Exploring the educational impact of diverse technologies in online virtual museums

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Abstract: This research explores the learning outcomes of online virtual museums employing diverse technologies such as images, videos, 3D reconstructions, etc. It presents the selection criteria (imageability, interactivity, navigability, personalisation, communication) of the five online virtual museums (VMs) involved in the analysis, each of which brings forward a
prominent visualisation technology. Then, it describes the methodology of the evaluation process, in which a group of 164 (n = 164) participants, after exploration of the virtual museum websites, answered a self-administered questionnaire including 12 questions based on the concept of generic learning outcomes: a) knowledge and understanding; b) skills; c) change in attitude and values; d) enjoyment, inspiration and creativity; e) action, behaviour and progression. The results of a statistical analysis investigating the educational impact of each VM are analysed. The potential educational advantage of incorporating complex 3D reconstructions in a VM is questioned. A new methodology for analysing VMs is required. This paper contributes to the understanding of the educational impact of VMs in relation to their underlying technology and human computer interaction (HCI) features. Therefore, conclusions have a wider impact and can be generalised to be relevant even after design changes of the VMs selected for the evaluation.

**Keywords:** virtual museums; educational impact; generic learning outcomes; GLO.


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1 Introduction

New museology has recently shifted its focus from the museum exhibits to the experience of the visitors in the museum. Museology views the museum as an educational tool in the service of the development of society; an environment for learning and enjoyment for its visitors (Vergo, 1989). Following the same rationale, virtual museums (VMs), provide virtual visitors the freedom to interact via a constructive cultural dialogue. Visitors
explore its content, context and contextualised knowledge providing inspiration and exercising autonomy. Thus, visitors become active participants, as they create their virtual tour and paths, constructing their own knowledge concerning the exhibits, but also knowledge about themselves (Sylaiou et al., 2009). The work presented here aims to verify whether the so-called VMs, e.g., the interactive, online reconstructions of museum galleries and exhibits (Sylaiou et al., 2008; Pujol and Lorente, 2013), promote learning, even when users perceive them as game-like experiences.

Museums use the World Wide Web for different purposes ranging from advertising to e-visiting, collection exploration, cultural mediation (Mateos-Rusillo and Gifreu-Castells, 2016) and multi-faceted interactive, or in some cases gamified educational experiences (Sylaiou et al., 2009; Pujol and Lorente, 2013). Various studies have examined the importance of learning for museum visitors and the educational leisure time offered (Falk and Dierking, 1992, 2000; Falk et al., 1995a, 1995b, 1998, 2007; Hedge, 1995; Astor-Jack et al., 2007; Kelly and Fitzgerald, 2011). VMs’ elements encourage the interaction and communication between curators and the public by provoking wider participation and engagement and potentially result in strong educational impact. Museums’ digital, as well as 3D interactive content can strengthen visitors’ motivation, trigger aesthetic sensitivities and creativity, and provide new approaches that engage visitors in new personalised interactive museum experiences (Mundy and Burton, 2013). Most of these resources, including the presentation of exhibits through online databases or even the 3D reconstruction of actual museum architectural spaces and the inclusion of panoramic videos and images complemented with information, comply with the museum’s ultimate educational scope (Falk and Dierking, 2000; Hooper-Greenhill, 2007; Walker, 2008) and can motivate individuals to get more deeply involved with the VM content and therefore enhance their reasoning process and become motivated to know more about the exhibitions, augment their cognitive ability to integrate and understand the information presented (Katz and Halpern, 2015). In this sense, virtual learning environments and current constructivistic theories of learning share common motivation (Hein, 1991; Mulcahy, 2016).

VMs help distant visitors to expand their existing knowledge by communicating new ideas and creating meanings based on their interactive experience with the VM and its contents. However, the link between the virtual visitor’s experiences and the birth of new ideas is subject to implementation issues, therefore, the hypothesis that the underlying technologies may have an impact on the quality of the educational experiences and their outcomes is worth investigating. Such links have been employed by museums for building complex and multifaceted learning environments (Falk and Dierking, 2000, 2012) and are, namely: reproduction of a meaningful context; use of primary sources and discovery of (scientific) strategies; interactive exploration that leads to the user’s own polysemous interpretation of contents; personalisation of information (subject and depth) and presentation methods (visual, audio); adaptation of activities to different interests and skills; social collaboration; and finally, conceptualisation of the process as an experience, and not just as passive acquisition of knowledge. Yet, as more museums move towards digitising and presenting their collections online, a series of questions have been raised with regard to the effectiveness and the specific advantages of online VMs for learning (Bitros et al., 2010; Lorente and Kanellos, 2010). It has been shown that interactive game-relevant features increase motivation and learning in general (Piaget, 1951), but also in the museum context of online, interactive resources (Csikszentmihalyi and
It is doubtful, though, whether such technologies strengthen both the educational impact and experience of VMs. VMs may enhance visitors’ motivation to learn by providing them the opportunity to discover and select the information they want to have and construct their own knowledge. In Packer and Ballantyne (2002) a questionnaire has examined similarities and differences among the sites in relation to visitors’ expectations, perceptions of learning opportunities, engagement in motivated learning behaviours, and perceptions of the learning experience. Packer (2006) explores the commonalities between learning for fun and other theoretical constructs such as ‘experience’, ‘flow’, ‘intrinsic motivation’, and ‘curiosity’. In another study (Bayne et al., 2009), the primary source of the educational value of the VMs is considered as the ability of users to take, manipulate, re-distribute and re-describe digital objects. A conceptual model has been used as a guideline in designing and evaluating VMs (Rahime et al., 2011) in terms of efficiency, ease-of-use and satisfaction. In the framework for evaluating impacts of informal science education projects (2009) a framework with the following categories: awareness, knowledge or understanding (of), engagement or interest (in), attitude (towards), behaviour (related to), skills (based on), has been adopted.

The goal of this paper is to define both conceptually and experimentally the educational impact of diverse visualisation methods utilised in online VMs employed for presenting cultural information and artefacts. The main scope of this paper is to analyse the learning benefit of museums’ digital online resources in relation to the specific prominent visualisation technology utilised, even when, other, less apparent visualisation technologies are combined. The ultimate goal of this work is to associate learning outcomes with specific visualisation technologies which even when user interface design changes, the integration of each in an online museum will communicate specific learning characteristics. Five museum websites were selected incorporating varied visualisation technologies including online resources such as panoramic images; text and scalable images; searchable databases; Web3D environments; and educational videos relevant to the historical context or content of a museum. Then, a comparative evaluation was conducted, during which the subjects explored the resources provided by each online resource and answered a self-administered questionnaire. The questionnaire covered multi-faceted perspectives of learning such as knowledge, skills, values, feelings and behaviour, defined as generic learning outcomes (GLO) (Hooper-Greenhill, 2004), investigating perceived knowledge acquisition.

2 GLO and museum online resources

This section presents an overview of the most significant developments in the areas of learning, educational learning and gaming experiences on museum environments.

2.1 Learning

Museums, and by extension their digital counterpart, are considered learning environments commonly used in informal learning (Falk and Dierking, 2000; Hooper-Greenhill, 2007; Walker, 2008). This is based on the notion of learning as a "continuous, contextually driven effort to make meaning of a situation, in order to survive and prosper within the world; an effort that is best viewed as a never-ending..."
dialogue between the individual and his or her physical and socio-cultural environment” (Gammon and Burch, 2008). Learning is an active process, of constructing new ideas, concepts, attitudes and their own identity, based upon their previous knowledge and experiences (Hein, 1991; Hooper-Greenhill, 2004). These are usually organised in specific cognitive structures, which provide meaning to new experiences. Such schemes or mental models allow individuals to adapt to, explain, and interact with the world around them. Consequently, the museum’s effectiveness with regard to learning relies on the ability to convey information about the objects and their context in an engaging, meaningful, diversified and self-controlled way (Falk and Dierking, 2000). Users may experiment and learn by doing, acquire new and construct upon existing knowledge, evaluate their own practice, learn how to navigate, search and find information they are interested in, gain new experiences, competencies and confidence. This process of exploration, experimentation and discovery motivate visitors of online museum resources to explore diversified multimedia information provided to them. Having the opportunity to practice, they can improve their skills and accomplish tasks easily and effectively. VM visits can be considered as opportunities to enhance learning, motivation and confidence.

2.2 Gaming experiences

Computer games and serious games can exist in the form of mobile applications, simple web-based solutions, more complex ‘mashup’ applications, e.g., combinations of social software applications, or in the shape of ‘grown-up’ computer games, employing modern games technologies to create virtual worlds for interactive experiences. Such experiences may include socially-based interactions, as well as mixed reality games that combine real and virtual interactions, all of which can be employed in cultural heritage applications (Anderson et al., 2010). The main strength of serious gaming applications may be generalised as being in the areas of communication of learning goals, visual expression of information, collaboration mechanisms, interactivity and learning via entertainment (Zyda, 2005; Paliokas and Sylaiou 2016).

However, there are two diverse views in relation to the pedagogical value of serious games. One argues that while pedagogy is an implicit component of a serious game, it should be secondary to entertainment and independent of its pedagogical content or value (Zyda, 2005). On the other hand, there exist design methodologies for the development of games incorporating pedagogic elements, such as the so-called four dimensional frameworks (de Freitas and Oliver, 2006) which advocate that a solid pedagogical framework is the most significant element of serious games.

Serious games have demonstrated to be effective educational tools, whereas for users with limited prior knowledge of digital media, they have been proven equally effective as traditional media (Schrader and Bastiaens, 2012a, 2012b). Therefore, learning is not only about the acquisition of factual knowledge, as in more traditional learning practices, but involves the so-called GLO categorised to provoke (Hooper-Greenhill, 2004):

a  increase in knowledge and understanding (about one or more subjects and everyday life)

b  increase in skills (intellectual, social, emotional, communicational, physical, problem-solving or related to information management)

c  change in attitudes and values (about one self, other people, a subject, or a situation)
d evidence of enjoyment, inspiration and creativity (during the task)
e evidence of action, behaviour and progression (during the task or intentions, possible changes in the future)

2.3 Educational learning

The definition of learning as a set of outcomes involving and enhancing different experiential and emotional skills links them with the notion of playful learning (Piaget, 1951). The term has developed as a rebuttal to the idea that games are purely for leisure purposes. Its use goes back to Plato and the Socratic method with its playful seriousness (Ardley, 1967), which stresses the importance of play as a teaching method (Plato 803d; Hunnicutt, 1990). A more recent example of playful learning was described by van Eck and Kolstee (2012) illustrating three different augmented reality examples. In another study, the design and formative evaluation of an interactive augmented reality simulation for informal learning environments was proposed (Oh et al., 2016).

In this paper, we will adopt the comprehensive GLO methodology to evaluate selected VM implementations employing diverse underlying web technologies in relation to VMs’ educational impact and user’s playful experience, rather than focus on their cultural content (artefacts), game mechanics and communication strategies. We consider learning as a dynamic process triggered by virtual visitors’ behaviours and skills formation while their active engagement with VMs occurs. Past research has shown that playful applications can promote and enhance users’ mental exercise, fantasy, creativity, and communication (Cassell and Ryokai, 2001; Defazio and Rand, 2011). Learning by playing, as the main concept of game-based learning (GBL), has been successfully applied in cultural heritage (Costabile et al., 2010). Gaming elements such as cooperation, competition, score, time limits without taking account specific game mechanics, were shown to motivate and attract students (Mikalef et al., 2013). Also, recent studies investigated how technological applications can be efficiently used and developed for learning (Giannakos et al., 2014).

3 Evaluation criteria, selected cases and problem statement

Building and managing online VMs is a complex activity that involves the technological, managerial, epistemological, museological, cognitive, and educational fields (Marty, 2008). Depending on the choices by the design team, the final online museum can incorporate varied interactive technologies which determine the visitors’ final experience and subsequent attitudes towards the use of digital media in museums. In order to cluster the wide range of existing museum websites into specific representative categories and subsequently examine their learning impact, an initial team of four scientists was assembled (39–56 years old) working in academia bearing an average of ten years of research and teaching experience in Art education, educational design, and use of information and communication technologies in education. The work presented aims to identify visualisation categories and factors that go beyond the specific design of a website and explore the efficiency of such factors for learning. By introducing such factors, the constantly evolving online museums could be classified according to them. Even if the actual website design changes, a classification is still going to be possible as
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well as the relevant hypothesis concerning the site’s learning outcomes, based on the presentation methodologies and factors represented. Online VMs were initially divided according to the main visualisation method adopted by each one of them, which can be grouped in five categories incorporating:

- panoramic images (QTVR)
- scalable images with text
- searchable databases
- 3D environments
- videos.

Subsequently, the VMs were selected by a second group of experts, after a small pilot study was conducted. They have navigated freely the websites, they have filled a questionnaire concerning their user-friendliness, usability of interfaces and overall user satisfaction, measurements of performance were recorded, while the tasks were completed, and the VMs achieving the highest scores were selected. For this purpose a team of 11 experts on computer graphics, human computer interaction (HCI) and cognitive psychology was assembled. Four of them were working in academia in computer science and psychology departments, five of them in research labs, and two of them in industry. They all had extensive experience in designing and evaluating cultural heritage websites. The experts shared a pool of 62 preselected museum websites. They worked independently to extract the quality dimensions which – according to their personal understanding and recent literature results – may influence the end user’s experience. Subsequently, the extracted quality dimensions were merged into a set of five qualities or capacities which correspond to the five visualisation categories above (Table 1):

- **Imageability** is defined as the “quality in a physical object that gives it a high probability of evoking a strong image in any given observer. It is shape, colour, or arrangement, which facilitate making of vividly identified, powerfully structured, highly useful mental images of the environment” [Lynch, (1960), p.9]. The diversity of virtual elements and the complexity of features such as shape and texture are added values in imageability. This quality mainly corresponds to the inclusion of panoramic images in online VMs. The category comprised 23 websites.

- **Image scalability** provides the opportunity to examine museums artefacts or parts of them in detail by applying zoom tools over high resolution images. These zoom-on-demand features allow the dialectic between visitors and artefacts not possible in the real-world museum. Image scalability mainly corresponds to the inclusion of scalable images and text in online VMs. The category comprised 19 websites.

- The **navigability** is the degree to which visitors can search the museum’s online databases in order to satisfy a number of queries. Users give queries using keywords and evaluate the results which typically contain 2D representations, flat scans and the related metadata of the artefacts. Navigability mainly corresponds to the inclusion of searchable databases in online VMs. Navigability gives its position in virtual spatiality in cases of online resources which visitors use an avatar to freely navigate not only to the multimedia objects of the online database, but on the museums’
physical simulated space and the 3D representations of museum exhibits. This is very similar to other very popular Metaverses like SecondLife for example. Virtual spatiality corresponds to the inclusion of 3D interactive environments in online VMs. The category comprised 11 websites.

- Last, but not least, the narration is the degree the storytelling is inserted into the visitor’s experience to offer a personal view and foster engagement. As Dziekan (2005) stated the discursivity of multimedia associated with a dialectical aesthetic can be characterised by montage-like spatial juxtaposition achieved through hyperlink structures and search-ability drawn upon for narrative effect. Narration mainly corresponded to the inclusion of video material for presenting narrative of the past or present in online VMs. The category comprised 9 websites.

### Table 1 Qualities of museum online resources

<table>
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<tr>
<th>Quality</th>
<th>Definition</th>
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<tr>
<td>1 Imageability</td>
<td>Perceptual quality of an online museum that makes it memorable</td>
</tr>
<tr>
<td>2 Interactivity</td>
<td>The human computer interaction (HCI) functionality that makes an online museum able to communicate with its visitors</td>
</tr>
<tr>
<td>3 Navigability</td>
<td>The degree to which navigation capabilities are perceived from structural elements of the online museum</td>
</tr>
<tr>
<td>4 Virtual spatiality</td>
<td>The extension of physical museum space and the metaphors of architecture to virtual space</td>
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<tr>
<td>5 Narration</td>
<td>Narration via a collection of videos that engages the virtual visitors to explore a topic, for instance of historical nature, and form their personal view.</td>
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Each of the above qualities was utilised in different degrees by the online VMs selected to be evaluated. For example, one museum category may have a high degree of imageability and be highly narrative, but it may have a low degree of interactivity and navigability. Although it is never the case that an online VM only utilises a single visualisation technology, there is, in the cases presented here, a prominent visualisation technology reflecting one of the qualities mentioned. Even if technology evolves fast, the qualities presented are fundamental to online content presentation.

Therefore, the pre-selected online museums were compared against these specifications and a ‘winner’ was selected for each category which strongly reflected one factor, even if containing also elements of other factors. The non-prominent methods were not classified as they were not widely adopted. Four online museums serve as extensions to existing physical museums, while one is entirely imaginary. The actual museum websites selected utilised as most prominent one of the five presentation methods listed above. When selecting the online museums to be reviewed, the geographical location of each museum was not taken into account.

#### 3.1 Imageability in panoramic images

In 3D online museums of high imageability, users can experience and interactively navigate the simulated real-world museum space through panoramic images that can be manipulated thanks to a set of interactive tools, such as rotate and pan, zoom in and out. Exploring panoramic views of the rooms renders the aesthetic and cultural values of the
museum as a real-world institution. This technique is appropriate for museums in which the architectural settlement is highly memorable, or in which it is important to convey the design of the exhibition, e.g., the selection, placement, lighting of objects, and continuity and cohesion of the exhibition discourse).

The case selected for this study, labelled as M1, is the ‘virtual exhibition tours’ (http://www.nga.gov/onlinetours/index.shtm) of the National Gallery of Art in Washington. When immersed in this online environment, visitors can select specific works of art being offered to observe larger image views, close-up details, streaming audio commentary and information about the object (Figure 1).

**Figure 1** Screenshot of the van Gogh virtual exhibition tour at the National Gallery of Art in Washington (see online version for colours)

3.2 Interacting with scalable images and texts

Visitors of online museums view elements of the exhibits not visible to the naked eye because of their size or because of the physical museums’ spatial proximity restrictions. Image exploration tools enhance the interactivity of online museums as well as the overall museum experience (Sylaiou et al., 2009).

The selected case for this study, labelled as M2, is the Metropolitan Museum of New York (http://www.metmuseum.org/). In this online environment, visitors can navigate the museum’s collection, locate exhibits of their interest, and take as much information as possible via zoomable images and detailed textual exhibit information (Figure 2). Furthermore, they can select exhibits they like and create a personal virtual gallery.
3.3 Navigability: searching utility for images and texts

This type of online museum environments offers multiple search options and enhanced image manipulation. Searchable databases typically contain 2D representations in the form of photos and flat scans of objects along with their corresponding metadata, which are uploaded to the museum’s online database, in order to make an ever growing selection of the museum’s collection available to varied audiences. The hallmark of these sites is a search engine, which allows searching by content, concept, or metadata, thanks to an entry point usually consisting of a text area in which visitors enter search criteria based on keywords. Cultural databases differ from thematic areas in that they apply taxonomies to help end users narrow the results of their queries and/or to present results in a more meaningful way. Depending on the institution and the goal, different taxonomies may be used. When relying on taxonomies, search engines initially request the selection of a pre-defined category (for example, the period) and then apply searching criteria on the remaining results.

The case selected for this study, labelled as M3, is the Museum of Modern Art (http://www.moma.org/explore/collection/index). Utilising its database, visitors can
navigate the various thematic areas of the museum as well as search its collections by artist, work or keyword. It also offers advanced search that allows adding refinement criteria such as period or object management status (Figure 3).

Figure 3  The advanced search engine of the Museum of Modern Art online database, NY, USA (see online version for colours)

3.4  Virtual spatiality: simulation of a 3D reconstructed museum space

This type of online resource allows ‘free’ and interactive real-time navigation in a 3D space that reproduces more or less realistically the actual museum galleries. These virtual spaces contain 3D representations of museum exhibits along with associated information. The navigation capabilities exploit the structural elements of the 3D reconstruction. This kind of online resources usually seeks to reproduce as realistically as possible the experience of the visit, with the added value of the multimedia information, as well as the hypertext/spatial navigation provided and the possibility to zoom and rotate individual objects (Paliokas et al., 2010). Previous research has stipulated that the 3D reconstruction of the physical museum corresponds more accurately to the concept of ‘VM’ (Pujol and Lorente, 2013) evaluating the degree of perceived presence by virtual visitors and the factors enhancing a ‘sense of being’ in a 3D online museum (Sylaiou et al., 2009). Moreover, the simulative design of the VM can be assimilated to a game-like experience,
in which a playful and emotional component is involved, and the user has control over the exploration.

Figure 4  Snapshot of the van Gogh VM, Amsterdam, the Netherlands (see online version for colours)

The case selected for this study, labelled as M4, is the van Gogh VM (http://www.vangoghmuseum.nl/), which constitutes of a typical example of a 3D reconstruction of a museum setting using computer-aided design tools and gaming technologies (Figure 4). The navigation is possible thanks to a user interface that is freely available for download or may be embedded in the web browser using standard plug-ins. The game-like experience of the Web3D environment is fulfilled by supplementary navigation tools like 3D maps, virtual GPS-like guides, and points of interest (POI) annotation.

3.5 Narrative videos

The last category corresponds to VM websites containing narrative embedded videos. The selected case for this study, labelled as M5, is the Virtual Silver Screen of the Library and Archives Canada (http://www.collectionscanada.ca/silverscreen/). The website uses Flash technologies to present a wide range of Canadian films characterised as historic documents of the early 20th century organised by themes and arranging story facts that the user can select for visualisation (Figure 5). This category is closely related with digital storytelling, which corresponds to the combination of narrative and digital content (images, sound, and video), in order to create short movies involving human protagonists (Springer et al., 2004). In this paper we consider narrative as the way the story is arranged and told [Reeve, (2009), p.75]. Its aim is to provide the virtual visitor with the opportunity to reconstruct the history of this era in his/her mind. Narrative
elements are scenes, or events, instead of actions, because an action implies a short duration (Wolff et al., 2007). We consider that narrative undertakes to tell of an event, or a series of events [Genette, (1980), p.25], which are causally related to a central theme, or plot (Mallon and Webb, 2000) in a thematic, temporal/chronological and logical way. This sequence of events proposes a narration with a meaning that can be different for every virtual visitor, since changing the temporal ordering of events in the narrative is often used to communicate different meaning (Wolff et al., 2007). The VM consists of multimedia resources and the virtual visitor has the control not obliged to follow the sequence of events of a pre-generated story, but selecting the sequence of events, omitting events, or selecting the ones to focus.

**Figure 5** Snapshot of the home page of the virtual screen silver of the Library and Archives, Canada (see online version for colours)

Digital storytelling allows many of the elements of traditional storytelling (personal meaning-making, structured framework, attention, and social interaction) to be integrated and to address diverse learning styles (Pujol et al., 2013). The narrative framework helps integrating learning experiences into a plausible storyline (Robinson and Hawpe, 1986 after Dickey, 2006), engages through fantasy and provides opportunities for comprehension, imagination, inquiry and reflection (Conle, 2003 after Dickey, 2006). Narrative videos help the virtual visitors to entertain and at the same time assign meaning to the VM content, arouse emotions, construct their understanding and build their knowledge upon the stories presented in the videos.
4 Evaluation methodology

The aforementioned visualisation technologies are powerful tools for communicating VMs’ educational impact/messages. Our research problems are:

a to classify VMs according to diverse visualisation technologies

b to identify which are the learning outcomes of museum websites that use varied visualisation technologies, such as panoramic images; text and scalable images; searchable databases; Web3D environment; and videos.

It was anticipated that the learning impact would be greater in the Web3D environment because of the intense 3D interactive visual impact and the affordances for interactivity. The evaluation methodology employed is based on the premise that each of distinct visualisation methods of associated capacities as analysed in the previous section serve and may differentiate between learning outcomes. The results will form the basis for the comparable evaluation of visualisation methods incorporated in online museums in relation to their educational impact associated to the presentation and interaction methods of museum artefacts. Based on selected criteria, this evaluation method will provide comparative evidence collected for each VM category.

4.1 Participants

A total of 164 volunteers (males and females, aged 19–37), mainly undergraduate and postgraduate students from the Aristotle University of Thessaloniki, Greece, participated in the experiment, conducted on university campus. All participants reported to have at least basic knowledge of computers and good knowledge of the English language. All students selected had never visited the VM websites before. Participants in all conditions were naive as to the purpose of the experiment.

4.2 Procedure

The evaluation and the interviews took place at the laboratory of Photogrammetry and Remote Sensing of the Aristotle University of Thessaloniki, Greece. The interviews have taken place in laboratory-like conditions that are the most suitable for an evaluation (Preece et al., 2002), where no visitors were allowed, so as the users can be concentrated in an isolated environment on the completion of the questionnaires administered to them associated to their experience. The evaluation involved one participant at a time and assistants instructed the end-users when help was needed while completing specific tasks. Neither errors nor time completion of assigned tasks were recorded because it was not our intention to test the users’ performance, but the online museums’ performance. The evaluation employed cued testing (Rennie and McClafferty, 1996), which involves explaining to the users the purpose of the project and asking them to perform specific tasks or to answer questions. Four steps were undertaken:

1 goal setting: users start with a plan of the tasks to be accomplished

2 exploration: users explore the interface and discover useful actions
3 selection: users select the most appropriate actions for accomplishing their task
4 assessment: users interpret the system’s responses and assess its progression).

The participants were allowed to choose the virtual exhibitions and exhibits they preferred in order to feel they had the control over their own learning. The same procedure was repeated for each of the five museums, one participant at a time. Each participant experienced all websites and the order of the websites was established randomly. The questionnaires were completed directly after the exploration of the online museums.

4.3 Questionnaire

The questions were formed after extensive pilot studies. The questionnaire was administered after exposure to the five online VMs and comprised of 12 questions (Table 2) that participants rated on a seven-grade Likert scale. In addition to the quantitative information, qualitative comments were also collected. The choice of an evaluation based on personal judgments instead of independent, objective methods is justified by the active and conscious role attributed to the learner, as well as by the definition of learning as outcomes other than just an increase in factual knowledge (Hein, 1991; Scardamalia and Bereiter, 2006).

Table 2 Questions included in the questionnaire and their correspondence with the GLOs

<table>
<thead>
<tr>
<th>Questions</th>
<th>GLO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Do you think you learned/acquired some general knowledge after visiting the VM?</td>
<td>a</td>
</tr>
<tr>
<td>2 Did you learn anything specific that you particularly like or being impressed by?</td>
<td>a</td>
</tr>
<tr>
<td>3 Did browsing the website was helpful for better understanding and/or to deepen your knowledge of some of the issues that deals with?</td>
<td>a</td>
</tr>
<tr>
<td>4 Did the virtual tour help you to learn how to look for information in a VM on the Internet?</td>
<td>b</td>
</tr>
<tr>
<td>5 Have you been informed about museum exhibits that you can look for/search?</td>
<td>b</td>
</tr>
<tr>
<td>6 Did you get information about computer programs that are being used in websites and you will possibly use them in the future?</td>
<td>b</td>
</tr>
<tr>
<td>7 Do you have any positive or negative feelings after the exhibits you saw and what are they?</td>
<td>d</td>
</tr>
<tr>
<td>8 Did the tour and the theme of the exhibits seemed pleasant to you?</td>
<td>d</td>
</tr>
<tr>
<td>9 Was there anything that you were surprised with (meaning as surprise learning: i.e., as opposed to existing knowledge – “I did not know that …!”) And if so, please provide a concrete example.</td>
<td>d</td>
</tr>
<tr>
<td>10 Were there any virtual exhibits you saw that will trigger you to research some of the issues that deal with?</td>
<td>e</td>
</tr>
<tr>
<td>11 After navigating the website do you think visiting in the future other (or the same) VMs webpages?</td>
<td>c</td>
</tr>
<tr>
<td>12 Based on the exhibits you saw and the website would you decide to visit the regular museum?</td>
<td>c</td>
</tr>
</tbody>
</table>
The first three questions concerned the knowledge and the comprehension of the content presented while interacting with each online museum. Questions were related to the educational impact in general (Q1); given the users’ personal interests and previous knowledge (Q2); and with regard to the specific subject presented in the website (Q3). The next three questions sought to evaluate whether the online VMs aided users improve their skills with regard to information retrieval (Q4, Q5) and whether website design and experience with presentation methods incorporated in an online museum can be useful when browsing other sites (Q6). The following three questions dealt with the feelings arising during the experience, more specifically engagement (Q7), enjoyment (Q8), and surprise (Q9). Q10 investigated evidence of initiative acquired in addition to the completion of the tasks. Finally, the last two questions aimed to record any positive attitudes awaken by each online museums (Q12) or similar resources (Q11).

4.4 Statistical analysis

The questionnaires were subsequently subject to statistical analysis. The first part of the analysis investigated whether the VM (M4) was the one considered most efficient for learning because of the high fidelity 3D simulation of the actual physical space of the museum provided. The hypothesis would be that it simulates a real visit and, therefore, potentially its emotional component by allowing self-controlled navigation in a reconstructed space as well as interaction with cultural objects. The answers to the VM questions were tested for normality before performing the analyses using the Shapiro-Wilk test and the one-sample Kolmogorov-Smirnov test. We proceeded with non-parametric test Kruskal-Wallis associated to the dataset derived from each question’s ratings in order to reject the null hypothesis stating that scores are similar for all museums. The hypothesis is rejected on sig. (P) < 0.05.

We examined which museums provoked different responses associated to the questions highlighted by Kruskal-Wallis test using the non-parametric test Mann-Whitney U Test. Finally, we adjusted p values for multiple comparisons by multiplying the p value with the number of comparisons (e.g., not adjusted p = 0.011 * 10 => adjusted p = 0.11). For all statistical tests, a significance level of 0.05 was maintained (p must be < 0.05 to be significant). p < 0.1 shows a trend towards significance which in some cases can be interpreted that if more samples were available possibly the comparison would be significant. In relation to statistical trends, however, interpretations of results lead to assumptions to be verified in future work.

5 Results

According to the Shapiro-Wilk non-parametric test for normality, only certain questions associated to specific online museums follow a normal distribution. If p < 0.05, the distribution is not normal. We proceeded with the non-parametric test Kruskal-Wallis applied to each question’s dataset of replies in order to reject the null hypothesis stating that all scores are similar for all museums. The hypothesis is rejected on sig. p < 0.05. We then examined based on the Mann-Whitney test which museums presented differences in the questions highlighted by Kruskal-Wallis. We finally adjusted the p values for multiple comparisons by multiplying the p value with the number of comparisons (e.g., not adjusted p = 0.011 * 10 => adjusted p = 0.11). The adjusted p must be < 0.05 to be
significant. In the corresponding table (table 5) result with similar letters correspond to the pair of museums with different scores and in the last column the unadjusted p value is presented correspondingly.

Based on the above, statistically significant differences were revealed:

- in question 4, M2 [median (MDN) = 6, interquartile range (IQR) (5–6)] with M5 [MDN = 5, IQR(4–6)] with adjusted p = 0.02
- in question 5, M2 [MDN = 6, IQR (5–6)] with M5 [MDN = 5, IQR (4–6)] with adjusted p = 0.02
- in question 12, M1 [MDN = 7, IQR (5–7)] with M5 [MDN = 5, IQR (2–7)] with adjusted p = 0.04.

Also the following differences present a trend:

- in question 8, M1 [MDN = 6, IQR (5–6.75)] with M5 [MDN = 5, IQR (4–5)] with adjusted p = 0.08
- in question 8, M2 (MDN = 6, IQR (5–6)] with M5 [MDN = 5, IQR (4–5)] with adjusted p = 0.08
- in question 12, M2 [MDN = 7, IQR (5–7)] with M5 [MDN = 5, IQR (2–7)] with adjusted p=0.09.

6 Discussion

Summarising the above, the main outcomes concerning the statistically significant differences revealed are the following:

6.1 Information retrieval skills (Q4) – acquisition of factual knowledge (GLO b)

The results of question 4 (Q4) illustrate that resources based on text-plus-scalable images embedded in online museum M2 communicate information more efficiently than video embedded in museum M5, in order to acquire skills related to information retrieval. The responses to questions related to the acquisition of factual knowledge, while being exposed to the online museums, did not reveal additional statistically significant differences. This may be due to the fact that regardless of the content or the presentation method, online VMs are still perceived both by designers and by users as ‘internet’ and therefore homogenised. Online VMs do not contain entirely different presentation methods (e.g., strictly database, or spatial reconstruction, QuickTime images, or text-plus-images), but instead they contain a mix of representation methods focusing mostly on mainly text and images, which makes a formal classification and experimental design challenging. The users responded that by navigating VM websites, they had also strengthened their information seeking skills on the Internet.
6.2 Exhibits search (Q5) – increase in information management skills (GLO b)

Along the same line, the results of Q5 show that resources presented as visible text incorporating scalable images (M2) are considered to inform about searchable objects better than the website containing a list of videos (M5), even though they are part of a storyline. This makes sense when considering the fact that a list of videos does not contain embedded metadata, nor does it provide enough information about the content of the audiovisual documents. The difference between M2 and M5 is that the former was designed focused on demonstrating cultural objects while the Silver Screen represents an archive and a real-world museum.

6.3 Attitudes toward museums – willingness to visit the real museum (Q12) – behaviour and progression/intention in the future (GLO e)

M1, the VM that uses panoramic images scores better than M5, the VM that uses videos in question 12, which concerns whether based on the exhibits the user viewed while accessing the museum’s online resources, a museum consecutive visit of the real-world museum will follow. The answers of Q12 indicate that resources based on panoramic images promote the willingness to visit the real-world museum, more strongly than online museums relying on video archive. This may be due to the fact that, while the first online museums are based on simplicity and have direct reference to the real setting, the video archive puts emphasis strictly on the collection of video documentaries, which can be more comfortably explored at home. In any case, these results do not support the initial skepticism by museums in terms of their contents’ online digitisation initially supporting that the display of museum collections on the World Wide Web would prevent the public from visiting the real museum (Sanders, 2002).

The main outcomes concerning the statistically significant trends revealed are the following:

6.4 Emotions (Q8) – enjoyment (GLO d)

The results of Q8 show a statistical trend, revealing that the VM including the panoramic tour (M1) and the VM including scalable images and text (M2) score better and induced a higher level of enjoyment than the VM embedding narrative videos (M5). Although digital narrations have proven to be engaging, it is possible that the Graphical User Interface associated to their use could be more intuitive and attractive to the user. Without such an interface, learning environments, such as museums, may be counterproductive according to constructivistic theories for non-formal learning use case scenarios.

What is surprising, though, is the fact that M3 e.g., a website including a search utility did not prove to reveal significant differences when compared to the remaining online museums concerning learning outcomes and enjoyment. A possible reason may be that the format based on text-plus-scalable images is more user-friendly than text-based search engines: while in M1 the user can navigate via a panoramic tour the site of the museum, in M2, the user is offered a pre-visualisation of the contents.
6.5 Information retrieval and enjoyment (Q12) – behaviour and progression/intention in the future (GLO c)

The fact that M2 allows interacting with scalable images and text scores better in Q12 than the VM including narrative videos (M5) does support one of the main hypothesis of the present study that a more realistic representation of the world and interactive interface enhances the cognitive and emotional involvement of the user. The reason may be that in a VM incorporating mainly videos, it is challenging to locate the cultural objects of interest which when demonstrated by an abstract/symbolic representation method, similar to text and images, enhance enjoyment.

The lack of systematic statistical differences did not support the initial hypothesis that 3D interactivity and gamification would provoke a productive learning experience. However, the statistically significant results presented here based on investigations of data acquired when participants responded to individual questions yield important ramifications for design of visualisation tools and techniques. A possible reason for the lack of statistical differences may be the homogeneous design and perception of online resources, which results in an overlap of scopes and capacities, and indicates that a new analytical approach is needed. Users consider that the traditional text-plus-images method, endowed with interactive capacities, is still the more suitable and enjoyable solution for obtaining information about museum collections and for encouraging its contemplation in the real setting. The experience-centred and immediate interaction that includes textual context information involving simple and scalable images, 3D models and contextual content can lead to meaning-making that is related to learning, challenge virtual visitors’ minds and expand their view of the world through enriched learning, without technological complication.

The hypothesis that museum M4 incorporating an accurate, realistic 3D reconstruction of the physical space of the actual museum and game-like experiences would induce more efficiently specific learning outcomes was not supported. Therefore, 3D online museums do not necessarily guarantee better learning outcomes, since the research presented here have found no measurable impact on learning outcomes. It is significant, though, that subjects familiar with game playing stated that the 3D online exhibition of museum M4 looked ‘realistic’ and was ‘interactive’, ‘appealing’ and ‘exciting’. Another user said: “I always like Van Gogh but I haven’t got the chance to visit the real museum in Amsterdam. It is amazing to have the opportunity to navigate the VM and see details of his paintings!”

However, focusing on navigating 3D environments undermine users’ sense of control over the interface (Shyam Sundar et al., 2015) and is not translated to a higher level of enjoyment (Sylaiou et al., 2010). It is notable that several people experienced difficulties when navigating the M4 VM. One participant stated that “It is a bit confusing; I am not sure what to do”. Another one said that “it is an interesting environment, but I need help, someone to provide me with explanations”. Experiencing such usability difficulties is contrary to one of the basic principles of design of educational games. Games for education must foster the rapid acquisition and use of knowledge by reducing unnecessary cognitive overload that may prevent the distribution of cognitive resources that are necessary for efficient learning (Lee et al., 2006; Plass et al., 2009). Generally, negative user impressions could arise by a slow internet connection at home, when interacting with a complex 3D environment in real-time. 3D technologies require fast connections for efficient real-time interaction. Designers should take into account that
although the development of such technologies occurs in well-equipped labs or industry, the users often browse online museums during their leisure time at home. The online museums should be incorporating optimised technologies for such use. It has been shown that navigation effort detracts (Bitros et al., 2010) from concentrating on the museum’s contents.

7 Conclusions

In summary, this paper presented an evaluation study involving online museum resources meant to enhance participants’ learning outcomes. A range of visualisation technologies were explored including the widely used 3D reconstruction technologies in order to investigate the effect of diverse technologies incorporated in online museums on learning outcomes (Gratch et al., 2015; Kampouropoulou et al., 2015). The paper aimed to identify visualisation categories and factors that go beyond the specific design qualities of a website. It studies the effectiveness of specific visualisation technologies and conclusions can be drawn even for online museums not included in the study but incorporating similar technologies. Therefore, the impact of this study is not limited to design changes of online museums.

When classified, the visualisation and interaction factors taken into account could be evaluated in relation to their educational impact. The basic mechanism behind educational advantage of VM is related to a greater level of engagement, mostly because they implement interactive learning and learning-by-doing concepts (Said and Suboh, 2014). In other words, motivation in VM – especially in immersive VR applications – offers a “significant educational advantage over more traditional educational approaches” as noted by Fowler et al. (2015) and supported by many more (Annetta et al., 2009; Jacobsen and Holden, 2007). In this study, the educational effectiveness of VM was questioned to shed more light into the practical aspects of the learning-through-culture concept intermediated by web technologies and the value of visiting a virtual gallery by distance.

The work presented investigated whether VMs in the form of interactive reconstructions of museum settings, are efficient for learning because they contain the simulative, edutainment dimension inherent to game-like experiences. The theoretical foundation of the study is that museum visiting and playful learning have certain elements in common, which crystallise in online museums thanks to their simulative and experiential dimension. On the other hand, their learning impact can be investigated following the concept of the GLOs (Hooper-Greenhill, 2002, 2004; Moussouri, 2002; Graham, 2013). They also can be assimilated in online museums, because of the fact that they cover a range of experiential and attitudinal skills. To that end, five representative museum websites were selected according to specific criteria. A group of individuals explored the resources and answered a self-administered questionnaire comprising 12 Likert-scale questions that covered various GLOs, e.g., knowledge, skills, values, feelings, behaviour.

During the experiment participants received help from tutors while interacting with the VMs, when needed. Had they explored the M4 3D interactive museum on their own, at home, on an even slower Internet connection without tutors’ help, they would most probably have had interaction and navigation issues, especially those with limited previous experience in Virtual Reality and games. Such problems might have resulted in
even worse educational outcomes. The lack of statistically significant results between the VM incorporating a 3D game-like environment and the rest can be also explained by the fact that online resources contain a mix of representation methods (mainly text and images everywhere) rather than solely database, or spatial reconstruction, QuickTime images, or text-plus-images), which makes their formal classification according to visualisation method provided difficult. We classified the VMs according to their most prominent visualisation method; however, there were multiple overlaps of technologies provided and selected VMs often included more than one visualisation method, which were, often, not so apparent compared to the prominent one. Although a formal experimental design is challenging, we are confident that by selecting the most prominent visualisation method, interesting conclusions can be drawn concerning its usefulness as well as interactivity challenges faced by users.

This study confirmed that VMs which implement concepts of GBL such as the ones which allow their virtual visitors to navigate in a virtual architectural space, have a great influence in connecting virtual experiences and real life in critical thinking, which is in line with other related GBL studies (Turvey, 2006). Gamification on cultural education may still face some resistance and studies point at the time teachers need to learn new technologies and the unavailability of educational gaming resources (Wastiau et al., 2009). Indeed, we have found a limited set of VM game-like educational resources in comparison with the traditional educational resources.

Results led us to conclude that VMs as narrative learning environments are not a panacea thanks to their explorative nature given by various web technologies. The ‘pure’ discovery experiences offered by narrative-centred learning environments have been proven ineffective (Mayer, 2004; Mott et al., 2006). Similarly, we conclude that the technology-assisted delivery of digital museum content suffers from the lack of guidance. The gaming or playful approach in VMs design can offer an alternative kind of guidance behind the roles, players and distant visitors undertake. The system-driven guidance provided by VM designers is what gives a meaning to the virtual visit.

Overall, game-like, playful experiences are possibly far more complicated than simple 3D camera moves. In order to take advantage of gamification in VMs, designers should invest in all typical contemporary game design characteristics such as visible and customisable avatars, visitor’s visibility, audio tour on demand, internal search engine implementations, integrated communication tools, specific tasks to be performed, multilevel challenges, quantitative symbolic rewards, etc, some of these acting as navigation aids with well-defined purpose. For instance, the capability of an internal search engine caused one user to note that “it is very interesting, but at the same time difficult to find what you’re looking for”. In other words, without well-defined game mechanics, 3D camera navigation by itself may not deliver the expected learning outcomes expected when immersed in a VM.

Future research will evaluate European and American VMs that use the same visualisation methods and explore whether there will be any differences in results. Also, it would be invaluable to investigate the responses of users resembling the actual visitor population of a museum derived from diverse cultural, educational and age groups. Future work could also include an investigation of the still largely unexplored learning impact of Web 4.0 technologies, as well as crowdsourcing incorporated in participatory VMs.
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References


Exploring the educational impact of diverse technologies


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