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Learning through Multi-touch Interfaces in Museum Exhibits: An Empirical Investigation

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ABSTRACT

Interactive technologies are employed in museums to enhance the visitors' experience and help them learn in more authentic ways. Great amounts of time and money and many man-hours of hard work have been spent. But do such systems indeed achieve their goals? Do they contribute to a greater user experience (UX) and learning effectiveness? In this paper we describe the use of the "Walls of Nicosia" a 3D multi-touch table installed at the Leventis Municipal Museum in Nicosia, Cyprus. Two groups of students actively participated in this empirical study (they attended the 5th year class at elementary school, all aged from 10 to 11 years old): a) The traditional group (control group) where students took a guided tour throughout the museum and learned about the walls of Nicosia through printed maps exhibited at the museum and b) the virtual group where students interacted with the multi-touch application. The main aim of the study was to assess the learning performance and user experience between the two groups. Results showed no statistically significant differences in the learning performance but the virtual group reported user experience at significantly higher levels. The main findings are discussed and ideas for future research are presented.

Keywords

Interactive learning environments, Evaluation methodologies, Elementary education, Virtual reality, Multimedia/hypermedia systems

Introduction

Traditionally museums were using only real objects as exhibits to convey information to their visitors. During last two decades a new trend exists which is based on the involvement of the visitor and thus museums exploit technologically advanced systems to achieve their targets (Wishart and Triggs, 2010). The use of such systems aim in two directions: firstly to attract more visitors to the museums and secondly to "pass" the knowledge to their visitors in a more effective way.

Great amount in budgets and many man-hours of hard work and effort are spent to develop such systems. Does it really worth to do so? Do such systems indeed achieve their goals? Do they enhance the user experience (UX)? In this study we evaluate the learning performance and user experience of such a system installed at the Leventis Municipal Museum in Nicosia, Cyprus. The system under investigation is a 3D multi-touch table that runs an application about "the Walls of Nicosia" which is the fortification of Nicosia in different historical periods. We compare the results with those achieved with the traditional way of getting information from a museum which is by studying the exhibits (printed maps).

In the following section we describe related work on interactive systems installed at the museums. The Section 3 describes the multi-touch system that is evaluated and the application "The Walls of Nicosia" that runs on it. The next section, Section 4, is about the method that has been followed for the empirical evaluation. Results of the experiments are demonstrated at the Section 5. Finally at the last section we discuss our results and we give directions for further work on the subject.

Related work

Technology is exploited recently by modern-day museums as a tool to convey information to their visitors; physical or virtual ones. Many museums setup technologically advanced systems in their physical space to attract more visitors and convey information in a more effective way or use online technologies in order to disseminate knowledge to remote visitors as well. Such systems are (or at least they should be) based on a theoretical background for learning and knowledge in the context of museum's content. In this section we give a brief theoretical background on learning related to technology and then we review work that has been done on interactive systems implemented in museums.

Hawkey (2004) made a review of aspects of learning provided by museums and galleries through the use of digital technologies. There are different learning philosophies regarding the learning opportunities in museums: should museums offer delivery or engagement? Should the underpinning rationale be a passive/transmission view or an active/constructivist view? Different taxonomies of learning experiences in a museum have been proposed. Gammon (2001) in his practical guide for museum evaluators classifies the learning process to cognitive, affective, social, skills development and personal categories. Hooper-Greenhill et al., (2003) proposed a quite similar set of learning experiences in a museum: a) knowledge and understanding, b) skills, c) values and attitudes, d) enjoyment, inspiration and creativity, and e) activity, behavior and progression.

During the recent years main emphasis has been put on a constructive process where the visitor feels that she is a privileged participant who has several possible learning pathways and possibilities. Accordingly, most of the proposed learning taxonomies take into account new learning developments and theories; such developments approach learning in the digital age as not a passive transmission of information to the learners/users of interactive technologies but as an active process through which people construct new understandings of the world around them (Resnick, 2001).

Such an approach can be verified by recent research findings that highlight the crucial role that technology and interactive systems can play in helping to maintain museums as constructive learning spaces. Interactive systems used by museums can be separated in two categories; those accessible from remote visitors, through online multimedia or VR systems and those systems that are located within the physical space of a museum. In the first category we have virtual museums, which extend the physical museums in a variety of ways (Bennet & Hodges, 2005). Focusing on 3D representations, a virtual museum may be a digital depiction of the existing museum and its exhibits (Kunkel & Averkiou & Chrysanthou, 2008; Patias, Chrysanthou, Sylaiou, Georgiades & Michael & Stylainidis, 2008), or it might include a combination of objects existing in several museums, while in some cases the 3D objects that have been modeled are based on description of historical documents (Gaitatzes & Christopoulos & Roussou, 2001). This category of systems, aims to convey information and knowledge that can be found at the museums, to virtual visitors who are not able to visit physically the museum.

Systems in the second category, that are located within the museum, aim to attract more visitors at the physical space of the museum. They provide modern ways of learning while increasing the satisfaction of museum's visitors. They allow the virtual interactivity of the user with a 3D representation of objects or the tour within virtual worlds. This category includes applications that run on VR systems (Roussou, 2001), Augmented Reality systems (Wojciechowski, Walczak & White & Cellary, 2004), haptics devices (Loscos, Tecchia, Frisoli, Carozzino, Widenfeld & Swapp & Bergamasco, 2004), multi-touch tables (Averkiou & Chrysanthou, 2009; Geller, 2006) etc. These technologies combine in a great extent entertainment and education/ training.

Several studies have examined the aforementioned systems and applications for their learning strengths and affordances. Issues such as the learners' engagement and motivation, as well as the increase of learning performance and retention of knowledge have been investigated (Ang & Wang, 2006; Hut, 2007; Nijholt, 2000). More recently there is a focus on the provision of authentic learning experiences and the organization of learning activities. In the MuseumScouts project (Wishart & Triggs, 2010) a learner-centred approach in museums is adopted. In this project learners use information they collect during authentic learning opportunities in a museum to design short interactive multimedia teaching presentations with collaborative authoring tools.

Evaluation of such systems (Chittaro & Ieronutti & Ranons, 2004; Karoulis & Sylaiou & White 2006; Tzanavari, Vogiatzis, Zembylas & Retalis & Lalos, 2005) is another main research issue, since they are used by users with a great diversity in their profiles. Despite the increasing interest in the evaluation of museum interactive technologies, there is little knowledge regarding the crucial issue of user experience (UX) evaluation. Vavoula, Sharples, Rudman, & Meek & Lonsdale (2009) presented an evaluation of Myartspace, a service on mobile phones for inquiry-led learning. Such a service allowed students to gather information during a school field trip which is automatically sent to a website where they can view, share and present it, back in the classroom or at home. The evaluation during this study focused on usability issues, educational effectiveness and the impact of the new technology on school museum visits practice.

Reynolds & Walker & Speight (2010) described a three-stage qualitative evaluation programme of web-based museum trails in the Victoria and Albert Museum in London. The trails were only partially successful from a technological standpoint due to device and network problems. Nevertheless student feedback showed that overall the trails enhanced students' knowledge and their interest in the museums' objects.

The Walls of Nicosia

The application "The Walls of Nicosia" is an interactive application that runs on a multi-touch table (Figure 1). The aim of this application is to allow the user to have a virtual tour through the fortifications of Nicosia across the centuries and learn about the Walls of the city at each historical period. The target was to explain and present the development of the area and the history of the development of the fortifications of the city – From a Roman and Byzantine Castle to a Medieval Royal Capital and a Venetian Fortified city.

Figure 1. The application "The Walls of Nicosia" runs on a multi-touch table.

The application uses 3D models (Figure 2) representing the fortifications of the city as well as the most important landmarks for five historical periods: pre-Roman (villages with no fortification), Roman castle, Byzantine castle, Lusignan Walls and Venetian Walls.

Figure 2. The fortifications of the city with the most important landmarks demonstrated with 3D models.

The interaction is achieved through the multi-touch surface of the table. A menu appears on the top of the screen of the table with a clickable button for each historical period. The users can navigate through time by touching using one finger on the corresponding button. They can then interact and study the 3D models of the historical period they choose using intuitive gestures, touching the surface with one or two fingers at a time. The users are able to zoom in/out, pan and tilt the virtual camera.

A helping menu exists on the interface of the application, describing which gesture should be used by the user in order to perform a specific operation. A compass, on the top-right corner of the interface, assists the users with orientation. Traditional music is played for each historical period, in order to immerse the user.

The multi-touch table hardware is based on back projection. A projector, connected with the host computer resides inside the table. The final image on the top surface is produced with the use of a mirror that reflects the projector image. This technique is used in order to virtually increase the space within the table and allow us to use a standard DLP project (not a short throw one). The gestures of the user's fingers are tracked using infrared light. 300 LEDs and an infrared camera have been mounted inside the table for the finger tracking. LEDs emit light toward the table surface. When a user touches the surface the infrared light is reflected back and the infrared camera captures that light. Each frame that is captured by the camera is processed in order to detect the position of the user's fingers on the screen.

Pedagogical affordances of "The Walls of Nicosia"

The main purpose of "The Walls of Nicosia" is to provide rich interactivity and to facilitate users/visitors engagement and participation. "The Walls of Nicosia" was developed so as to provide several pathways to explore the walls of Nicosia during distinct historical times. Priority was given to provide an inquiry-based learning experience to the visitors. Inquiry learning is considered to be a very effective pedagogical strategy for a museum visit (McLeod and Kilpatrick, 2001). To this end, this interactive 3D application followed the pedagogical approach of guided-inquiry (Colburn, 2000). A typical scenario of guided inquiry in a museum prescribes a short introduction (by the teachers and museum guides) and then it is expected that students/visitors will be guided to uncover critical concepts for themselves and finally learn from the museum's objects rather than simply learn about them. "The Walls of Nicosia" provides opportunities for "hands-on" exploration while the 3D models of each historical period and the facility to zoom in/out, pan and tilt the virtual camera provides a greater sense of interactivity and authenticity to the users.

Methods

Research design

This study compared two different types of classes: (a) a traditional one (control group) where children took a guided tour throughout the museum and learned about the walls of Nicosia through printed maps exhibited at the museum and (b) the virtual group where children interacted with the multi-touch application "The Walls of Nicosia". The main aim was to assess the learning performance and user experience between the two groups. The two different classes were based on the same learning content and learning objectives and both of them were located at the same place, the Leventis Municipal Museum of Nicosia. Accordingly in this study the following research questions were investigated:
Are there any differences in the learning performance between students of the traditional group and the virtual group?
Are there any differences in the user experience between students of the traditional group and the virtual group?

Participants

The participants for the study were *randomly* selected from a list of elementary schools in Nicosia. In total 53 children (24 girls and 29 boys) participated in this study from 3 Elementary Schools of Nicosia. The children attended the 5th year class at elementary school, all aged from 10 to 11 years old.

Data collection

Quantitative data were collected and observations were made by the authors that supported quantitative findings. Two questionnaires were developed:

- A pre-test questionnaire containing two parts, one part for collecting demographic information (age, gender, year at school) and the second part for evaluating learning performance, i.e., a knowledge test regarding the walls of Nicosia. The knowledge test contained 10 multiple-choice questions on issues related with the walls of Nicosia. This test was developed by the authors in collaboration with a colleague who is a school teacher and teaches topics on local history. The content validity was assessed by three experienced teachers who were responsible for the visit in the museum and they had very good knowledge about the history of Nicosia at different times.

- A post-test questionnaire containing two parts, one part for assessing the user experience and the second part for evaluating learning performance. As already mentioned the users in this field study were children. Therefore in order to assess the user experience we employed the Smileyometer and the Again-Again table (appendix). Both of them are tools contained in the FunToolkit (Read, 2008), which is a well-known and validated technique for assessing user experience with technology when the users are children (reliability analysis shown Chronbach's Alpha a = 0.786, for the total scale and N = 53). The knowledge test was the same as included in the pre-test.

Students' observation took place for both classes. The focus of this observation was to capture their motivation and experience as expressed by gestures, body movements, attention and words.

Procedure

Concerning the procedure, the 53 students that participated in this field study were randomly (by using the lottery method) assigned to one of two groups: the traditional group (control group) and the virtual group. None of the students had ever been taught anything about the walls of Nicosia before. In addition as pointed out, both interventions (traditional class and virtual class) were based on the same learning content and learning objectives. Therefore we can assume that any differences in the learning performance and user experience can be attributed to the different type of classes (i.e. the two different interventions). Before starting the museum visit, students from both classes completed the questionnaire with demographic information (gender, age and year at school) and the knowledge test. Right after, the visit began in parallel for the two groups which last about 60-65 minutes. The visit experience included three parts: the first part was an introductory talk given by the teachers along with the presentation of the main exhibits (maps and multi touch table). The second part (20 minutes) was dedicated to a lively discussion and commentary on the Walls of Nicosia. The third part (20 minutes) focused on the assessment of User experience and the final knowledge test.

One researcher was present at each group. The traditional group entered the room with maps. Maps of the walls of Nicosia from different chronological periods are exhibited in this room. The teacher talked to the students about the fortifications showing to them the corresponding information on the maps (Figure 3).

Figure 3. Exhibition of the printed maps at the traditional group

The multi-touch table running the application was set up in a separate room. Students entered the room and a short introduction about the system followed by the researcher. Then the teacher talked to the students about the Walls. The teacher was interacting with the application while she was talking to the students and she was showing the corresponding information for the walls on the system.

Teaching and discussion in both groups was interactive. The teachers asked students several questions about the walls (e.g., their shape, extend etc) and prompted the students to express and share their opinions. The students were requested to find the answers by studying the maps for the traditional group or by interacting with the system for the virtual group. The researcher that observed the virtual group noted that there was a great enthusiasm and curiosity by the students. In cases where students did not give an answer, the correct answer was then given by the teacher. After the introduction and presentation of the system (first part of the visit), students in the virtual group were called to interact with the multi-touch table two at a time (second part). Afterwards students were given around 20 minutes (third part) in order to complete the post-test questionnaire by filling out the Smileyometer, the Again-Again table and the knowledge test.

Data analysis and results

This study investigates a) whether there is a difference in learning performance between the students of the two different groups and b) whether there is a difference in user experience between the students of the two different groups. In order to identify any differences in the learning performance for the pre-test and the post-test phase an independent samples t-test analysis was performed. Significance level was set at 0.05 for all the analyses performed. For the investigation of changes in the learning performance within each group across the pre-test and the post-test phase, two paired-samples t-test were performed. Concerning the knowledge tests, a total score was calculated ranging from 0 to 10. Independent samples t-test was also employed in order to compare user experience between the two classes.

Comparison of two groups regarding the learning performance

As far as concerns the pre-test phase, the t-test analysis did not revealed statistical significant differences [(t51) = -.304, p = .762] between the traditional group (M = 2.81, SD = 1.642) and the virtual group (M=2.69, SD=1.258) (Table 1). Such finding reveals that both groups had similar background knowledge on the walls of Nicosia.

Table 1. Pre-test learning performance

	Intervention	N	Mean	Std. Deviation	t	Sig. (2-tailed)
Pre-test knowledge score	Virtual group	26	2,69	1, 258	-,304	,762
	Traditional group	27	2,81	1,642		

For the post-test phase the independent samples t-test analysis did not revealed statistical significant differences ((t51) = -1.889, p = .065) between the traditional group (M = 7.81, SD = 1.902) and the virtual group (M = 6.81, SD = 1.980). Although learning performance shows that traditional group performed higher at the post-test knowledge questionnaire (Table 2), this was a non statistical significant result.

Table 2. Post-test learning performance

	Intervention	N	Mean	Std. Deviation	T	Sig. (2-tailed)
Post-test knowledge score	Virtual group	26	6,81	1,980	-1,889	,065
	Traditional group	27	7,81	1,902		

Regarding the change in the learning performance within each group across the pre-test and the post-test phase, the two paired-samples t-test showed significant changes for both groups (Table 3). In the traditional group there was a

significant increase in learning performance from pre-test (M = 2.81, SD = 1.642) to post-test phase (M = 7.81, SD = 1.902), t(26) = -10.221, p<0.001). Mean increase in learning performance was 5,000. In the virtual group there was also a significant increase in learning performance from pre-test (M = 2.69, SD = 1.258) to post-test phase (M = 6.81, SD = 1.908), t(25) = -9.474, p<0.001). Mean increase in learning performance was 4.115 (Table 3), which was slightly smaller than the increase in the traditional group.

Table 3. Changes in learning performance

					Paired differences		
		Mean	N	Std. Deviation	Mean	T	Sig. (2-tailed)
Traditional group	Pre-test learning performance	2,81	27	1,642	-5,000	-10,221	,000
	Post-test learning performance	7,81	27	1,902			
					Paired differences		
		Mean	N	Std. Deviation	Mean	T	Sig. (2-tailed)
Virtual group	Pre-test learning performance	2,69	26	1,258	-4,115	-9,474	,000
	Post-test learning performance	6,81	26	1,980			

Comparison of two groups regarding the user experience

We move on with the analysis of the second research question which is about the user experience. Independent samples t-test was also employed in order to compare user experience between the two classes. For the Smileyometer, the analysis showed statistical significant differences [(t51) = 3.042, p = .004] between the traditional group (M = 3.96, SD = 0.898) and the virtual group (M = 4.65, SD = 0.745). It is evident that students from both classes reported high levels of user experience, however findings from this analysis shows that virtual group reported user experience at significantly higher levels (Table 4). For the Again-Again table, analysis also revealed statistical significant differences [(t51) = 2.947, p = .016] between the traditional group (M = 2.33, SD = 0.452) and the virtual group (M = 2.73, SD = 0.679) (Table 4).

In order to control other variables for possible effects on the results, additional test were performed. In more details, we tested whether gender had a significant impact on learning performance and user experience. No statistical significant differences were found for learning performance as for the pre-test [(t51) = 1.516, p = 0.136] and the post-test [(t51) = - 1.070, p = 0.290]. No statistical significant differences were found for user experience [(t51) = -0.693, p = 0.492, for the smileyometer] and [(t51) = .144, p = 0.886, for the again-again table].

Table 4. User/visitor experience

	Intervention	N	Mean	Std. Deviation	T	Sig. (2-tailed)
UserExperience (smileyometer)	Virtual group	26	4,65	,000	3,042	,004
	Traditional group	27	3,96	,833		

	Intervention	N	Mean	Std. Deviation	T	Sig. (2-tailed)
UserExperience (again-again table)	Virtual group	26	2,73	,452	2,947	,016
	Traditional group	27	2,33	,679		

Observations

It was observed that students participating in the traditional group were passively listening to the teacher without any active role in the learning procedure. On the other hand students in the virtual group were enthusiastic and actively

engaged in the whole process. This finding is also confirmed by the quantitative analysis as far as concerns the user experience analysis.

The discussion in the virtual group was very lively and kept the interest of the students during the whole visit. For instance, as soon as the teacher of the virtual group switch to the Venetian period a student said *"oh now I can see the shape of the ramparts"* which was one of the questions of the knowledge test while another student started to count how many ramparts exist that was the issue of another question. Some other instances from the process: When the teacher pointed out on the display the shape and direction of the river we observed that the students came nearer to the table to be able to see by themselves the river and interact with it. In addition another student stated that *"the Walls are very big!"* and the teacher confirmed his observation saying that they indeed cover several square Kilometers.

Discussion and future research

In this study, "The Walls of Nicosia", a 3D multi-touch table which is part of the permanent exhibition at the Leventis Municipal Museum of Nicosia, is presented. The main focus is on investigating the user experience and the learning effectiveness after the interaction with this interactive technology. Two groups of students, who were visiting the museum, participated in the study. In the virtual group students interacted with the 3D multi-touch application in order to learn about the history of walls in old Nicosia, while in the traditional group students took a guided tour throughout the museum and learned about the walls of Nicosia through printed maps exhibited at the museum.

The results showed no statistically significant differences in the learning performance between the two groups. Although results of learning performance shows that traditional group performed higher, this was a non statistical significant result.

Initially it was expected that students in the virtual group would perform better; many other studies (Wishart & Triggs, 2010; Tüzün, Yilmaz-Soylu, Karakus & Inal & Kizilkaya, 2009; Ke & Grabowski, 2007) with students have showed that interaction with 3D applications, such as games, virtual worlds etc. can contribute to higher learning performance across several topics (history, geography, mathematics, literature). Although the learning performance was increased in a statistically significant way in both groups (comparing knowledge before and after the museum visit), there was no significant difference in the learning performance between the two groups. Other studies as well (Wrzesien & Raya, 2010; Papastegriou, 2009) demonstrated no differences in the learning performance, mainly due to the perceived novelty of the interactive technology at hand. For instance in this study, the innovative way of exploring and navigating the 3D multi touch interactive environment may explain the learning performance of the virtual group. The several novel features and the realistic 3D graphics of the "Walls of Nicosia" may have distracted to a certain extent the students in the virtual group. On the other hand the physical tour at the museum's exhibition seems a more natural way of learning about the history of walls of the old Nicosia. This was more or less confirmed by the informal observations of the researchers and the commentaries made by the students after their visit.

As far as concerns the user experience issues, findings from this study shows that virtual group reported user experience at significantly higher levels (as depicted in Smileyometer instrument). They seem to enjoy it more than the other students, being more engaged and they expressed a greater intention to repeat such a visit (as drawn from the Again-Again table). Such findings confirm relevant data from other studies as well (Wrzesien and Raya, 2010; Papastergiou, 2009).

The study has some specific limitations. The knowledge test we developed was quite short and focused on factual type of knowledge and short-term retention. In a future study a longer-term retention of knowledge and other types of knowledge (other than simple concepts and mere facts) can be evaluated. To this end, future studies can perform some post-museum visit activities in order for the students to reflect upon what has been learned during their museum visit and further assess whether knowledge can be retained.

Regarding the organization of the field study: The fact that students in the virtual group were called to interact with the multi-touch table two at time may have influence the user experience. Additionally there were two different

teachers who were responsible for the museum visit for the respective groups of students. Despite the fact that the learning content and objectives were the same and the protocol for the "teaching" process, the presentation of the exhibits by two different persons could influence the results in both the learning performance and the user experience.

At the current state the "Walls of Nicosia" does not provide the opportunity to build an avatar, so as to enhance the perception of presence and the ownership of the virtual environment. Such enhancements can lead to a greater contribution to the learning effectiveness and the user/visitor experience; this could be investigated in a future study. Moreover, a future study can pursue the deeper investigation of the impact that individual museum's visitor characteristics (such as specific learning and cognitive styles) may have on the learning process and the whole user/visitor experience. Moreover, a future work could include an assessment of anticipated user experience of both groups, which can further enlighten the focal research questions.

In conclusion, this study demonstrates that the use of new types of interactive systems contribute to the experience of visitors in museums, enhancing their level of active participation and engagement and their intention to repeat visits. As for the learning gains that the visitor should grasp, it can be argued that such interactive technologies provide new learning experiences no less than the traditional exhibition methods. In many cases and after the novelty effect has passed, such interactive technologies can provide more authentic learning and entertainment at the same time.

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References

Ang, K., & Wang, Q. (2006). A case study of engaging primary school students in learning science by using active worlds. *In* R. Philip, A. Voerman, & J. Dalziel (Eds), *Proceedings of the First International LAMS Conference 2006: Designing the Future of Learning (*pp. 5-14). Sydney, Australia: The LAMS Foundation.

Averkiou M., & Chrysanthou Y. (2009). Evaluating a multitouch interface for 3d navigation inside the virtual world of a museum exhibit. In K. Debattista, C. Perlingieri, D. Pitzalis & S. Spina (ed.), *Proceedings of Vitural Reality, Archaeology and Intelligent Cultural Heritage.* Aire-la-Ville, Switzerland: The Eurographics Association.

Bennet, J., & Hodges, A. (2005). The development of science museum web sites: Case studies. In L. T. W. Hin, & R. Subramaniam (Eds.), *E-Learning and Virtual Science Centers* (pp. 366-392). Hershey, PA: Information Science Publishing. doi:10.4018/978-1-59140-591-7.ch018

Chittaro, L., Ieronutti, L., & Ranon, R. (2004). Navigating 3d virtual environments by following embodied agents: A proposal and its informal evaluation on a virtual museum application. *PsychNology Journal: Special issue on Human-Computer Interaction, 2*(1), 24-42.

Colburn, A. (2000). An inquiry primer. *Science Scope, 23*(6), 42-44.

Gaitatzes, A., Christopoulos, D., & Roussou, M. (2001). Reviving the past: cultural heritage meets virtual reality. In D. B. Arnold, A. Chalmers, & D. W. Fellner, *Proceedings of the 2001 conference on Virtual reality, archeology, and cultural heritage* (pp. 103-110). New York, NY: ACM

Gammon, B. (2001). *Assessing learning in museum environments: A practical guide for museum evaluators.* London, UK: Science Museum.

Geller, T. (2006). Interactive tabletop exhibits in museums and galleries. *IEEE Computer Graphics Applications. 26*(5), 6-11.

Hawkey, R. (2004). *Learning with digital technologies in museums, science centres and galleries* [Report 9, Futurelab Series]. London, UK: King's College.

Hut, P. (2007). Virtual laboratories. *Progress of Theoretical Physics, 164*, 38-53.

Hooper-Greenhill, E., Dodd, J., Moussouri, T., Jones, C., Pickford, C., Herman, C., … Toon, R. (2003). *Measuring the outcomes and impact of learning in museums, archives and libraries.* Retrieved from the Research Centre for Museums and Galleries website: http://hdl.handle.net/2381/65

Karoulis A., Sylaiou S., & White M. (2006). Usability evaluation of a virtual museum interface. *Informatica, 17*(3), 363-380.

Ke, F., & Grabowski B. (2007). Gameplaying for math's learning: Cooperative or not? *British Journal of Educational Technology, 38*(2), 249-259.

Kunkel, T., Averkiou, M., & Chrysanthou, Y. (2008). A web-based virtual museum application. In M. Ioannides, A. Addison, A. Georgopoulos, L. Kalisperis (Eds.), *Proceedings of the 14th International Conference on Virtual Systems and Multimedia* (pp. 275-277). Budapest, Hungary: ARCHAEOLINGUA

Loscos, C., Tecchia, F., Frisoli, A., Carozzino, M., Widenfeld, H. R., Swapp, D., & Bergamasco, M. (2004). The museum of pure form: touching real statues in an immersive virtual museum. In D. W. Fellner & S. N. Spencer (Eds.), *Proceedings of the 5th International Symposium on Virtual Reality, Archaeology and Cultural Heritage* (pp. 271-279). The Eurographics Association.

McLeod, J., & Kilpatrick, K. M. (2001). Exploring science at the museum. *Educational Leadership, 58*(7), 59-63.

Nijholt, A. (2000). Agent-supported cooperative learning environments. In Kinshuk I., Jesshope C., & Okamoto T., *International Workshop on Advanced Learning Technologies (IWALT 2000)* (pp. 17-18). Los Alamitos, CA: IEEE Computer Society Press.

Papastergiou, M. (2009). Digital game-based learning in high school computer science education: Impact on educational effectiveness and student motivation. *Computers & Education, 52*(1), 1-12.

Patias, P., Chrysanthou, Y., Sylaiou, S., Georgiades, C., Michael D., & Stylianidis, S (2008). The development of an e-museum for contemporary arts. In M. Ioannides, A. Addison, A. Georgopoulos, & L. Kalisperis (Eds.), *Proceedings of the 14th International Conference on Virtual Systems and Multimedia*. Budapest: ARCHAEOLINGUA.

Read, J. C. (2008). Validating the fun toolkit: An instrument for measuring children's opinions of technology. *Cognition Technology & Work, 10*(2), 119-128.

Resnick, M. (2001). *Revolutionizing learning in the digital age.* Retrieved from http://people.ku.edu/~ghada/portfolio/standards/st2/digital.pdf

Reynolds, R., Walker K., & Speight C. (2010). Web-based museum trails on PDAs for university-level design students: Design and evaluation. *Computers & Education, 55*(3), 994-1003.

Roussou, M. (2001, June). *Immersive interactive virtual reality in the museum.* Paper presented at the Trends in Leisure Entertainment 2001, London, UK.

Tüzün H., Yilmaz-Soylu M., Karakus T., Inal Y., & Kizilkaya, G. (2009). The effects of computer games on primary school students' achievement and motivation in geography learning. *Computers and Education, 52*(1), 68-77.

Tzanavari, A., Vogiatzis, D., Zembylas, M., Retalis, S., & Lalos, P. (2005). Affective aspects of web museums. *Studies in Communication Science, 5*(1), *39-56.*

Vavoula G., Sharples M., Rudman P., Meek J., & Lonsdale P. (2009). Myartspace: Design and evaluation of support for learning with multimedia phones between classrooms and museums. *Computers & Education, 53*, 286-299.

Wishart J., & Triggs P. (2010). MuseumScouts: Exploring how schools, museums and interactive technologies can work together to support learning. *Computers & Education, 54*(2), 669-678.

Wojciechowski R., Walczak K., White M., & Cellary W. (2004). Building virtual and augmented reality museum exhibitions. In D. P. Brutzman, L. Chittaro, & R. Puk. (Eds.), *Proceedings of the ninth international conference on 3D Web technology* (pp. 135-144). New York, NY, USA : ACM.

Wrzesien M., & Raya M. A. (2010). Learning in serious virtual worlds: Evaluation of learning effectiveness and appeal to students in the e-junior project. *Computers & Education, 55*(1), 178-187.

Appendix

Questionnaire for user experience:

1) How was your experience in this visit?

2) Would you like to do it again?

Yes	Maybe	No