

# Evaluation of a Cultural Heritage Augmented Reality Game

S. Sylaiou<sup>1\*</sup>, K. Mania<sup>2</sup>, F. Liarokapis<sup>3</sup>, M. White<sup>4</sup>, K. Walczak<sup>5</sup>,  
R. Wojciechowski<sup>5</sup>, W. Wiza<sup>5</sup>, P. Patias<sup>1</sup>

*1 Aristotle University of Thessaloniki, Laboratory of Photogrammetry  
and Remote Sensing, Greece*

*2 Technical University of Crete, Greece*

*3 Masaryk University, Brno, Czech Republic*

*4 University of Sussex, U.K.*

*5 Poznań University of Economics, Poland*

**Abstract:** The ability to develop sophisticated and flexible web and mobile applications based on augmented reality (AR) and gaming engine technologies is incredible taking into account the plethora of powerful mobile computing devices for displaying such applications. In this respect, the research community is challenged to investigate the factors that make such technologies effective, productive and engaging. In this paper, we investigate the efficacy of augmented reality in a simple cultural heritage game, by evaluating real-time feedback from users. The game has been implemented within the ARCO (Augmented Representation of Cultural Objects) system using its flexible AR scenario authoring tools and dynamic content composition and delivery technology. The game has been presented within an Augmented Reality Interface—a specialized application enabling AR on a user’s computer. The ARCO system, a result of the ARCO project, allows museums to create their own virtual museum exhibitions based around a collection of cultural objects. A typical virtual museum would be composed of exhibition spaces that present these digital objects to a user, for example, on a web page, on a mobile device or in a virtual environment. A virtual museum can present these digital objects in the form of an interactive AR game or quiz. Through the use of interviews and structured questionnaires, user feedback has been collected for evaluation to enable us to improve the game characteristics, but more importantly to understand whether AR based games are educationally useful, meaningful and appealing to users. In this respect, our study revealed that AR based games are appealing and do attract user engagement and interest, however, because of the integration of real-world and 3D elements, AR games also have problems and deficiencies.

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\* sylaiou@photo.topo.auth.gr

## 1. Introduction

*Anything that we have to learn to do, we learn by the actual doing of it...*

Aristotle *Nicomachean Ethics*, Book II, p .91

Museums can be characterized as places for learning. However, as a consequence of the limited capabilities of displaying physical artefacts, museums often unintentionally communicate views about what they consider worth learning through the way that their artworks, objects and historical material are presented. To escape this criticism museums must contribute to a variety of learning aptitudes, and account for visitor prior experience (e.g., with technology) when they present their collections to the public. It is perhaps naïve to think any museum can take or even afford this approach for every object, but they can implement limited digital resource strategies that alleviate such perceptions. For example, at one end of the spectrum providing a simple on-line browse and search interface for digitised archives are not beyond a museum's basic web presence, while the addition of social media to allow users to comment on collections is also possible. At the other end of the spectrum, the application of sophisticated 3D and augmented reality to represent a museum's digital objects provides a great level of user interaction possibilities, particularly when combined in a game based scenario—affordability for the museum is another question. Nevertheless, museums have more recently made greater efforts to discover new technological ways to present their artefacts and enhance learning experiences and visitors' engagement<sup>1</sup>. Further, because a visitor's activities related to exploration of an object can be experiential involving learning by doing, a museum's digital objects and collections can also be personalized and configured to respond easily to visitors' feedback interactively.

Quite early on, MacDonald and Alsford stated "... museums cannot remain aloof from technological trends if they wish to attract 21st century audiences" (MacDonald and Alsford, 1997). Museum visitors are becoming more accustomed to technology in this setting and expect exhibits and information to be technologically aware (Falk and Dierking, 2000). Lately, emerging technologies, such as 3D web standards and augmented reality (AR), are employed to transform, enhance and 'augment' a museum learning experience by employing in-house installations (e.g., multimedia based kiosks) or web-based material involving some form of computer graphics, thereby effectively creating a 'virtual museum' premise. AR enables an enriched experience by superimposing virtual objects on a view of the real world or on a video of the real world captured in real-time. Such emerging technologies can

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1 "Engagement is defined as the quality of user experience that facilitates more enriching interactions with computer applications and is defined by a core set of attributes: aesthetic appeal, novelty, involvement, focused attention, perceived usability, and durability" (O'Brien and McLean, 2009).

become a powerful communication channel offering a virtual ‘direct’ and personalized experience. These technologies transform users who were passive viewers of static exhibits into more active users of a museum experience through the use of interactive interfaces (Liarokapis et al., 2008). Sylaiou et al. suggest “Museum visitors use and interact with a virtual museum environment via a constructive dialogue that provides them with access to thematic information and explanations about the museum objects’ context selecting an appropriate level of information and amount of detail they prefer” (Sylaiou et al., 2009). Museums shift their focus from the high-quality presentation of physical collections to the making of meaningful digital presentations related to the artefacts and their interpretation. There is the constant need for virtual museums to reach out and attract larger and more diverse audiences and find ways to understand visitor expectations and experiences in order to address the needs of diverse user groups and be responsive to various communities’ interests. Despite the number of AR applications in museums, the impact such ‘virtual’ exhibits have on the social ecology of exhibitions is largely unexplored (Reeves, 2004; Schmalstieg, 2005).

More and more, AR technology has started to be recognized as an indispensable tool that can improve, on a daily basis, human activities in gaming, communication, medicine, education, design and many other domains. AR, in this sense, has been acknowledged as a potential strategy for education. If AR technologies are combined with the so-called ‘serious games’, they can enrich educational experiences either in situ in a museum, via a mobile phone or by remote access to a museum’s website. In their paper Belotti et al. state “designing games that support knowledge and skill acquisition has become a promising frontier for training, since games are able to capture concentration for long periods and can present users with compelling challenges” (Bellotti et al., 2009). It is widely recognized that games can be devised not only for fun, but also as a means to provide effective learning experiences in museum settings (Anderson et al., 2010). The main challenge concerning serious gaming technology is when, how and why the combination of AR and games promote learning. Realizing the goals of AR and gaming and harnessing them to successful digital heritage applications could be accomplished by human-centred design, employing robust evaluation metrics and human-centred experimentation. In this paper, we investigate the efficacy of using augmented reality technology in a cultural heritage game, by evaluating real-time feedback from its users.

The AR game evaluated in this study has been created with the help of the ARCO system (White et al., 2004; Walczak et al., 2006). The ARCO system, built within the 5<sup>th</sup> EU Framework Program project entitled ARCO (Augmented Representation of Cultural Objects) is a comprehensive solution for creating and managing virtual museums. The ARCO system users store and manage cultural objects and associated multimedia objects together with corresponding metadata and present the col-

lected objects in variety of interfaces, including web pages, virtual reality environments, mobile devices, and AR interfaces. These operations are supported by the ARCO system through specialized built-in managers available in the ARCO Content Management Application (ACMA) interface, which enables the creation of interactive game and educational scenarios (Wojciechowski et al., 2004). A user — teacher or museum creator — may build game scenarios, parameterize them, and manipulate visualized objects. A prepared game is then delivered dynamically on-demand to an end-user (a pupil or a museum visitor) through the ARCO Exhibition Server and visualized by the Augmented Reality Interface (ARIF) — an AR application installed on a recipient's computer.

## **2. Background**

### **2.1 Overview of the ARCO evaluation research**

Evaluation of the ARCO system was largely focused around evaluating the user interfaces (ACMA and ARIF) through a formative and summative approach using participatory design principles (Banathy, 1992; Carr, 1997; Kensing, 2003; Muller, 2007). In particular, the ARCO evaluation focused on the ACMA interface, which is a content management system for use by museum professionals to manage digital objects in the database together with their associated media objects (3D, images, video, etc.) and relevant metadata allowing online publishing of virtual museums, and the ARIF interface, which is a tool used to present 3D objects in a virtual museum through an online web browser that can switch to an augmented reality view of the same 3D objects. Utilising both empirical and expert based approaches, Sylaiou et al., conducted evaluations of ACMA and ARIF in collaboration with Victoria and Albert Museum curators and domain level experts (Karoulis et al., 2006, Sylaiou et al., 2008, Sylaiou S., et al., 2010). These evaluations adopted questionnaire surveys based on (a) the QUIS (Questionnaire for User Interaction Satisfaction) to assess user satisfaction (Chin et al., 1988), and (b) a Cognitive Walk-through session with domain and usability experts (Polson et al., 1992). Of particular interest were the findings related to the evaluation of the ARIF interface. The ARIF evaluation showed that both museum curators and visitors responded positively to this type of augmented reality interface, and indicated presence was associated with satisfaction and gratification (Sylaiou et al., 2009). The experimental AR game scenario included cultural information and required users to interactively answer a series of questions as well as resolve tasks employing an AR interface.

### **2.2 AR game-based learning**

Many studies have explored the potential and contribution of computer games to the learning process (Kafai and Ching, 1996; Ricci et al., 1996; Rieber, 1996; Pren-

sky, 2001; Gee, 2003; Squire and Barab, 2004). AR lends itself very well to the concept of creating interesting and engaging games for different areas including education, learning, training and entertainment; in this respect it is an ideal technology for integration into interactive museum exhibitions or kiosks. Billingshurst et al. demonstrate an excellent example of the use of AR with a high degree of user interaction with their MagicBook (Billingshurst et al., 2001). The Magic book concept is used like any book, where the user simply turns the pages. However, in this case a page usually contains some form of fiducial marker, which is recognised through the AR application's image software, to effect the placement of a 3D object on the marker. When viewed through a hand held device, e.g. a smartphone or the desktop PC screen it gives the appearance of the object popping out of the book, hence the term Magic Book. The BBC identified in recent research that young children (around 5 years old) respond positively to AR based learning scenarios, simulating their imagination, and enabling them to learn through play in a natural way (Thomas, 2006). Slightly older children, aged 10+, also demonstrated an ability to learn and understand, for example, how the Earth, Sun and Moon interact through the use of AR as a teaching tool (Kerawalla et al., 2006). Many other studies also illustrate the validity of using AR for educational purposes: medicine (Nischelwitzer et al., 2007), teaching and learning (Liarokapis, 2007), and learning and performance (Holzinger et al., 2008). Further, AR implicitly involves the user being 'immersed' in the educational activity; therefore immersion should be designed into the educational AR game from the perspective of engagement and motivation, including interactivity, narrative, 'flow' and fidelity (Csikszentmihalyi, 1990; de Freitas and Liarokapis, 2011).

Several AR evaluation studies show that this technology implemented in a gaming or quiz scenario is an effective educational tool (Andersen et al., 2004; Nilsen et al., 2004; Liarokapis, 2006). Recent studies concerning an AR workspace in terms of interaction and pedagogical concepts, show that AR increases students' motivation to learn, could be an effective educational instrument, increases vividness of complex or abstract subjects and users confirmed a high perception of usefulness and enjoyment (Krauß and Bogen, 2010). The use of usability questionnaires combined with semi-structured, qualitative interviews was illustrated during the usability testing of the Virtual Showcases system (Virtual Showcases, 2004). Moreover, Seagram and Amory (2005) used qualitative and quantitative methods investigating game-based learning about serious diseases. Another system based on a competitive gaming-learning environment built to stimulate students' motivation to learn has also been evaluated (Chang et al., 2003). Other AR game-based learning environments have been evaluated to assess their efficacy from a user perspective (Nilsen and Looser, 2005, Liarokapis, 2007). The study presented in this paper explores the system usability of a simple cultural AR game developed with the ARCO system to examine the efficacy of AR in a museum learning context, dis-

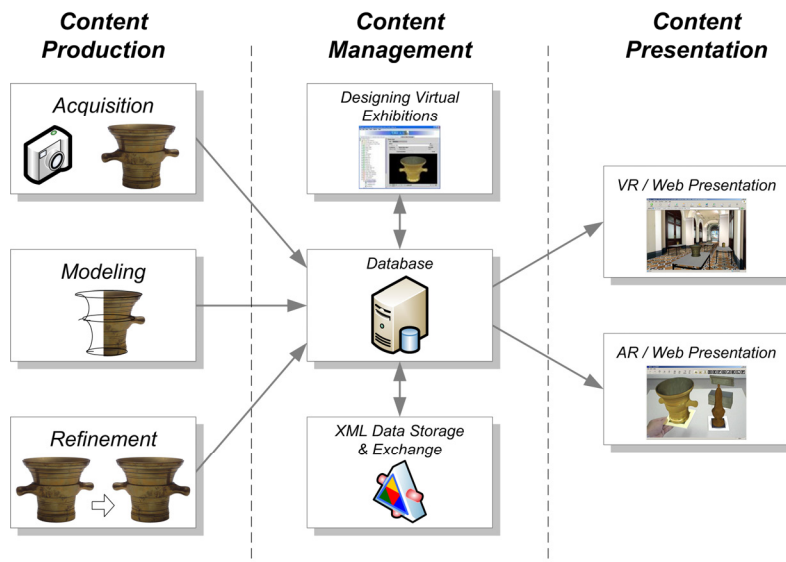
cover its appealing and pleasant attributes as well as any problematic elements in an AR game, and see whether the educational usefulness of an AR learning scenario influenced the individuals' subjective impressions concerning the AR museum game presentation. The evaluation is conducted both qualitatively through observational feedback as well as quantitatively through structured questionnaires.

### 3. The ARCO system

Before we discuss the game methods, materials and evaluation of the simple AR game, we outline the ARCO system, and its augmented reality capabilities.

#### 3.1 General information

The ARCO system provides a set of tools that museums can use to create, manage, and present digital artefacts within interactive virtual museums online (White et al., 2003; White et al., 2004). The overall architecture of ARCO and the dataflow within the system are presented in Figure 1.



**Figure 1:** ARCO system architecture and dataflow

The latest version of the ARCO content pipeline utilises Flex-VR (Walczak, 2009, 2012) to build 3D/VR/AR applications. With Flex-VR, complex interactive 3D application content can be relatively easy created by museum staff by configuring predesigned geometrical, logical and behavioural components. Three main phases can be distinguished in the ARCO content pipeline (Figure 1): *content production*,

*content management* and *content presentation*. Content production includes processes required for the creation of a museum's digital representations of its artefacts. Digital representations may take the form of 3D models, images, sounds and videos as well as other multimedia objects. Museum artefacts with simple geometry can be modelled in 3D with classical 3D authoring software such as *3ds Max*, *Maya*, etc., which can also be augmented with a set of additional plug-ins that simplify the process of creating 3D models. More complex objects can be modelled using one of several scanning techniques, such as laser or photogrammetry scanning. Such 3D modelling techniques were demonstrated in the ARCO project (White et al., 2003; White et al., 2004, ARCO, 2005).

Content management starts with a museum's digital representations being acquired by ARCO's database using the *Cultural Object Manager*, which is one of the ARCO Content Management Applications (ACMA) manager tools. Once digitised and captured in the ARCO database a digital representation is composed of a set of media objects — each media object represents a different view of the artefact (cultural object), e.g. 3D view, image view, movie view, etc. — and associated metadata (Mourkoussis et al., 2003; Patel et al., 2005). After a collection of digital representations is acquired, a museum can then build a virtual museum exhibition, which is configured with ACMA's *Presentation Manager*. ARCO enables creation of different kinds of virtual museum exhibitions, from 2D multimedia web pages, through interactive 3D web presentations, to complex AR games. ARCO employs the notion of *presentation templates* that separate the design and programming of the virtual museum's *presentation* code (e.g. 3D and web code) from the actual process of creating the virtual museum exhibition (the creativity process). Museum staff can then perform the creativity process without experience in 3D modelling and computer programming. Presentation templates are created by an IT specialist and contain all program code necessary to build virtual museum exhibitions.

The structure of an ARCO based virtual museum or exhibition is based around *presentation spaces* in the database. Each presentation space can represent a complete virtual museum, an exhibition in the virtual museum or even part of an exhibition. Thus, a virtual museum can be sub-divided into several smaller exhibitions with sub-spaces representing geometrical (e.g., different museum rooms) or logical (e.g., different stages of a game) elements of a virtual museum or exhibition. Presentation spaces are akin to folders, which may contain instances of cultural objects (digital representations of the museum's artefacts) and instances of presentation templates — content templates and behaviour templates. Presentation properties can describe presentation spaces, cultural objects within presentation spaces, or media objects within cultural objects within particular presentation spaces. In addition to fixed lists of cultural objects, ARCO enables assignment of cultural object selection rules to presentation spaces, enabling creation of virtual galleries with content selected dynamically based on metadata records. A virtual museum or ex-

hibition designer (which could be the curator) can build a virtual museum exhibition by creating a structure of presentation spaces, then creating instances of content templates and behaviour templates in these spaces, then assigning cultural objects and cultural object selection rules, and finally setting presentation properties. In ARCO, the concept of *presentation domains* is used to differentiate content presentation in different environments, on different platforms or for different groups of users. For this purpose, multiple instances of presentation templates can be assigned to presentation spaces. Typically, one domain is used for internal museum use, e.g. a museum kiosk, and one for Internet based exhibitions. Other domains may be used for specific purposes, e.g. to distinguish touch screen interfaces and standard keyboard/mouse interfaces or to use other forms of presentation such as AR games (Wojciechowski et al., 2003, 2004). Virtual museums or exhibitions, accessible to end-users, e.g. in the form of 3D web presentations or AR games, are dynamically generated on-demand based on the presentation structures stored in the ARCO database. The use of different templates, different template parameter values and different presentation properties permits different forms of presentation of the same content. Since the presentations are created on-demand, they can be personalized for different user groups or created in response to specific user queries.

### 3.2 ARCO AR tools and methods

The ARCO virtual exhibitions can be visualized using standard web browsers, but the web browser must be enabled with a VRML/X3D plug-in, or a specifically designed Augmented Reality Interface (ARIF) application (Wojciechowski et al., 2003) based on the ARToolKit library (Kato et al., 2000; ARToolWorks, 2012) must be used. In a web browser, a user can browse virtual museums or exhibitions based on 3D VRML or 2D web pages (with embedded 3D, images, video, etc.). Further, such exhibitions can be configured for local displays inside a museum, e.g. a museum kiosk, and remotely over the Internet. ARCO provides an ARIF application, which is used for displaying web-based presentations enhanced with visualization of cultural objects in AR environments. ARIF has two components: a web browser and an AR browser. The web browser is used for navigating the virtual exhibitions and selecting cultural objects for presentation in an AR environment within the AR browser. To indicate locations of virtual objects in the AR environment, there are fiducial markers placed in the real environment. The real environment is observed by a camera, which streams the captured video to the AR browser. The AR browser then overlays cultural objects (their 3D model) in to the video image corresponding with the position and orientation of the markers placed in the physical environment. A camera and a screen for displaying the ARCO virtual exhibitions can be integrated into a kiosk, which can be located within the museum premises. Also, it is important to provide users with enough space for the



manipulation of markers in front of the camera.

AR learning environments are based on ARCO virtual exhibitions, which contain behaviour templates, encoded in XML, specifying the course of learning scenarios. Different learning scenarios can be implemented based on the same virtual exhibition when supplied with different behaviour templates, e.g. a scenario designer can adapt the presentation to different age groups and various expectations of users. The key element of the scenarios is learning metadata, which are specified as parameters of the behaviour templates. Each of the learning scenarios designed for presenting cultural objects from a given virtual exhibition can be characterized by different metadata. The metadata can be specified in the ACMA tool with an easy-to-use editor, which enables users to set up the metadata values without requiring manual coding in XML. In the AR game scenario presented in this paper, the learning metadata for each cultural object consists of a list of questions, answers, and object description. These metadata values are used to generate content presented in the AR game at runtime.

#### **4. Materials and methods**

In order to perform the evaluation of the cultural heritage AR game, first we had to deploy and test the ARCO system, select a user group, develop some simple AR content in the context of a simple game, and define the experimental procedure and evaluation metrics.

##### **4.1 Apparatus and visual content**

The ARCO system is set up in a Windows PC environment with suitable lighting conditions for the ARIF component, which also includes a web camera. The ARIF architecture and rendering of digital objects is built around the ARToolKit (Billinghurst et al., 2001; Wojciechowski et al., 2004; Liarokapis, 2007) as discussed above.

##### **4.2 Participants**

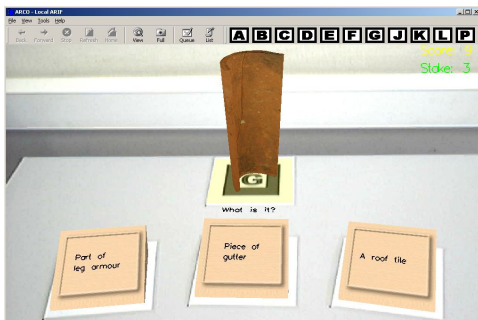
Twenty-nine subjects from the Departments of Computer Science and Psychology at the University of Sussex (16 males, 13 females, age range: 19–33) participated in the evaluation of the AR cultural heritage game. The volunteers employed in this study were not involved in any of the technical development stages of the ARCO system.

##### **4.3 Visual content and experimental procedure**

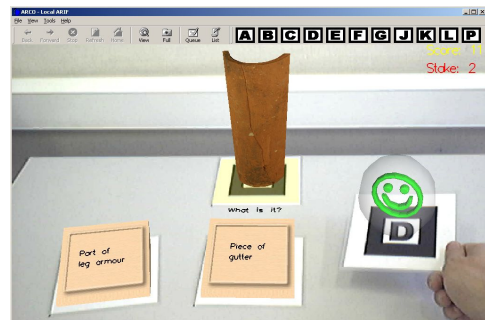
The AR game or quiz was based on an historical and archaeological context presented in an interactive scenario focused on question and answer AR scenario. We

designed with our ARCO ARIF system a simple AR game structure that supports learning through visualisation, creativity and experimentation (Prensky, 2005). Archaeological artefacts from Fishbourne Roman Palace, UK were modelled in 3D, including a partial representation of the Palace itself for use as the 3D content in the AR game. At the beginning of the game or quiz scenario, a welcome web page was displayed in the web browser component of the ARIF application. The web browser's opening page includes a brief story about Fishbourne Roman Palace and an introduction to the quiz, which is about the archaeological artefacts. The goal was to test the users' ability to discover information about the artefacts and the Palace in the context of an AR game.

The AR game environment included setting up the markers on the experimental table top, after which a 3D model of an artefact appeared on a marker with a corresponding question. The possible answers to the question were displayed on the available markers (Figure 2a). The 3D model was rotated around to enable users to observe it from different angles. Turning each of the three markers to the other side revealed whether the answer selected by a user was correct or not (Figure 2b). A correct answer was indicated by a 3D green smiling face, whereas a 3D red sad face displayed on the other side of the marker indicated an incorrect answer. In this way, users participated in the AR game experience and discovered the correct answers by exploration and via a dialogue with the system.

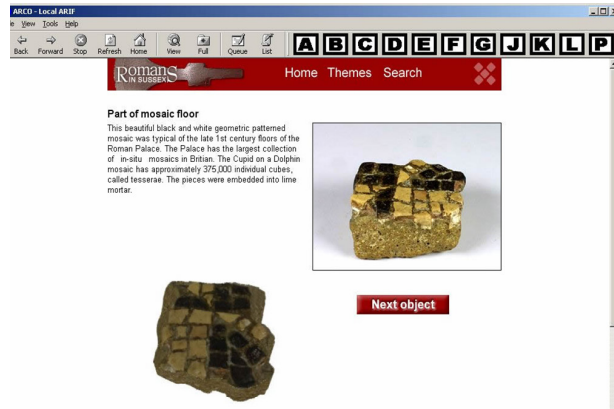


**Figure 2a:** Visualization of an example cultural object



**Figure 2b:** Selection of the correct answer (White et al., 2004)

During the game, each correct answer was awarded a number of points, whereas a wrong answer decreased score for a given question. The visual feedback on the answer selected by a user was also accompanied with appropriate audible feedback expressing approval or disapproval. When all questions regarding a cultural object were answered correctly, the ARIF application was switched to the web browser for presenting more detailed information on the cultural object, as shown in Figure 3. Next, the user could carry on the game experience and explore the interactive presentation of the remaining cultural objects.



**Figure 3:** The detailed information on a part of an ancient mosaic floor

At the end of the AR game, the final results were presented in the web browser component. If a user earned enough points, he/she could see a 3D reconstruction of one of the Palace wings, as depicted in Figure 4. Clearly, this is only a simple scenario, which could be extensively elaborated particularly with the new plethora of commercial AR SDKs now available in mobile formats, with specific web and mobile 3D standards such as OpenGL ES and WebGL.



**Figure 4:** The game results — 3D reconstruction of a part of the Fishbourne Roman Palace

The user evaluation and associated interviews took place in the Computer Graphics Centre, at the University of Sussex, UK. It involved only one participant at a time, while research assistants guided the participants on how to use the system.

During the evaluation process all “users were provided with written instructions concerning sets of pre-determined tasks while navigating through the ARIF interface. The evaluation used cued testing, which involves guiding users while exposed

to the system and asking them to perform specific tasks or to answer questions” (Sylaiou et al., 2010). It was interesting to explore the relationship between the educational usefulness of the learning scenario and previous user experience with virtual reality, augmented reality and computer games. Users’ willingness to play the AR game again offered a measure of engagement.

Initially, the users were informed about the game tasks. During the next stage, users moved through the contents of the AR museum game. They explored the interface and made decisions in relation to defined tasks. Finally, the system usability was assessed without keeping track of users’ errors, or the time needed to complete the tasks, because the evaluation was focused on assessing system performance rather than users’ performance.

#### 4.4 Evaluation metrics

The experimental scenario included cultural heritage information and required users to interactively answer a series of questions as well as resolve tasks employing an experimental AR interface. The AR cultural heritage game relates to learning by doing and to discovery learning (Hein, 1998). According to the ISO-standard 9241 (ISO, 1998), “*usability* of a system is its ability to function effectively and efficiently, while providing subjective satisfaction to its users”. Nielsen defines the usability of an interface as being usually associated with five parameters:

(1) Easy to learn: a user can get work done quickly with the system, (2) efficient to use: once a user has learnt the system, a high level of productivity is possible, (3) easy to remember: a casual user is able to return to using the system after some period without having to learn everything all over again, (4) few errors: users do not make many errors during the use of the system or if they do so they can easily recover them, and (5) pleasant to use: users are subjectively satisfied by using the system; they like it (Nielsen, 1993).

In order to address these parameters, a qualitative as well as a quantitative evaluation was conducted. The qualitative evaluation was based on observation of problems encountered while users were playing the AR game. The main quantitative evaluation instrument used for this study was the ACMA-ARIF Tutorial Questionnaire (ARCO, 2005), which included six main questions for subsequent analysis:

(1) The educational usefulness of the learning scenario within a museum/class room is (poor/excellent), (2) The presentation of questions in the AR environment is (poor/excellent), (3) Answering questions using double-sided markers is (very difficult/very easy), (4) The integration of the web and AR presentation is (poor/excellent), (5) The scoring mechanism is (nonsense/essential), and (6) The sounds accompanying the learning scenario are (nonsense/essential) (Karoulis, Sylaiou and White, 2006)

There was an additional question exploring the users’ intention to try AR technologies again scored on a 7-point Likert scale (not at all/definitely).

## 5. Results and discussion

### 5.1 Qualitative analysis

Two important concepts regarding the usability of an interface are ‘transparency’ and ‘intuitiveness’ (Nielsen, 1993; Preece et al., 1994). Transparency refers to the ability of the interface to fade out in the background, allowing the user to concentrate during his work on *what* needs to be done and not on *how* to do it. In our case this means not interfering with the learning procedure, while *intuitiveness* refers to its ability to guide the user through it by the use of proper metaphors and successful mapping to the real world. For example, by providing the user with the appropriate icons, correct labelling, exact phrasing, constructive feedback, etc. (Karoulis, Sylaiou and White, 2006). *Transparency* and *intuitiveness* were assessed by initially gathering observational information in relation to the problems encountered while users resolved the tasks of the AR game, forming the qualitative part of the evaluation.

The interviewer took careful notes of the participants’ responses and then the interviews were transcribed. The results were elaborated using manual content analysis coding and were categorised according to words and phrases that were repeated often creating patterns. For the data processing, a cutting and sorting technique was used. Phrases and expressions that were considered as important were arranged in categories with common characteristics and the common themes concerning the problems encountered and the suggestions for the system improvement were discovered. This information together with users’ suggestions for system improvement was grouped and is documented in an ARCO project deliverable D16 Assessment and Evaluation Report on the ARCO System. Table 1 presents a summary of user feedback responses specific to the AR cultural heritage game used as a scenario for the ARIF part of that evaluation study documented in D16.

The problems encountered and issues raised were grouped according to the functionality of the graphic elements, the quality of the graphics, the ease of navigation, the functionality of the AR elements, the aesthetic issues in relation to the look and feel of the application as well as any general technological problems that need to be addressed. Most notable observations in relation to the AR game functionality proposed the improvement of the navigation interface as well as 3D interface in order to intuitively manipulate the 3D models embedded in the AR quiz as well as the provision of on-line help concerning the scoring mechanism while playing. Moreover, the contrast between background and AR graphical elements when superimposed is considered crucial for successful AR applications because the integration of the real-world view as well as the graphics elements in one environment should be visually clear. Higher resolution could help towards visual clarity too.

**Table 1:** *Qualitative evaluation of the AR game (Giorgini et al, 2004 Karoulis, Sylaiou, and White, 2006, Sylaiou et al, 2008)*

<b>Problems encountered</b>	<b>Description</b>	<b>Suggestions for system improvement</b>
<b>1. Functionality of Graphic Elements</b>	Background, colour and size of fonts	The fonts should be more obvious and legible Change the contrast of the button in relation to background Consider higher contrast between interface elements and background
<b>2. Quality of the VRML models</b>	The quality of the VRML model should be improved	More details about the VRML model should be provided/ Higher resolution of the VRML models' textures
<b>3. Navigation</b>	Sense of control on the navigation	Add a quit option
<b>4. Help</b>	Missing explanatory information	Provide better explanation about the scoring mechanism. For example, an indication of the number of correct and wrong answers Provide hints when answering questions Provide a brief introduction to the quiz. For example, a clip or a movie
<b>5. AR game elements functionality</b>		On the web browser certain icons could be added such as navigation buttons, zoom in, rotate, pan buttons, etc. Minimize text Blocking the correct answer instead of turning over the markers The game rule signifying that when a player turns the same marker twice, two points are lost should be abolished
<b>6. Aesthetic issues</b>	Poor quality of graphic elements	Use different emotion icons Use a clapping hand instead of a smiley face to indicate a correct answer Depending on the score a bigger reconstruction should be built Omit the sounds of applause and the smiling faces when the user selects a correct answer, as well as the sounds of disappointment and the sad faces used when the wrong choice is selected
<b>7. Content enrichment</b>		Addition of more questions
<b>8. Technological problems</b>	The smiley face did not work	Correction of bugs

While the users played the AR game, navigation was challenging. Two users noted that they had lost control of the navigation between the elements of the game proposing a 'quit' option to be added. More detailed feedback includes: Four users required explanations about the game and the scoring mechanism and proposed the addition of a help file that explains the scoring mechanism more clearly. Four participants stated that the navigation to the system would be '*easier with instructions*' whereas, five participants said that '*you need someone to guide you*'. The interviewers also proposed to add a brief introduction to the AR quiz '*for example a clip or a movie*' and provide more explanation about the scoring mechanism. The use of a clapping hand instead of a smiley face to indicate a correct answer was preferred. The participants suggested that the application developers should omit the sounds of applause and the smiling faces when the user selects a correct answer as well as the sounds of disappointment and the sad faces used when the wrong choice is selected. (Karoulis, Sylaiou, White, 2006). Feedback, though, indicating whether in an AR game a player has completed a task successfully or not is considered essential, however, it could be adapted according to age group and type of user. Issues raised in relation to the functionality problems of the AR game elements could be resolved by adding explanatory graphical icons on the web browser. Usability issues such as the ones derived from the qualitative analysis, if not resolved, would have been a severe obstacle towards completing an educational task with concentration and engagement. The qualitative evaluation based mostly on observational data proved to be invaluable proposing a list of guidelines for future development of any AR game.

## 5.2 Quantitative analysis

The quantitative elaboration was based on calculating the group mean response to the six main questions posed to users answered by selecting a rating out of a 7-point Likert scale as detailed in Section 4.4. A seventh question was designed to assess the users' future plans to explore augmented reality again. All questions were answered by selecting a rating out of a 7-point Likert scale.

Figure 5 illustrates the participant's responses to the questions based on a 7-point Likert scale. At the time of this study, AR as a methodology was very new with available library in need of much more functionality; nevertheless the results show an overall positive response with a great interest to explore AR further in the context of cultural heritage AR games. This provides a promising motivation for developing more sophisticated AR gaming installations for museums. The data from which the graph of Figure 1 is derived is detailed in Table 2.

Descriptive statistics in Table 2 show that the participants consider that the proposed learning scenario is useful reflected by a mean value 4.17 on a 7-point Likert scale (SD: 0,711). The presentation of the questions on the AR interface could be improved resulting in a mean quality response value of 3,93 out of 7 (SD: 0,615).

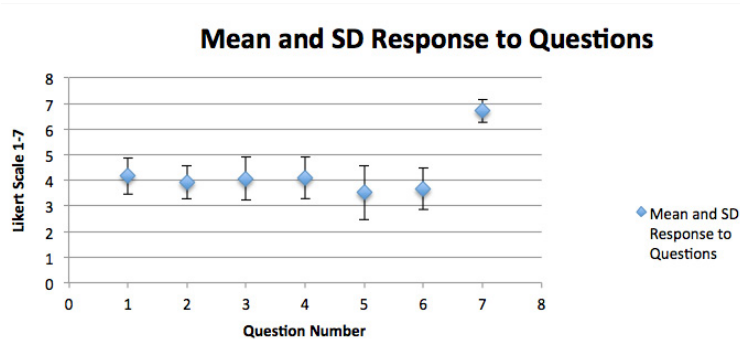


Figure 5: Quantitative analysis

Table 2: Descriptive statistics (29 Users)

Main User Questions	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Std. Error	Statistic
1 Educational usefulness learning scenario	3	5	4,17	,132	,711
2 Presentation questions in AR	3	5	3,93	,121	,651
3 Answering questions using double sided markers	2	5	4,07	,156	,842
4 Integration of AR web presentation	3	5	4,10	,152	,817
5 Scoring mechanism	1	5	3,52	,196	1,056
6 Sounds accompanying learning scenario	2	5	3,68	,155	,819
7 Intention to try virtual or augmented reality in the future	6	7	6,72	,084	,455

This result was expected, because according to the qualitative data a major area of usability problems was related to the functionality of the graphic elements of the AR game. Complaints concerning the clarity of the fonts' size and colour, which to some appeared blurred and 'not obvious' resulted in lower ratings. A design guideline for AR applications involving text and imagery would be that existing fonts and superimposed elements should be of high contrast in relation to the background. Further, newer more sophisticated AR SDKs, e.g. Qualcomm, will take care of this problem.

When assessing the ease of use of the AR double-sided markers and the seamless integration of the AR game and the web presentation, means of 4,07 out of 7 (SD: 0,842) and 4,1 out of 7 (SD: 0,817) were received respectively. Two of the partici-



pants noted that the quality of the 3D models was not satisfactory and that it may be useful in the future to include textures of higher resolution, again future AR development with more sophisticated AR SDKs, and gaming engine graphics and functionality will alleviate this problem. Textures applied to the 3D models and images of the cultural objects were of medium resolution so as for the AR game to be computationally efficient for storage and transmission over the Internet. A design guideline for AR applications would be to include as high-resolution textures and images as possible taking into account computational load. Whether the scoring mechanism was essential and understandable resulted in a mean rating of 3,52 out of 7 (SD: 1,056). Similarly, assessing whether the sounds accompanying the learning scenario were essential resulted in a mean rating of 3,68 out of 7 (SD: 0,819). Both questions communicate to the designer of AR educational games that it is essential that the scoring of an AR game should be well explained. Moreover, the sounds may be vital when they accompany an intuitively designed gaming scenario.

A mean value of 6.72 out of 7 (SD: 0,455) indicated a very positive response by users with an intention to try virtual or augmented reality in the future.

A correlation conducted between the ratings of usefulness of the educational scenario and the ease of use of the AR game questions resulting in a significant positive correlation (Pearson-r correlation coefficient  $r = 0,490$ ,  $p < 0.01$ ) signifying that the educational goals of any AR game may be accomplished when the AR game narrative is clear.

A significant correlation was not observed in relation to the relationship between the educational usefulness of the learning scenario and previous user experience with virtual reality, augmented reality and computer games. Therefore, such technologies are open to the public without the need of previous user experience with similar environments.

The AR cultural heritage game being evaluated was based on a very simple scenario utilising an early prototype augmented reality application, as such technological problems and system bugs were apparent. These were addressed in the improved version of the ARCO ARIF system now open for licensing.

## **6. Conclusions**

The study revealed that AR games are appealing and attract user engagement and interest, however, because of the complexity of AR technologies, AR games may also have problems and deficiencies. The evaluation provided invaluable recommendations concerning factors that were considered an important determinant of AR engaging experiences. Summarizing the research results, the following main outcomes are apparent:

- The users must use intuitively the graphic elements of the user interface. The background must have high contrast colour combinations, in order to avoid confusion with interface elements, like buttons. Also, the colour and the size of the fonts must be legible.
- The 3D models must be of high quality, as photorealistic as possible.
- The users must have obvious exit and a sense of control over the Virtual Environment of the AR game.
- A help file that explains the functions of the AR game to the users must be provided.
- The game must be challenging, so as to help testing users' skills, increasing their interest and enhancing learning.

The evaluation suggested a series of system refinements to ARCO's ARIF component. Changes applied based on feedback received during the qualitative and quantitative evaluation detailed above improved the problematic features of the game. The evaluation framework proposed combining both qualitative feedback as well as quantitative elaboration of findings in relation to ease of use and efficiency of interface elements was considered complementary and useful. Such a framework would be applicable in the broader context of educational interfaces (whether web, VR or AR based) providing a fair methodology with the prospect of eliciting reliable and valid evaluation results.

The development of AR based education tools or museum interactive systems based on AR technology is fraught with problems that can lead to mixed feelings from visitors. When it works, it is outstanding as an educational tool that captivates and motivates the user. But when an AR object fails to materialise (pop out of the book, for example) due to poor lighting conditions or bad choice of fiducial/marker, etc., it can lead to disappointment. So as long as the AR system and environment is carefully designed to avoid these common pitfalls, the interactive experience will engage the user increasing their motivation to learn. Mobile computing devices and the latest AR SDKs that are geared for mobile devices will see a greater uptake of AR and gaming technologies built into mobile applications for museums based learning scenarios. Such scenarios, museum games or virtual museums deploying AR could also exploit the human perceptual system to better understand how we perceive AR across different display media, smartphone, tablet, screen, etc. particularly in terms of immersion. Assessing the efficacy of AR in such environments would be beneficial.

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