77	4.19 ± 1.18	7.88	4	244	0.09	0.18
Q21	4.10 ± 1.03	4.22 ± 0.97	1.74	4	242	0.78	0.08

Table 4.10: Chi-squared analysis for avatar questions.

4.4.5 Correlation analysis

The correlation analysis for the Pos1 questionnaire is shown in Figure 4.5. A correlation between Q14 and Q25 was found. This correlation means that the more fun the children had, the higher the score they gave to the game. Another correlation was found between Q23 and Q24. Q23 was related to depth perception and Q24 was related to the sense of presence. This result indicates that viewing the 3D elements as coming out of the screen is closely related to the feeling of being able to touch these elements.

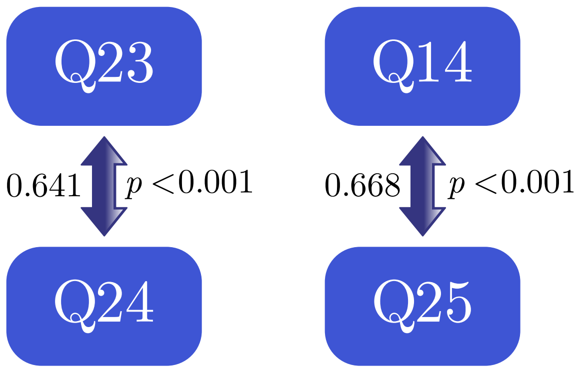


Figure 4.5: Significant correlations for questions

4.5 Conclusions

In this study, Natural User Interfaces were used as a complement for interaction with children in learning environments. Two different configurations were developed with the background of an educational game based on historical ages on a timeline from Prehistory to the Contemporary Period. First, we built an application that combined frontal projection and NUI support. Second, we developed another system that combined an autostereoscopic display with NUI support. Third, we compared the two configurations. The autostereoscopic configuration combination allows the users to have a complete experience without having to carry devices or wires on their bodies. To our knowledge, this is the first time this combination has been presented, especially for education. In the autostereoscopic configuration, the children could see themselves in the autostereoscopic 3D display, and the game was controlled by gestures. In contrast, the frontal projection configuration simulated a tactile table.

The second of our hypotheses was that children would increase their knowledge about the subject of the game by using the two systems, and that the autostereoscopic system would lead to better learning results. Comparing their initial knowledge and their knowledge after playing, statistically significant differences were obtained, which corroborates the first part of the second hypothesis. Differences in age, gender, and which system was played first were also considered. These analyses revealed that boys improved their knowledge a small amount more than girls, and indicate that older children improved their knowledge quite a bit more than younger children. These results indicate that systems of this type are more suitable for older children (9-11 years old) than for younger children 7-8 years old. However, there was no statistically significant difference between the acquired knowledge using the two systems. Therefore, the second part of our second hypothesis (the autostereoscopic system will obtain better learning results) was not corroborated. Although unexpected, it is an excellent result because it means that the game is well suited for learning outcomes and that the two systems can be used for this purpose. For the system the children liked the most, the children preferred both configurations (45%), followed by the autostereoscopic system (40%), and then the Frontal Projection (14%). In our first hypothesis, we predicted that children would prefer the autostereoscopic system. From the percentages, we can affirm that this hypothesis has been corroborated (both + autostereoscopy > both + frontal projection). For depth perception, the results showed that the 3D sensation (Q23) was mainly perceived and appreciated, being more evident when the children played with the autostereoscopic system after playing with the frontal projection system. The results revealed that autostereoscopy gave the children the feeling of being able to touch the 3D elements (Q24). Q24 was related to presence. Q23 and Q24 were correlated. From our point of view, these results are important and can be exploited for the development of educational games. For ease of use, when Q16 was analyzed, a statistically significant difference was found in which the autostereoscopic system was scored higher. However, when the children were asked explicitly about the easiest system to use, they preferred the frontal projection system (41%), followed by both systems (31%), and the autostereoscopic system (27%). From these results, we consider that the frontal projection system is easier to use which corroborates our third hypothesis (the frontal projection system will be easier to use). Our opinion is that, in the frontal projection system, the children interacted easily and fast simply by placing their hands over the buttons. However, they had some problems using the autostereoscopic configuration when trying to get to get the correct position of the hand on the 3D world by moving their arms in the air, forward and backwards. More studies should be carried out to assure that the frontal projection system is the easiest to use. For the system they control better, again, the children chose the frontal projection system (44%), followed by the autostereoscopic system (28%), and both systems (26%). In this case, the children maintained their preference for the frontal projection system. Our opinion is that the easier the game is to use, the better they control the game. For the most comfortable system, the children chose the frontal projection system (44%), followed by the autostereoscopic system (28%), and both systems (26%). For the most fun experienced (Q14), the results showed that the children gave high scores when asked about fun. For an analysis between subjects, no statistically significant differences were found, but there were statistically significant differences for analysis within subjects in favour of the system played the second time (either autostereoscopy or frontal projection). We would like to highlight that the second time the children played, they chose the time period of the history and they did not play long enough to the complete game. This fact could have influenced this result. A correlation between Q14 and Q25 (global score) was found. This correlation means that the more fun the children had, the higher the score they gave to the game. For the role of the avatar, the children liked the avatar and they also thought he was helpful. These results reveal the importance of having some kind of character guiding the children throughout the game (someone to tell the children what they must do in each part of the game / lesson). With regard to the topic of the game, some of the knowledge questions revealed that data like dates or the names of historic events are the most difficult for children to remember.

Based on our study, we considered that, playing games using the entire body as controller and an autostereoscopic vision is metaphorically similar to the real-world experience. In this situation, the selection of elements is done by using your hands and interacting by yourself with no external devices such as glasses or controllers. In addition, the user has depth perception. With regard to the interaction with the Kinect in the autostereoscopic configuration, some 7-year-old and 8-year-old children had trouble with being calibrated by the Kinect sensor due to their short height (Kinect needs a minimum user height in order to work properly). This problem did not appear in Frontal Projection because the skeleton of the user was not used for hand detection. The user calibration in this case did not depend on the height of the user because the only thing the Kinect camera could detect were the arms of the children and their distance from the camera.

Psychologists and philosophers have studied the influence that playing games has on the learning process of children and they have concluded that entertainment is an important factor that helps to improve learning (Albert and Mori, 2001; Taran, 2005). With applications like the ones presented in this thesis, children can learn using new technologies and, at the same time, they can have a good time playing the game, which promotes their learning. Nowadays, lots of video-games use techniques like Natural User Interfaces or 3D displays; however, to our knowledge, this is the first time that this combination has been used to develop a learning environment for children.

Study 2: Individual against Collaborative learning

5

"Be yourself; everyone else is already taken."

— Oscar Wilde

5.1 Introduction

In this chapter a study that emphasizes the use of collaborative interactions between the children as a complement for learning environments is presented. The collaborative method, where the children have to play with the game in couples, is compared with an individual method, where the children have to play with the game alone.

These two methods are played with the very same developed game detailed in previous chapter. A total of forty six children of primary school tested the systems.

5.2 Design of the evaluations

The developed game described in the previous chapter (see section 3.3) was played by a group of children. This section explains in detail the participants, the measurements and the procedure carried out during the evaluations.

5.2.1 Participants

A total of 46 children participated in our 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 their third grade academic course of primary education. The mean age was 8.52 ± 0.59 years old. The children were students from three different summer schools in Valencia.

5.2.2 Measurements

To retrieve data for the analysis, two questionnaires in a web-based form were used, designed to obtain the knowledge that the children acquired while playing with the game. These questionnaires consisted of thirteen questions, showed in Table A.1, about the contents that the children learned while playing with the game developed in this thesis. Comparing the answers given by the children in the pretest with the answers given in the post-test (which had the same thirteen questions), it was possible to find out whether had been an increase of knowledge.

5.2.3 Procedure

The participants were assigned to one of these two groups:

- Group A: Participants that played in couples (collaborative mode). These couples were made by one boy and one girl, two boys, or two girls.
- Group B: Participants that played solo (individual mode) with no more company than the monitor. The children of this group had to select the options that appeared in the two sides of the screen by using their two hands.

Figure 5.1 shows graphically the procedure of both groups. The following protocol was used:

1. A pair of children from Group A, or a child from Group B, filled out the pre-test questionnaire (PreCouple for Group A and PreIndiv for Group B).
2. These children, or this child, played with the developed autostereoscopic game.

3. Then, they / he / she filled out the post-test questionnaire (PosCouple for Group A and PosIndiv for Group B).

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

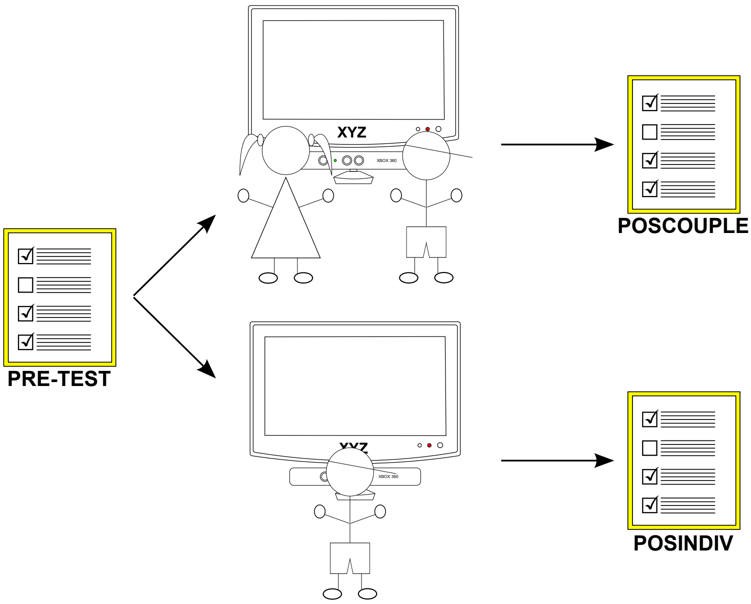


Figure 5.1: Study procedure

5.3 Results

The data from the study were analyzed using the statistical open source toolkit *R*[1] with the *RStudio*[2] IDE.

5.3.1 Learning outcomes

To measure how much the children learned after they played with the game, the knowledge variable was analyzed. This was achieved by analyzing the answers to the questions Q1 to Q13 (shown in Table A.1) before playing (pre-test), and after

[1] Available at http://www.r-project.org
[2] Available at http://www.rstudio.com

playing (post-test). Several t-tests were performed to determine whether or not there were statistically significant differences in the knowledge acquired. Figure 5.2 shows the box plot for the scores before and after playing the two game modes. A high dominance of correct questions after playing with the game (PosCouple

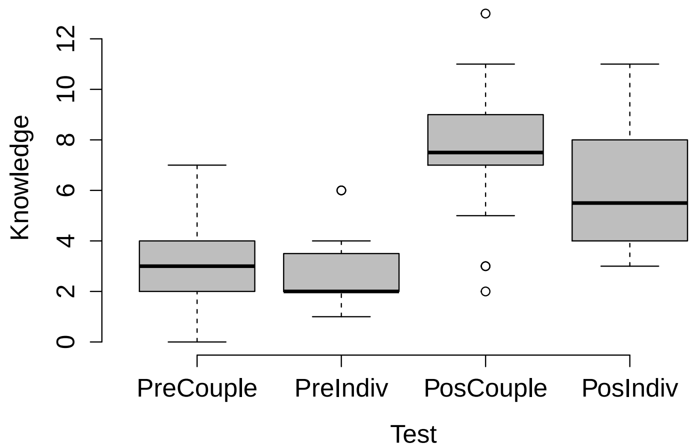


Figure 5.2: Scores of the knowledge variable in questionnaires, before and after play with the game, by couples and individually

and PosIndiv) over the pre-test (PreCouple and PreIndiv) can be observed. All t-tests are shown in the format: *(statistic [degrees of freedom], p-value, Cohen's d)*; and ** indicates the statistical significance at level $\alpha = 0.05$. Firstly, to determine whether or not there was difference between the initial knowledge in both pre-tests, 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 that there were 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, to determine whether or not 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 retrieved while playing with the game in couples was significantly higher than the knowledge acquired while playing the game individually. To complete the analysis and determine the questions where there were statistically significant differences, several t-tests were performed for each question between PreCouple – PosCouple, PreIndiv – PosIndiv, and PosCouple – PosIndiv questionnaires.

#	PreCouple	PreIndiv	t	p	Cohen's d
Q1	0.13 ± 0.35	0.19 ± 0.40	−0.48	0.635	−0.15
Q2	0.20 ± 0.41	0.12 ± 0.34	0.63	0.533	0.19
Q3	0.10 ± 0.31	0.31 ± 0.48	−1.84	0.07	−0.57
Q4	0.27 ± 0.45	0.25 ± 0.45	0.12	0.91	0.04
Q5	0.13 ± 0.35	0.12 ± 0.34	0.08	0.94	0.02
Q6	0.30 ± 0.47	0.00 ± 0.00	2.56	0.013**	0.79
Q7	0.03 ± 0.18	0.06 ± 0.25	−0.45	0.652	−0.14
Q8	0.77 ± 0.43	0.50 ± 0.52	1.87	0.068	0.58
Q9	0.57 ± 0.50	0.69 ± 0.48	−0.79	0.435	−0.24
Q10	0.20 ± 0.41	0.25 ± 0.45	−0.38	0.703	−0.12
Q11	0.03 ± 0.18	0.19 ± 0.40	−1.79	0.08	−0.55
Q12	0.20 ± 0.41	0.00 ± 0.00	1.96	0.056	0.61
Q13	0.03 ± 0.18	0.12 ± 0.34	−1.19	0.239	−0.37

Table 5.1: Means and standard deviations of questions for PreCouple and PreIndiv questionnaires, and t-test analysis. d.f. = 44

#	PreCouple	PosCouple	t	p	Cohen's d
Q1	0.13±0.35	0.73±0.45	−6.60	< 0.001**	−1.20
Q2	0.20±0.41	0.47±0.51	−2.80	0.008**	−0.51
Q3	0.10±0.31	0.80±0.41	−7.17	< 0.001**	−1.31
Q4	0.27±0.45	0.33±0.48	−0.63	0.54	−0.11
Q5	0.13±0.35	0.53±0.51	−3.89	< 0.001**	−0.71
Q6	0.30±0.47	0.47±0.51	−1.72	0.09	−0.31
Q7	0.03±0.18	0.40±0.50	−4.10	< 0.001**	−0.75
Q8	0.77±0.43	0.90±0.31	−1.28	0.21	−0.23
Q9	0.57±0.50	0.73±0.45	−1.54	0.13	−0.28
Q10	0.20±0.41	0.60±0.50	−3.03	0.005**	−0.55
Q11	0.03±0.18	0.63±0.49	−5.83	< 0.001**	−1.07
Q12	0.20±0.41	0.83±0.38	−6.24	< 0.001**	−1.14
Q13	0.03±0.18	0.27±0.45	−2.97	0.005**	−0.54

Table 5.2: Means and standard deviations of questions for PreCouple and PosCouple questionnaires, and t-test analysis. d.f. = 29

Table 5.2 shows that children who played with the game in couples acquired more knowledge in questions Q1, Q2, Q3, Q5, Q7, Q10, Q11, Q12 and Q13. This can be compared with the results in Table 5.3 provided by children who played the game individually. In this case, questions Q1, Q3, Q6, Q7, Q11 and Q12 were the questions with statistically significant differences.

#	PreIndiv	PosIndiv	t	p	Cohen's d
Q1	0.19±0.40	0.50±0.52	−2.61	0.019**	−0.65
Q2	0.12±0.34	0.19±0.40	−0.44	0.669	−0.11
Q3	0.31±0.48	0.75±0.45	−3.42	0.003**	−0.85
Q4	0.25±0.45	0.31±0.48	−0.37	0.72	−0.09
Q5	0.12±0.34	0.38±0.50	−1.73	0.1	−0.43
Q6	0.00±0.00	0.25±0.45	−2.23	0.04**	−0.56
Q7	0.06±0.25	0.44±0.51	−2.42	0.028**	−0.61
Q8	0.50±0.52	0.62±0.50	−0.81	0.43	−0.20
Q9	0.69±0.48	0.75±0.45	−0.56	0.58	−0.14
Q10	0.25±0.45	0.50±0.52	−1.73	0.1	−0.43
Q11	0.19±0.40	0.56±0.51	−3.00	0.008**	−0.75
Q12	0.00±0.00	0.62±0.50	−5.00	$<$ 0.001**	−1.25
Q13	0.12±0.34	0.12±0.34	0.00	1.00	0.00

Table 5.3: Means and standard deviations of questions for PreIndiv and PosIndiv questionnaires, and t-test analysis. d.f. = 15

Finally, to compare the knowledge acquired in each question after playing with the game, the results between the two post-tests were compared. Results are shown in Table 5.4, where Q8 stands out, being the only question with statistically significant differences.

A mixed design 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 generalized Eta-squared (η^2_G) (Olejnik and Algina, 2003), as in the previous study (see Chapter 4). The results of the analysis in Table 5.5 show that there were statistically significant differences in the gender and the age factors. The p-values in these cases showed statistically significant differences, and the effect sizes revealed that the most influential factor was age, followed by gender. There was also some interaction between the gender and age factors, but there were no statistically significant differences. A Tukey post-hoc test showed that the acquired knowledge was significantly different between children of ages 8 and 9, and between the interactions Boy:9-years-old - Girl:8-years-old, Couple:9-years-old - Individual:8-years-old, and Boy:9-years-old:Couple - Girl:8-years-old:Individual.

For the acquired knowledge variable, Figure 5.3a shows the interaction plot between gender and the two game modes. Boys acquired more knowledge than

#	PosCouple	PosIndiv	t	p	Cohen's d
Q1	0.73±0.45	0.50±0.52	1.59	0.11	0.49
Q2	0.47±0.51	0.19±0.40	1.90	0.06	0.59
Q3	0.80±0.41	0.75±0.45	0.38	0.70	0.12
Q4	0.33±0.48	0.31±0.48	0.14	0.89	0.04
Q5	0.53±0.51	0.38±0.50	1.01	0.31	0.31
Q6	0.47±0.51	0.25±0.45	1.44	0.16	0.44
Q7	0.40±0.50	0.44±0.51	−0.24	0.81	−0.07
Q8	0.90±0.31	0.62±0.50	2.32	0.03**	0.72
Q9	0.73±0.45	0.75±0.45	−0.12	0.91	−0.04
Q10	0.60±0.50	0.50±0.52	0.64	0.53	0.20
Q11	0.63±0.49	0.56±0.51	0.46	0.65	0.14
Q12	0.83±0.38	0.62±0.50	1.59	0.12	0.49
Q13	0.27±0.45	0.12±0.34	1.10	0.28	0.34

Table 5.4: Means and standard deviations of questions for PosCouple and PosIndiv questionnaires, and t-test analysis. d.f. = 44

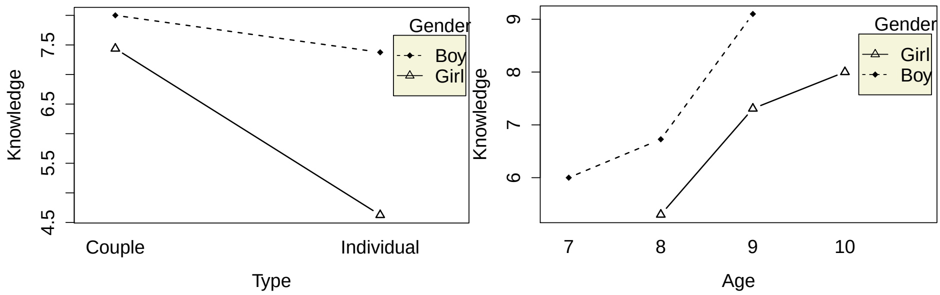
Factor	d.f.	F	p	η^2_G
Gender	1	4.54	0.083**	0.112
Age	3	1.74	0.032**	0.127
Pos (Coup./Ind.)	1	2.09	0.215	0.043
Gender:Age	1	0.80	0.024**	0.021
Age:Pos	1	1.30	0.045**	0.034
Gender:Age:Pos	1	0.15	0.075**	0.004
Other interactions	1	< 2.20	> 0.15	< 0.057

Table 5.5: Multifactorial ANOVA for the knowledge variable. N = 46

girls playing the two modes. Figure 5.3b shows the interaction plot between gender and age. From these figures, it can be observed that the score means at older ages were higher than at younger ages with statistically significant differences among the age groups. Also, the knowledge score playing the game by couples was a bit higher than playing the game individually, having statistically significant differences between genders as indicated by the above ANOVA analysis.

5.4 Conclusions

In this study, the educational video-game presented in Chapter 3 was used for test the level of the knowledge acquired by the children when playing in two



(a) By game mode (b) By age

Figure 5.3: Interaction plots for the acquired knowledge.

different modes. The first mode was the collaboration mode, where the children had to play with the game in couples with other children. The second mode was the individual mode, where only one child played at a time.

Our hypothesis was that the children would increase more their knowledge about the topic of the game when they play the game in the collaborative mode. Comparing their initial knowledge before playing with the game, we observed a very little difference in favour of the collaborative mode; however, when comparing their final knowledge after playing with the game, a more notorious difference arose. The results showed that the children who played in collaboration with another children, acquired more knowledge that the children who played alone. Differences in interactions like gender, age and game mode (collaborative or individual) were also considered. These analyses revealed that boys improved their knowledge more than girls, and indicate that older children improved their knowledge more than younger children, specially between 9 and 10-year-old children.

With game modes like the collaborative mode presented in this study, children can learn a wide variety of educational topics by using new technologies and having fun with their friends at the same time they are playing with them. The video-games of nowadays let the users select whether to play with more people or to play alone.

V

Discussion

Concluding remarks

6

"Live as if you were to die tomorrow. Learn as if you were to live forever."

— Mahatma Gandhi

6.1 Conclusions

In this thesis, we carried out a research about the impact on the learning of children when playing video-games with an educational background by using new technologies as Natural User Interfaces, autostereoscopy and frontal projection. An educational video-game was developed, based on the topic of the passage of time, learning about different historical periods. To our knowledge, this is the first work in which autostereoscopy and NUI have been used for the development of an educational game. Moreover, it is also the first work in which autostereoscopic display + NUI are compared with projected surface + NUI. The use of history as the subject of a computer game is also novel and has not been considered for the design of games that use new technologies, such as interactive tables, mobile devices, Virtual or AR.

The design of the game was done by following the theories of the Constructivism. With this video-game, the children learned new concepts about history and they were really engaged with the game. We developed the video-game and tested it with an autostereoscopic display, and we compared this system in the first study with another similar based on frontal projection. For the second study, we compared two modes of playing with the game with the autostereoscopic system: collaborative by playing in couples with another child, and individual by playing alone. Finally, we presented a statistical analysis with the data that we retrieved in the validations and provide an interpretation from these data.

In the first study, the children who evaluated the systems increase their knowledge about the topic of the game, and the increment of knowledge in both autostereoscopic and frontal projection systems was similar, with no statistically significant differences; however, the 3D perception was totally perceived by the children and they scored it in the validations.

In the second study, the children also increase their knowledge, but in this case, the children who played with the game in the collaborative mode increased their knowledge more than the children who played with the game in the individual mode. With these results, we can observe that the fact of playing video-games having an educational background with some friends will be better and the children will learn more about the topic of the game.

As a final conclusion, and in our opinion, the new technologies are appropriated for developing educational games and autostereoscopy is a technology to exploit in their development. Moreover, to play in a collaborative way facilitates the effectiveness of games with educational purposes.

6.2 Scientific contributions

The publications deriving from this thesis are the following:

- Martín-SanJosé, J.F., Juan, M.C., Seguí, I., Cano, J. Exploring natural user interfaces for learning environments. A comparative study using autostereoscopy vs. frontal projection. Submitted to *Computers & Graphics*. JCR, Impact Factor = 1.0

- Martín-SanJosé, J.F., Juan, M.C., Torres, E., Vicent, M.J. Individual and collaborative learning outcomes using natural user interfaces and autostereoscopy. Submitted to *IEEE Transactions on Learning Technologies*. JCR, Impact Factor = 0.823

- Martín-SanJosé, J.F., Juan, M.C., Martín, A., Bonet, S. (2012) *Manual de buenas prácticas de aplicación de la Realidad Aumentada en empresas.* CreateSpace Independent Publishing Platform.

6.3 Future work

With regard to future work, the autostereoscopic system 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. The interaction could also be improved, adding the recognition of new gestures. Our studies involved children, but other studies could be carried out with adults, and the results could be compared. In this thesis, we have compared two systems, but other comparisons are also possible; for example, using a control group in which the children learn about the same period of history using traditional learning. By studying the results of different comparative studies, we may be able to draw interesting conclusions (e.g., to determine how children preform under different conditions). We plan to compare learning about a period of history using the autostereoscopic system and traditional learning in a classroom.

Natural User Interfaces in the field of education are in their earliest stages, but they could be a very great addition to the learning process for different topics, and for adults as well as children. We also believe that the educational field can be improved with the use of the 3D perception. Nowadays, there are mobile devices that incorporate autostereoscopic systems such as consoles (e.g. Nintendo 3DS) or mobile devices (e.g. LG Optimus 3D).

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VI

Appendices

Questionnaires

A.

In this appendix, all the questionnaires that had been used in this experiment are presented. The possible choices to select as answers are placed below the questions. The column labeled with # shows the question numbering, and the columns labeled as Pre, Pos1 and Pos2 show the questionnaire that every question appears in.

A.1 Learning questions

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

#	Pre	Pos1	Pos2	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 d) Altamira cave e) 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

#	Pre	Pos1	Pos2	Question
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) the Contemporary Period c) Prehistory d) the Early Modern Period e) the Middle Ages

#	Pre	Pos1	Pos2	Question
Q13	•	•		Place each invention in the correct age. a) Map b) Mobile phone c) Cave paintings d) Aqueduct e) Castle

Table A.1: Learning questions (numbered as in the questionnaires)

A.2 System comparison questions

To determine the differences between the two systems the children were asked with the following questions.

#	Pre	Pos1	Pos2	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		•	•	Evaluate on a 1-7 scale the sensation of viewing the castle. Did it look like coming out of the screen? [1-7]
Q24		•	•	Did you think you were able to touch the castle? [1-7]

#	Pre	Pos1	Pos2	Question
Q25		•	•	Score the game from 1 to 10. [1-10]
Q26		•		Which of all the mini-games did you like the most? [Prehistory / Ancient Times / the Middle Ages / the Early Modern Period / the Contemporary Period]
Q27			•	Which system did you enjoy the most? Why? [Auto / Frontal / Both / None]
Q28			•	Which system was the easiest to use? [Auto / Frontal / Both / None]
Q29			•	Which system was the most comfortable? [Auto / Frontal / Both / None]
Q30			•	Which system did you control better? [Auto / Frontal / Both / None]
Q31			•	In which system were the images viewed better? [Auto / Frontal / Both / None]
Q32			•	Would you recommend any of these systems to friends? [Auto / Frontal / Both / None]
Q33			•	Which system was the most fun? [Auto / Frontal / Both / None]
Q34			•	Would you like to use any of these systems at school? [Auto / Frontal / Both / None]
Q35			•	Would you change anything about the game?

Table A.2: System comparison questions (numbered as in the questionnaires)

"It's kind of fun to do the impossible."

— Walt Disney